Centre of Excellence – Climate Change & Disaster Management (CoE-C2DM)

INDIVIDUAL RESEARCH PAPERS

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About CoE-C2DM

C2DM course equips participants with the knowledge and practical abilities to understand the science of climate change, its relationship with disasters and strategies for resilience building. It integrates Climate Change Adaptation (CCA) and Disaster Risk Reduction (DRR) into a unified framework consistent with all international frameworks, treaties, conventions and agreements on Disaster Risk Reduction, Climate Change. Through interactive lectures, individual research case, simulations and lab exercises, participants learn to assess climate risks, design adaptive strategies and implement resilience measures with advanced technologies as Artificial Intelligence (AI), Machine Learning (ML), Remote Sensing and GIS/GoeAI. The C2DM Courses offered by NDMA Center of Excellence facilitates national and international Government officials in disaster/crisis/emergency management, environment/climate, planning and related departments/offices, Provincial/state PDMA/GBDMA/SDMA staff and technical officers from national and equivalent international offices, Multilateral Institutions/organizations as World-bank, ADB, UN etc. and INGO personnel engaged in humanitarian response and resilience development projects as well as Private sector senior managers in industry and energy sectors, Researchers in relevant/linked disciplines/technologies of disaster management, environment, climate change or academics and development sectors. This Research Compendium is from participants of C2DM Course N-08/26 (24th August – 11th September 2026) participants.

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PARTICIPANT RESEARCH PAPER

Air Pollution in Karachi City: Risk, Vulnerability, Resilience and Policy Responses

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Certificate Course in Disaster Management

C2DM N-08/26

Center of Excellence - Climate Change & Disaster Management

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Abstract

Air pollution has emerged as a major environmental and public health hazard in Karachi, Pakistan's largest metropolitan city. Rapid urbanization, population growth, increasing vehicular traffic, industrial emissions, fossil-fuel combustion, construction activities, road dust, and open waste burning have contributed to deteriorating air quality. Fine particulate matter, particularly $PM_{2.5}$, represents a significant concern because of its ability to penetrate deeply into the respiratory system and contribute to adverse health outcomes. Research conducted in Karachi has identified vehicular emissions, industrial activities, oil combustion, and urban dust as important contributors to particulate pollution. The impacts of poor air quality are not equally distributed; children, older adults, people with pre-existing health conditions, outdoor workers, and low-income communities are particularly vulnerable. This paper examines the hazard profile, risk and vulnerability factors, community resilience, institutional and scientific gaps, mitigation strategies, risk communication, and policy options related to air pollution in Karachi. It concludes that reducing air pollution requires integrated governance, reliable monitoring systems, stronger enforcement, public participation, cleaner transportation and industrial technologies, and effective communication of air-quality risks.

Keywords: Air pollution; Community resilience; Environmental health; Karachi; $PM_{2.5}$

1. Introduction

Air pollution is one of the most serious environmental challenges facing rapidly urbanizing cities. Karachi, with its large population, expanding transportation system, industrial activities, construction, and energy demands, experiences substantial pressure on its environmental resources. The city's air quality is affected by emissions from vehicles and industries, fossil-fuel combustion, road and construction dust, waste burning, and other natural and anthropogenic sources. Recent scientific research has identified Karachi as a city experiencing serious particulate pollution and associated health risks.

The problem is particularly important because air pollution affects both human health and urban sustainability. Long-term exposure to $PM_{2.5}$ and other pollutants may increase the risk of respiratory and cardiovascular diseases and create significant economic and social costs. Research conducted in Karachi has found that concentrations of $PM_{2.5}$ can substantially exceed health-based guidelines, particularly during periods when atmospheric conditions allow pollutants to accumulate.

The purpose of this paper is to examine air pollution as an urban environmental hazard in Karachi and analyze its associated risks, vulnerabilities, resilience factors, institutional challenges, and policy responses.

Objectives of the Study

1. To examine the major sources and hazard profile of air pollution in Karachi.
2. To identify populations and communities most vulnerable to air-pollution exposure.
3. To assess scientific, technological, and institutional gaps in air-quality management.
4. To examine community resilience and risk communication mechanisms.
5. To propose evidence-based mitigation and policy recommendations.

Scope of the Study

This paper focuses on ambient urban air pollution in Karachi, particularly particulate matter and pollution generated by transportation, industries, combustion, urban dust, and waste burning. It examines environmental, health, social, institutional, and policy dimensions of the problem.

2. Regional Context & Hazard Profile

Karachi is Pakistan's largest metropolitan and economic center, characterized by rapid urbanization, dense population, extensive road traffic, industrial activity, and continuous infrastructure development. These characteristics increase the production of air pollutants and expose a large population to poor air quality.

$PM_{2.5}$ is among the most significant pollutants because these extremely small particles can penetrate deeply into the lungs and may enter the bloodstream. Other important pollutants include nitrogen dioxide (NO_2), sulfur dioxide (SO_2), ozone (O_3), black carbon, and toxic metals associated with particulate matter.

Scientific studies in Karachi have identified several important pollution sources. These include vehicular emissions, industrial discharges, oil combustion, soil and road dust, and secondary atmospheric pollutants. One Karachi study identified vehicular emissions as a major contributor to $PM_{2.5}$, while industrial emissions and oil combustion were also significant sources.

The hazard profile of Karachi is influenced by both local emissions and environmental conditions. During periods of lower atmospheric dispersion, pollutants may accumulate and increase human exposure.

For this study, the following concepts are used:

- **Hazard:** A potentially harmful environmental condition, such as high concentrations of $PM_{2.5}$ or toxic gases.
- **Exposure:** The presence of people, infrastructure, livelihoods, and ecosystems in areas affected by polluted air.
- **Vulnerability:** Conditions that make individuals or communities more susceptible to the harmful effects of air pollution.
- **Risk:** The likelihood and severity of harmful consequences resulting from the interaction of pollution hazards, exposure, and vulnerability.

3. Risk & Vulnerability Assessment

Air pollution in Karachi creates multiple forms of risk because exposure occurs across homes, workplaces, schools, roads, and public spaces. Unlike sudden disasters, air pollution is often a slow-onset and continuous hazard. People may be exposed repeatedly without immediately recognizing the severity of the risk.

Socio-economic Impacts

Poor air quality can increase healthcare costs, reduce productivity, contribute to absenteeism, and disrupt economic activities. Workers who spend long periods outdoors, including traffic police, street vendors, construction workers, delivery workers, and transport workers, may experience higher exposure to pollutants. Illness and reduced productivity can also affect household income, particularly among families with limited financial resources.

Air pollution can therefore create a cycle of environmental and socio-economic vulnerability. Lower-income households may have fewer opportunities to access quality healthcare, improve housing conditions, or reduce exposure. They may also live closer to congested roads, industrial areas, construction sites, or waste-burning locations.

Livelihood Disruption and Food Security

Air pollution may indirectly affect livelihoods by reducing workers' health and productivity. Outdoor workers are particularly vulnerable because their occupations require prolonged exposure to traffic emissions and dust.

Air pollution can also affect food security through its relationship with climate, agriculture, and environmental degradation. Pollutants such as ground-level ozone can negatively affect crop productivity, while broader air-pollution control policies may support both environmental protection and food security. Pakistan's National Clean Air

Policy recognizes the relationship between air quality, public health, and food security.

Vulnerable Groups

The most vulnerable groups include:

- Children, because their lungs and bodies are still developing.
- Older adults, particularly those with existing health problems.
- People with respiratory and cardiovascular conditions.
- Pregnant women and infants.
- Outdoor workers with prolonged occupational exposure.
- Low-income communities living near major pollution sources.

Gender Dimensions

Air pollution may have gender-specific consequences because men and women may experience different patterns of exposure depending on their social and occupational roles. Women may experience greater exposure to household pollution in settings where cleaner energy and ventilation are limited, while men may experience increased occupational exposure in transport, construction, and industrial work. Women also often carry significant caregiving responsibilities when family members experience pollution-related illnesses.

Factors Increasing Vulnerability

Major vulnerability factors in Karachi include:

1. Rapid population growth and urban expansion.
2. High traffic density and dependence on fossil-fuel vehicles.
3. Industrial activity near residential communities.
4. Construction activities and road dust.
5. Open burning of municipal waste.
6. Limited access to healthcare among economically disadvantaged populations.
7. Insufficient public awareness of daily air-quality risks.
8. Limited access to reliable local air-quality information.

Recent research and policy discussions continue to identify $PM_{2.5}$, vehicular emissions, industrial pollution, dust, and waste burning as important components of Pakistan's and Karachi's air-quality challenge.

4. Community Resilience Factors

Community resilience refers to the ability of individuals and communities to prepare for, respond to, and recover from environmental hazards. In relation to air pollution, resilience includes awareness, social networks, access to information, collective action, and the capacity to reduce exposure.

Social capital and community networks can play an important role in improving resilience. Community organizations, schools, healthcare providers, local government institutions, and civil-society organizations can share information regarding pollution risks and encourage protective behaviors.

Local coping mechanisms may include reducing unnecessary outdoor activities during periods of severe pollution, improving household ventilation where appropriate,

increasing greenery, avoiding open waste burning, and supporting cleaner transportation practices. Community participation is essential because many pollution sources are connected to everyday behaviors and local economic activities.

Indigenous and local knowledge may also help communities identify seasonal environmental changes, dust patterns, and locations where pollution is particularly severe. However, local knowledge should be combined with scientific monitoring to ensure that community decisions are based on accurate and timely information

5. Scientific & Institutional Gaps

A major challenge in addressing air pollution is the limited availability of continuous, comprehensive, and publicly accessible air-quality data. Earlier reviews of air pollution in Pakistan identified inadequate monitoring infrastructure, insufficient emission inventories, weak coordination, and limited integration between research institutions and policymakers as major barriers.

Scientific gaps include insufficient long-term local data, limited neighborhood-level monitoring, and inadequate understanding of how pollution exposure differs between communities. Karachi requires more detailed studies on personal exposure, indoor air pollution, occupational exposure, and the combined effects of multiple pollutants.

Technology can help address these challenges. Low-cost sensors, satellite observations, geographic information systems, and artificial intelligence and machine learning techniques can improve pollution forecasting and identify spatial patterns. However, AI and ML systems depend on reliable data and should complement, rather than replace, properly calibrated monitoring systems.

Institutional weaknesses include fragmented responsibilities, inadequate enforcement of emission standards, limited technical capacity, and insufficient coordination between environmental agencies, transport authorities, industries, municipalities, researchers, and public-health institutions.

Recent discussions by the Sindh Environmental Protection Agency have emphasized the need for coordinated action, improved monitoring infrastructure, evidence-based policymaking, and stronger stakeholder engagement.

6. Mitigation Strategies & Best Practices

Air pollution requires a combination of structural and non-structural mitigation measures.

Structural Measures

Expansion of reliable fixed and mobile air-quality monitoring stations.

- Development of cleaner and more efficient public transportation.
- Regular vehicle inspection and emission-testing systems.
- Adoption of cleaner fuels and electric mobility.
- Installation of pollution-control technologies in industries.
- Improved waste-management infrastructure to prevent open burning.
- Dust-control measures at construction sites.
- Expansion and protection of urban green spaces.

Non-Structural Measures

- Public education and awareness campaigns.
- Environmental training for industries and transport operators.
- Stronger enforcement of environmental regulations.
- Community participation in monitoring local pollution sources.
- Integration of air-quality considerations into urban planning.

Pakistan's National Clean Air Policy, adopted in 2023, provides a national framework for addressing air pollution. Its priority areas include improving fuel standards, controlling industrial emissions, preventing agricultural and municipal waste burning, and promoting cleaner household technologies.

International best practices demonstrate that air-quality improvement requires long term commitment, strong monitoring, emission standards, clean transportation, industrial regulation, and transparent public reporting.

7. Risk Communication & Early Warning

Effective risk communication is essential because air pollution is often invisible and its health impacts may not be immediately recognized. Residents should have access to clear and understandable information about daily air-quality conditions.

A people-centered air-quality warning system should include:

1. Real-time or regularly updated air-quality information.
2. Simple health guidance based on pollution levels.

3. Specific recommendations for children, older adults, and people with health conditions.
4. Communication in local languages and accessible formats.
5. Dissemination through mobile applications, television, radio, schools, healthcare facilities, and social media.
6. Community-level outreach for populations with limited internet access.

Risk communication should also be gender-sensitive and inclusive. Women, children, older adults, persons with disabilities, and economically disadvantaged communities may have different information needs and capacities to respond.

Last-mile communication is particularly important. Information should not remain limited to government websites or technical reports. Community organizations, schools, healthcare professionals, and local leaders can help translate scientific information into practical protective actions.

8. Policy Recommendations

The following policy measures are recommended for Karachi:

a). Strengthen Air-Quality Monitoring

Develop a comprehensive network of fixed, mobile, and appropriately calibrated monitoring systems and ensure that reliable data are publicly available.

b). Establish Integrated Air-Quality Governance

Improve coordination among SEPA, local government, transport authorities, public health institutions, industries, researchers, and civil-society organizations.

c). Reduce Vehicular Emissions

Introduce stricter inspection systems, improve public transport, encourage cleaner fuels, and accelerate the transition toward low-emission and electric mobility.

d). Strengthen Industrial Regulation

Require industries to comply with emission standards and adopt cleaner technologies.

Regular monitoring and transparent enforcement should be strengthened.

e). Control Waste Burning and Urban Dust

Municipal authorities should improve waste collection and disposal to eliminate open burning. Construction and road-development projects should implement dust-control measures.

f). Use Technology and Data

Integrate satellite data, ground monitoring, GIS, and AI/ML forecasting tools to identify pollution hotspots and support evidence-based decision-making.

g). Increase Community Participation

Communities should be included in identifying local pollution sources, monitoring environmental conditions, and designing awareness campaigns.

h). Integrate Air Pollution with Climate and Urban Planning

Air-quality policies should be linked with climate adaptation, transportation planning, energy policy, public health, and sustainable urban development.

i). Strengthen Institutional Capacity

Environmental and local government institutions require technical training, financial resources, laboratory capacity, and stronger enforcement mechanisms.

9. Conclusion

Air pollution is a major environmental hazard and public-health challenge for Karachi. Rapid urbanization, traffic emissions, industrial activities, fossil-fuel combustion, road dust, construction, and waste burning contribute to poor air quality. $PM_{2.5}$ is particularly concerning because of its ability to penetrate deeply into the respiratory system and contribute to significant health risks.

The consequences of air pollution are not equally distributed. Children, older adults, people with existing health conditions, outdoor workers, and low-income communities face greater vulnerability. Therefore, air pollution should not be addressed only as an environmental problem; it is also a social, economic, health, and urban-governance issue.

Building resilience requires science-based planning, reliable monitoring, effective institutions, social capital, community participation, and appropriate use of technology. Local and indigenous knowledge can support scientific information by helping communities identify environmental patterns and develop practical coping strategies.

Ultimately, Karachi requires an integrated approach that combines emission reduction, environmental regulation, cleaner transportation, industrial accountability, public awareness, risk communication, technological innovation, and community participation.

Evidence-based and coordinated action can reduce pollution exposure and contribute to a healthier, more resilient, and sustainable Karachi.

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Appendix A: Hazard–Risk Matrix for Air Pollution in Karachi

Hazard	Main Sources	Exposed Groups	Potential Impacts	Risk Level
$PM_{2.5}$	Vehicles, industries, combustion, dust	General population, children, older adults	Respiratory and cardiovascular problems	**High**
NO_2	Vehicle and industrial emissions	Roadside communities, outdoor workers	Respiratory irritation and reduced lung function	**High**
Industrial emissions	Factories and combustion sources	Nearby communities and workers	Toxic exposure and chronic health risks	**High**
Road and construction dust	Construction and traffic	Pedestrians and outdoor workers	Respiratory irritation and reduced visibility	**Moderate–High**
Open waste burning	Municipal and household waste	Nearby communities	Toxic smoke and respiratory illness	**High**

Appendix B: Key Community Preparedness Checklist

- Monitor available air-quality information.
- Avoid open burning of waste.
- Support cleaner transport and car-sharing where possible.
- Reduce unnecessary outdoor exposure during severe pollution episodes.
- Encourage schools and workplaces to provide air-quality awareness.
- Report visible industrial pollution and open waste burning to relevant authorities.
- Participate in community tree-planting and urban greening initiatives.
- Promote environmental education and local participation in pollution-control activities.

PARTICIPANT RESEARCH PAPER

ARTIFICIAL INTELLIGENCE FOR MULTI-HAZARD EARLY WARNING SYSTEMS

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Abstract

Multi-hazard early warning systems (MHEWS) are increasingly important as hazards become more interconnected and their impacts propagate across environmental, infrastructure and social systems. The research paper develops the framework presented in “Artificial Intelligence for Multi-Hazard Early Warning Systems” by integrating Internet of Things (IoT), cloud computing, remote sensing, geographic information systems (GIS), artificial intelligence (AI), communication technologies and emergency response. This research defined that for operation sequence first it detects then analyses. By using analysis, it will predict. The prediction will help for the early warning of hazards, response against hazards by using Artificial intelligent system. In this study Pakistan Hazards has been also analyzed and proposed the importance of Artificial Intelligence, Geographical Information System and Remote Sensing. The study examines the role of Artificial Intelligence in detection of hazard, forecasting, impact assessment, cascading-risk analysis and decision support. Infrastructure of cloud and contribution of internet of things (IoT), community response, are much helpful for spatial risk mapping by using GIS and remote sensing. Major Multi Hazards of Pakistan include flash floods, floods, landslides, earthquake, heatwaves, GLOFs, cyclones, drought, wildfires, urban fire and air pollution. Recent international literature indicates that AI can improve the speed and scale of early-warning analytics, but its value depends on observational infrastructure, interoperability, data quality, governance, validation, human oversight and inclusive communication. The paper proposes a phased implementation roadmap for Pakistan based on data foundations, multi-hazard modelling, interoperable architecture, operational validation and continuous learning.

Keywords: Artificial intelligence; Internet of Things; multi-hazard early warning system; cascading hazards; machine learning; cloud computing; GIS; remote sensing; disaster risk reduction; Pakistan; risk mapping.

1. Introduction

Disaster risk is no longer adequately represented by isolated hazard categories. Heavy rainfall can produce flash flooding, river flooding, soil saturation and landslides; a cyclone can combine extreme wind, rainfall and storm surge; drought, heat and wildfire can reinforce one another. UNDRR guidance therefore emphasizes multi-hazard systems capable of addressing interconnected and cascading risks, while WMO's Early Warnings for All initiative frames effective warning around four linked pillars: disaster risk knowledge; observation, detection, monitoring, analysis and forecasting; warning dissemination and communication; and preparedness and response.

Multi Hazard Early Warning System proposed for continuously monitors hazards, risk analyses, issues warnings and supports action before impacts become severe. It identifies Information of Things as the "eyes and ears", cloud computing as the scalable data and processing infrastructure, AI works as the analytical "brain", GIS as the spatial integration and visualization layer, and communication channels as the mechanism through which warnings reach people. This architecture is consistent with the emerging international view that AI should enable, rather than replace, institutional decision-making. The 2026 UNDRR/ITU/WMO/IFRC report specifically identifies AI as an enabling technology whose effectiveness depends on strong institutions, governance, robust observations, human oversight and people-centered design.

2. Basis and Scope of the Study

This paper is a presentation-based conceptual research paper supplemented by a focused literature review. In this research we developed a primary structure, terminology and Pakistan hazard framework. It covers 20 hazard categories, remote-sensing and GIS datasets, cloud-computing functions, early-warning technologies, and an end-to-end AI architecture. The literature review was used to verify and expand these concepts using authoritative guidance from UNDRR, WMO and NDMA and peer-reviewed research on AI, flood forecasting, trustworthy AI and Pakistan's multi-hazard early-warning arrangements.

The study does not claim that every technology listed in the research is currently operational at national scale in Pakistan. Instead, it distinguishes between an architectural capability and an operational capability. This distinction is important because

an AI model may be technically feasible while remaining unsuitable for life-safety use if training data is incomplete, observations are sparse, warnings cannot reach communities, or institutional responsibilities are unclear.

3. Literature Review

3.1 Multi-hazard early warning systems

UNDRR describes multi-hazard early warning systems as an essential component of comprehensive disaster-risk reduction because interconnected hazards require integrated solutions. [1] WMO's Early Warnings for All initiative similarly promotes people-centred, end-to-end Multi Hazard Early Warning System and seeks universal protection from hazardous weather, water and climate events by the end of 2027. [2] The global status literature shows that progress has been made, but significant capacity gaps remain in observation, forecasting, communication and preparedness. [3] These findings support the research's emphasis on an integrated chain rather than separate hazard-specific dashboards.

3.2 Artificial intelligence and early warning

Recent research shows rapid growth in AI applications across the early-warning chain. A 2025 systematic review found that AI is increasingly used for risk knowledge, warning dissemination, forecasting and response preparedness, while also identifying gaps in policy, application and responsible deployment. [5] A 2024 systematic review of trustworthy AI in natural disasters similarly reports that predictive AI can support early warning, risk assessment, evacuation planning and resource allocation, but stresses the importance of trustworthiness and responsible implementation. [6] These findings reinforce the research's position that AI should improve evidence and response timing without replacing accountable authorities.

3.3 AI for flood and cascading-risk prediction

Flood management is one of the strongest application areas for AI because flood risk depends on high-volume, heterogeneous and time-dependent observations. Recent review literature identifies machine learning and deep learning as increasingly important for prediction of flood, assessment of susceptibility and risk management. [7] The research extends this logic from single-hazard prediction to cascading risk: heavy rainfall can raise river levels, increase soil saturation and consequently elevate landslide

probability. This is a key conceptual advantage of Multi Hazard Early Warning System because the same observation can influence several hazard models.

3.4 Pakistan's early-warning context

Research reviewing Pakistan's National Multi-Hazard Early Warning System Plan found that implementation requires stronger alignment with the Sendai Framework and identified institutional and operational gaps, include the coordination and implementation challenges. [8] NDMA planning documents continue to emphasize multi-hazard early warning, preparedness of hazards, coordination and anticipatory action. NDMA's current Technical Early Warning platform describes capabilities including Artificial Intelligence/Machine Learning, satellite/remote sensing and multi-layered monitoring. [9] PMD's Flood Forecasting Division also operates an end-to-end flood monitoring, forecasting of Flood and warning platform using automatic weather stations, telemetric gauges, Doppler radar, satellite feeds and numerical/hydrological models. [10] Together, these developments demonstrate that the architecture proposed in the research can be connected to existing national institutions rather than designed as an isolated system.

4. Conceptual Framework: AI-Enabled MHEWS

The diagram mentioned below presents an end-to-end AI-powered Multi-Hazard Early Warning System (MHEWS). Its main idea is that disaster management is not a single technology; it is a continuous, interconnected chain in which information moves from hazard detection to analysis, warning, response, and learning.

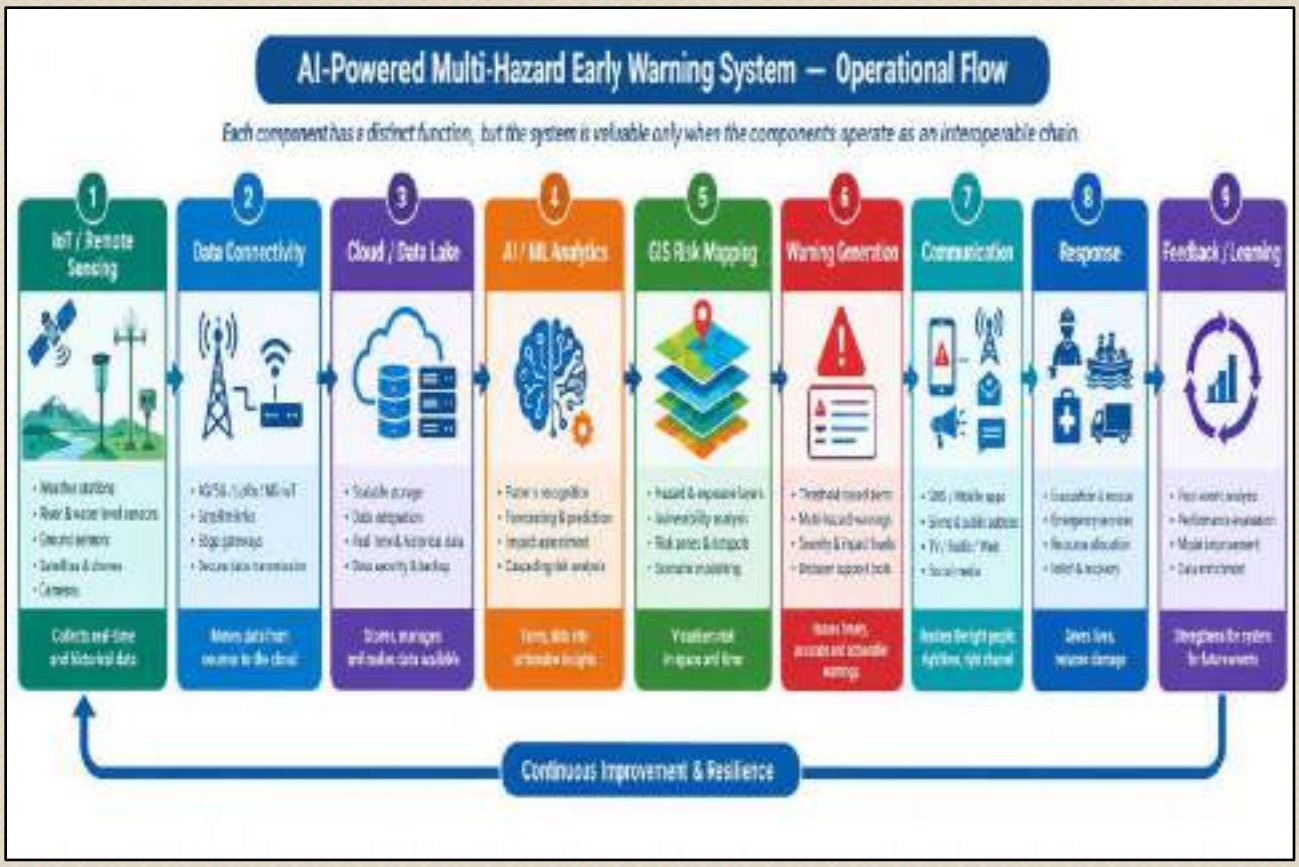


Figure 1. End-to-end AI-powered Multi-Hazard Early Warning System (MHEWS).

I. Internet of Things/ Remote Sensing: Detect

The system first collects information about hazards from multiple sources. Its purpose is to Capture real-time and historical environmental data. Sensors are used to detect rapidly rising water levels and satellites observe heavy rainfall over a watershed.

- Weather stations and rainfall gauges
- Ground sensors
- River/water-level sensors
- Satellites and drones
- Cameras

II. Data Connectivity: Transmit

The collected information must reach through processing system. Its purpose is to Move data reliably from the field to centralized or cloud infrastructure. The river sensor transmits water-level measurements every few minutes to the disaster-management platform is one of the examples.

- 4G/5G
- Satellite communication
- LoRa/NB-IoT
- Edge gateways
- Secure data transmission

III. Cloud / Data Lake Store & Integrate

This is the incoming information which stored and organized in a scalable environment. Its purpose is to create a common data environment where different datasets can be accessed and integrated. It can combine:

- Real-time sensor data
- Historical rainfall records
- Previous disaster records
- GIS layers
- Satellite imagery

IV. AI / ML Analytics as Analyze & Predict

This is the intelligence layer of the system. The AI analyzes rainfall intensity, soil moisture, river levels and historical floods and estimates the probability of flooding.

Artificial Intelligent/Machine Learning can perform:

- Forecasting
- Pattern recognition
- Impact assessment
- Cascading-risk analysis
- Prediction of hazardous conditions

V. GIS Risk Mapping: A Visualize Risk

The AI results are combined with geographic information. Its purpose is to convert analytical results into a spatial risk picture. Flood risk is the high example," GIS can show which villages, roads, bridges, hospitals or heritage sites are likely to be affected.

GIS can identify:

- Critical infrastructure
- Hazard zones
- Exposed population

- Historical/heritage sites
- Vulnerable buildings
- Evacuation areas
- Risk hotspots

VI. Warning Generation: Decide & Alert

It based on predefined thresholds and AI predictions; the system generates warnings. In a high-Risk Flood, the Immediate evacuation of low-lying communities recommended. Artificial Intelligent supports the decision; accountable authorities remain responsible for issuing official warnings.

Warnings can include:

- Hazard type
- Severity
- Location
- Expected impact
- Time window
- Recommended actions

VII. Communication: Reach People

The warning must reach the right people through appropriate channels. Its purpose is to Ensure that the warning is not only technically correct but actually reaches communities on time.

- SMS/mobile applications
- Sirens
- Public-address systems
- Television/radio
- Websites
- Social media

VIII. Response: Act

Its purpose is to convert an early warning into actions that save lives and reduce damage

This may involve:

- Evacuation
- Search and rescue

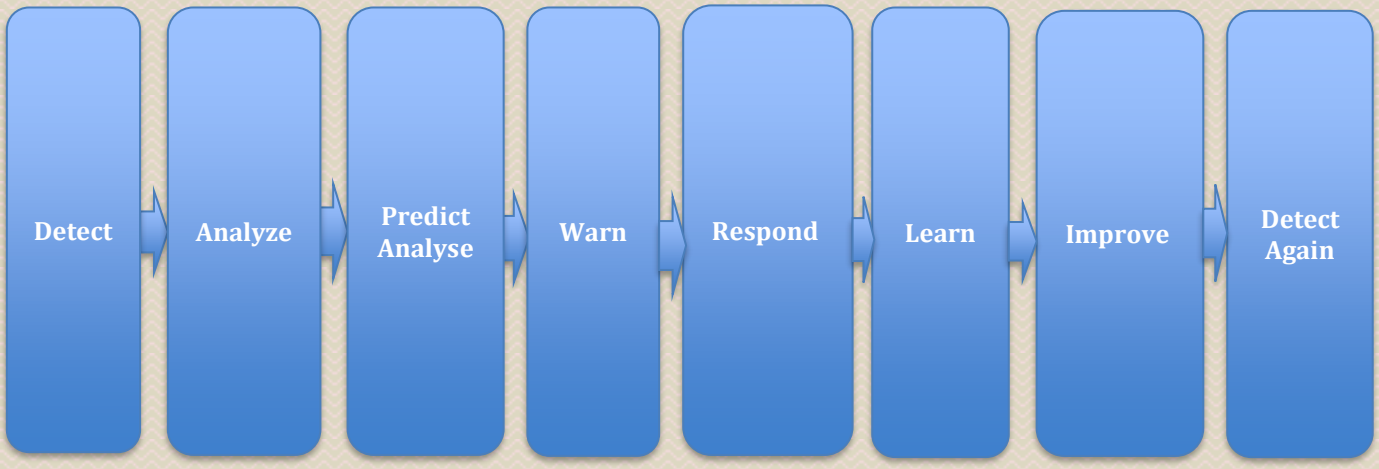
- Emergency medical services
- Resource allocation
- Relief operations
- Protection of critical infrastructure

IX. Feedback / Learning: Improve

The AI models can then learn from the new event and improve future predictions. After the event, information from the disaster and response is fed back into the system.

This includes:

- Post-event analysis
- Model improvement
- Performance evaluation
- Data enrichment
- Assessment of warning accuracy



So, the system does not end after a disaster. The response generates new data that improves the next cycle. Each component has a distinct function, but the system is a valuable only when the components operate as an interoperable chain.

4.1 Internet of Things and real-time observations

Internet of Things devices provide continuous local measurements of temperature, rainfall, river level, humidity, soil moisture, wind, ground movement, smoke, seismic activity and other variables. These observations can validate forecasts, update models and provide event-trigger information. For remote areas, edge computing can reduce

dependence on continuous connectivity by processing critical signals near the sensor and transmitting the relevant information only.

4.2 Cloud computing and data infrastructure

Cloud infrastructure provides scalable storage and processing for sensor streams, forecasts, satellite imagery, GIS layers and historical disaster records. The study shows that the cloud is divided into storage, processing and sharing functions. This is appropriate for a national Multi Hazard Warning System because different agencies require controlled access to common datasets. Cloud or hybrid infrastructure may also support model retraining, APIs, large-scale raster processing, dashboards and disaster-event archives.

4.3 Artificial intelligence and machine learning

Artificial Intelligence can be applied at multiple stages. For detection, models can identify anomalies in sensor and satellite observations. For prediction, ensemble, time-series, machine-learning and deep-learning models can estimate hazard probability, timing and intensity. For impact assessment, models can combine hazard information with exposure and vulnerability. For learning, observed outcomes can be compared with previous predictions so that model performance is continuously evaluated. However, life-safety decisions should remain under clearly assigned human authority, documented procedures, with validated thresholds, and model-monitoring arrangements.

4.4 GIS and remote sensing

Remote sensing provides spatially extensive observations where ground sensors are sparse. SAR can support flood detection and ground-deformation analysis; optical imagery can characterize land cover, vegetation and post-event damage; thermal observations can support heat and wildfire assessment; satellite precipitation products can supplement rain gauges. DEMs provide terrain information for flood, avalanche, landslide and GLOF modelling. GIS then integrates these datasets with population, roads, buildings, critical infrastructure, administrative boundaries and historical events to convert hazard predictions into spatial risk information.

4.5 Warning dissemination and response

A technically accurate forecast is not automatically an effective warning. Warnings must be trusted, understandable, timely and actionable. Pakistan’s national response planning

emphasizes that warnings must reach communities in time. It should use clear language and local languages. It should have alternative dissemination mechanisms in case of technical failure. [11] International research also shows that inconsistent alert wording, levels and symbols which can reduce public understanding and appropriate action. [12] Therefore, the Artificial Intelligent layer must be connected to pre-agreed warning protocols, community networks, evacuation plans, emergency services and feedback mechanisms.

5. Pakistan's Multi-Hazard Environment

The presentation identifies a broad national hazard portfolio like river, flash and urban floods, earthquakes, glacier retreat and GLOFs, landslides, extreme rainfall, urban and forest fires, heatwaves, drought, cyclones and storm surge, dust and windstorms, coastal flooding and sea-level rise, avalanches, smog, tsunamis and desertification. The spatial distribution varies substantially. Mountain regions require strong attention to landslides, GLOFs and avalanches, the Indus Basin requires flood forecasting and exposure mapping along southern and central Punjab. Sindh require heat and drought analytics and the coastal Sindh and Balochistan require cyclone, storm-surge and tsunami preparedness.

The principal research challenge is not simply to predict each hazard independently. The greater opportunity is to model relationships among hazards and between hazards and exposure. For example, an extreme-rainfall model can convert into a river-flood model while simultaneously updating soil-moisture and landslide models. Similarly, temperature, vegetation dryness and wind can jointly influence wildfire danger. This requires a shared geospatial data model, standardized metadata, common time references and interoperable APIs.

6. Proposed AI-Enabled Operational Architecture

A national architecture should contain six functional layers. Layer 1 contains Observation which collects IoT, river gauges, weather stations, satellite, radar, seismic and other observations. Layer 2 contains Data and Cloud which quality-controls, stores and distributes data through a national or federated data lake. Layer 3 contains Artificial Intelligent/Machine Learning which runs hazard-specific and multi-hazard models, forecasting, anomaly detection and impact estimation. Layer 4 contains GIS Risk

Intelligence which combines model outputs with exposure and vulnerability. Layer 5 contains Warning and Communication which converts risk levels into standardized messages and distributes them through cell broadcast/SMS, applications, web-GIS, radio, sirens and local authorities. Layer 6 contains Preparedness and Response which links warnings to operational procedures, resource allocation, evacuation and emergency services.

Cross-cutting controls should include cybersecurity, data governance, model validation, interoperability standards, audit logs, human oversight, disaster recovery, privacy protection, redundancy and capacity building. These controls are not secondary features: they determine whether an AI system is trustworthy enough for operational use.

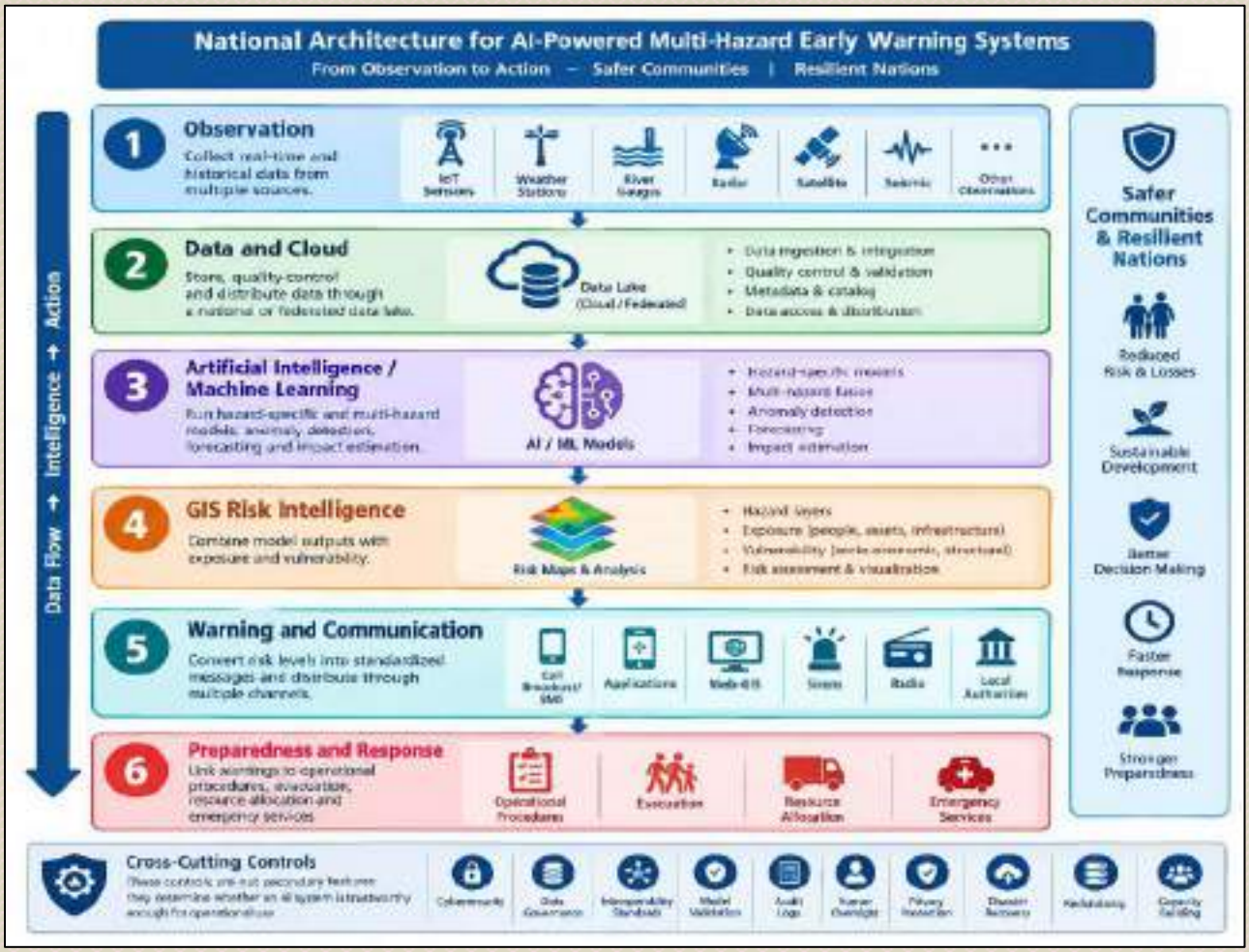


Figure 2. National Architecture for AI- Powered MHEWS.

7. Cascading Flood–Landslide Risk

The study of flood landslide is an example of multi-hazard reasoning. Heavy rainfall increases runoff and river discharge and raising flood probability. At the same time, infiltration and soil saturation increase which potentially reducing slope stability. An Artificial Intelligent system can combine rainfall forecasts, river levels, soil moisture, satellite imagery, terrain, land cover and historical events to estimate probability, severity, timing and spatial extent. GIS identify settlements, bridges, roads and critical facilities. The final output should not merely be a probability value. It should be an actionable product such as a risk map, warning level, evacuation guidance and resource-priority list.

8. Benefits of AI-Enabled MHEWS

- AI can process heterogeneous datasets faster than manual workflows.
- It identifies nonlinear relationships that are difficult to represent through simple thresholds.
- It provides spatially detailed risk information when combined with GIS.
- It supports continuous learning from new events.
- It enables scenario modelling and prioritization of exposed communities and infrastructure.
- Integrated architectures reduce duplication by allowing one observation network to support several hazard services.

9. Limitations, Risks and Ethical Considerations

AI should not be treated as an infallible predictor. Major limitations include sparse or biased training data, sensor outages, rare-event imbalance, changes in land use and climate, false alarms, model drift, missed events, limited interpretability and uncertain forecasts. Remote mountainous areas may have fewer observations precisely where warning lead time is most critical. AI systems can also reproduce biases present in historical datasets and may disadvantage communities that are poorly represented in the data.

For life-safety applications, the paper therefore recommends a human-in-the-loop model. AI should generate maps, evidence, probabilities and recommendations, while authorized institutions issue official warnings. Models should be independently validated, continuously monitored and periodically recalibrated. Warnings should be tested through

drills and community feedback. The latest international AI-for-Early Warning System guidance like stresses robust observation networks, human oversight, equity, governance, multilingual and low-connectivity compatibility, interoperability and sustained investment. [4]

10. Implementation Roadmap for Pakistan

Phase I-Foundation: identify priority hazards and pilot districts, inventory national datasets, establish metadata and interoperability standards, establish governance and data-sharing agreements and develop baseline models.

Phase II-Integration: connect NDMA, PMD, PDMAs/DDMAs, WAPDA and relevant technical agencies through APIs and secure data services, establish cloud/hybrid infrastructure and deploy operational dashboards.

Phase III-Multi-hazard intelligence: integrate landslide, flood, heat, wildfire, cyclone, seismic and other models. It introduces cascading-risk analytics, connect risk maps to exposure and vulnerability.

Phase IV-Operationalization and learning: conduct validation, simulations and drills, collect community feedback, measure warning lead time and false-alarm rates and continuously update models and procedures.

Performance should be assessed using measurable indicators: forecast skill, spatial accuracy, warning lead time, false-alarm ratio, missed-event rate, data latency, system uptime, communication coverage, percentage of warnings acknowledged, evacuation time and post-event model performance. These indicators should be reviewed jointly by technical agencies and emergency managers.

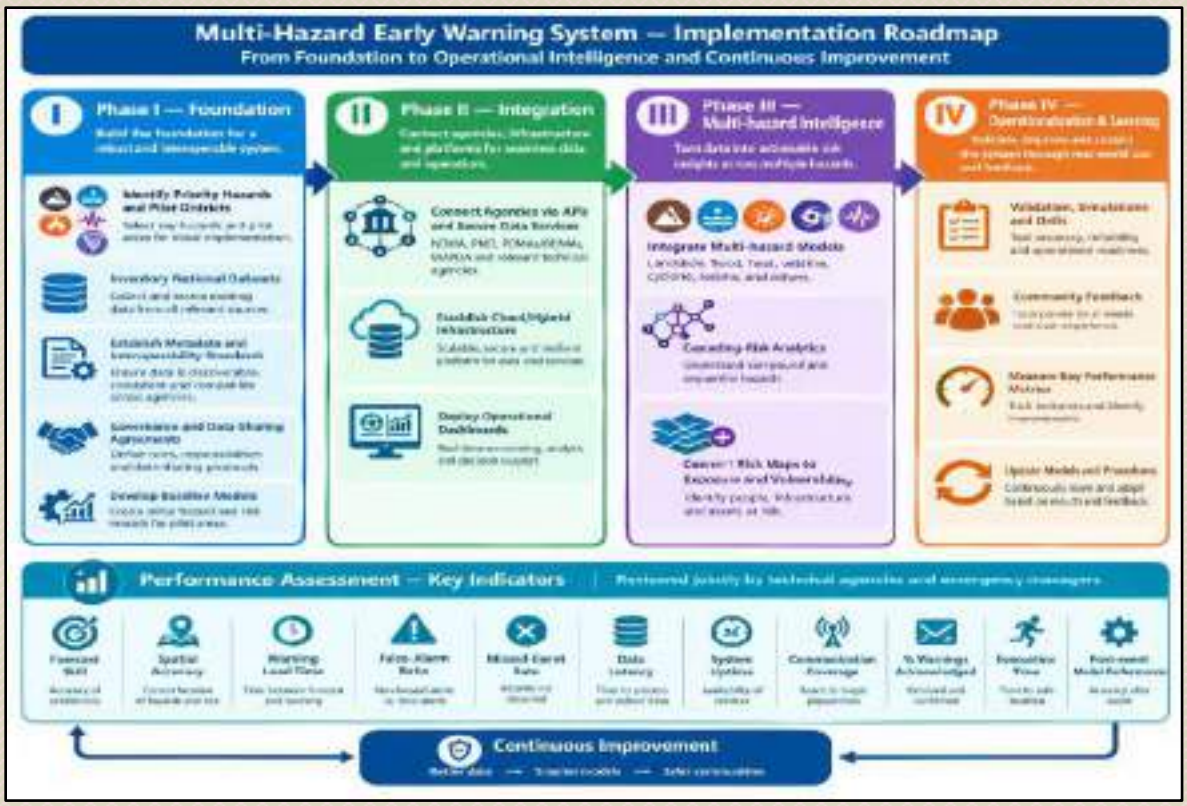


Figure 3. Road Map of Early Warning System.

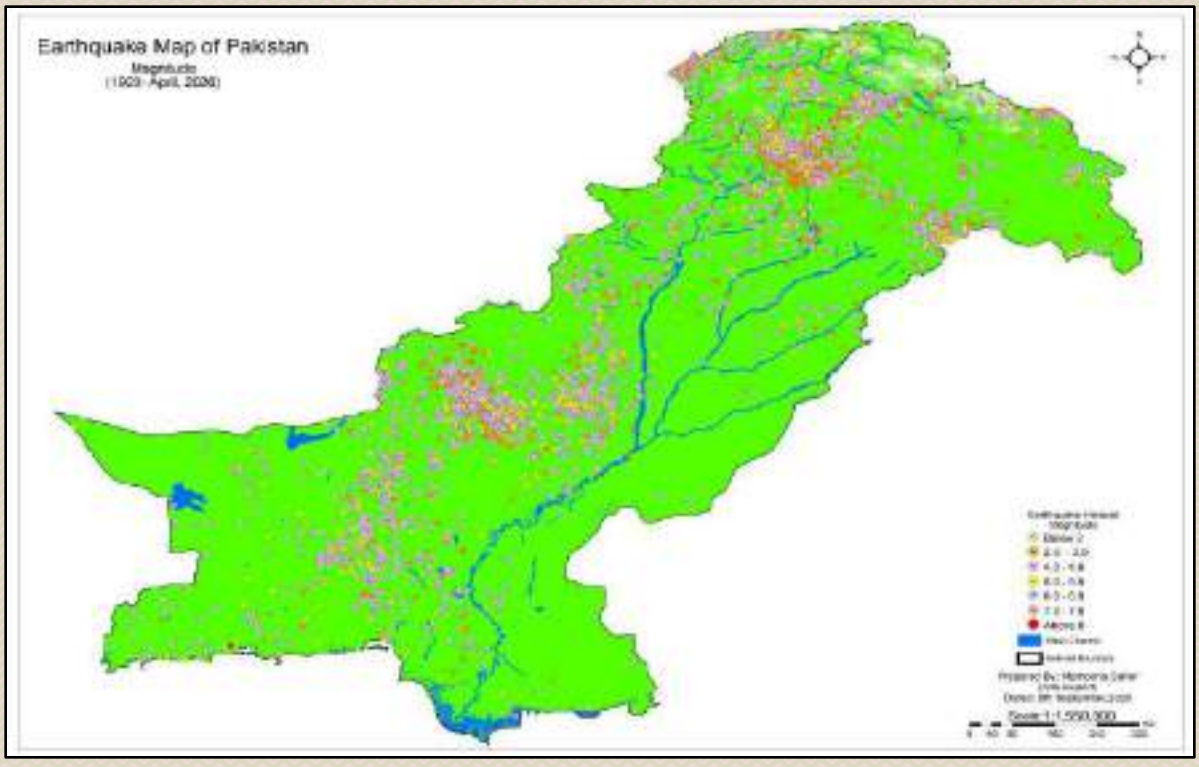


Figure 4. Location map of Earthquake Magnitude (1920- April, 2026)

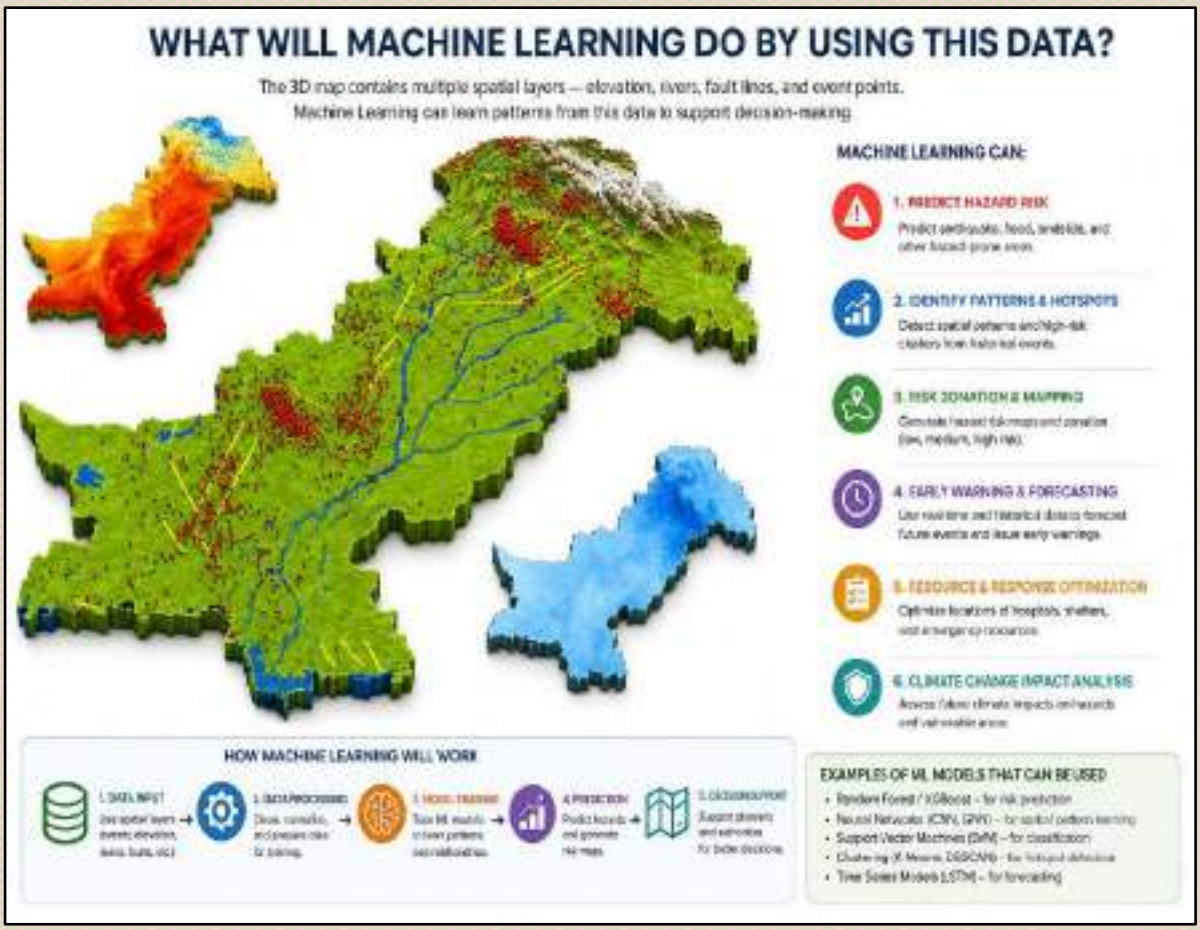


Figure 5. Role of AI/ML for the GIS/RS Based Map of Pakistan.

11. Discussion

The main contribution of the proposed framework is its integration of technologies that are often developed separately. AI without reliable observations is fragile, observations without analytics can overwhelm decision-makers, GIS without timely data becomes static. The warnings without response capacity do not reduce risk. The value of Multi Hazard Early Warning System lies in system integration.

For Pakistan, the framework is particularly relevant because national institutions already operate important components of the chain. NDMA provides federal disaster-management coordination. It has developed technical early-warning capabilities. PMD provides meteorological and hydrological monitoring and flood forecasting data. The other agencies contribute geological, hydrological, spatial and demographic information.

[9–11] The research priority should therefore be interoperability and operational integration, supported by common standards, rather than creating isolated AI platforms.

12. Conclusion

AI-enabled multi-hazard early warning systems offer a pathway toward faster, more spatially precise and more integrated disaster-risk intelligence. The study shows the architecture in which Internet of Things supplies real-time observations, cloud infrastructure enables scalable data and computing, GIS maps hazard and exposure, AI/ML performs detection and prediction and communication systems deliver actionable warnings. The literature confirms the potential of this approach while also demonstrating that AI cannot compensate for weak observations, ineffective communication or fragmented governance.

For Pakistan, the recommended direction is a people-centered, interoperable and human-supervised national architecture that builds on existing institutional capabilities. Priority should be given to data quality of data, cascading-hazard modelling, real-time integration, standardized warning protocols, cybersecurity, community preparedness and continuous validation. The ultimate measure of success is not the sophistication of the AI model but whether reliable risk information reaches the right people early enough to support effective action.

Recommendations

Community Awareness programs should be conduct and integrated with AI system so that community may have immediate awareness.

Plantation of Trees should be introduced and detect through AI system in which potential sites should be identified and proposed automatically. Lahore Government is working on a Tree Plantation Project named “Lahore Ring Forestation Plants”. Such project should be proposed for other potential sites through Artificial Intelligent System.

Seeds of fruits should not be waste; it should be kept safe. A fruit contains number of seeds, when people eat such fruits, they should suggest to collect on individual level and through on country sites which potentially identify through Artificial Intelligent System.

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PARTICIPANT RESEARCH PAPER

Anticipatory Action for Urban Flood Risk Management in Karachi

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Abstract

The city of Karachi, the economic center of Pakistan, is subject to recurrent flooding due to monsoon surges, high rainfall and encroached natural drainage and unplanned urbanization. The loss of life is repeated despite being warned of them ahead of historic events like the August 2020 spell, which saw the city receive 484 mm of rain and over forty deaths [1] and the July 2022 downpour, which brought over 340 mm of rain and fourteen reported deaths [2]. Karachi's disaster response is mostly reactive and is only triggered when flooding has started, not when impact is being felt. This paper focuses on how to reduce avoidable losses in the city, using Anticipatory Action (AA), action in anticipation of a hazard forecasted using predefined thresholds [3]. It presents a profile of the flood hazard and vulnerability of the city of Karachi, outlines the National Disaster Management Authority's (NDMA) approach to the AA principles and introduces a model that integrates rainfall forecasts, drainage and exposure data and a graduated trigger-to-action ladder with the use of a Geographic Information System (GIS). Operationalization of AA in Karachi is hampered by key gaps in institutions, data, and communication, which are identified. The paper ends with recommendations to develop a formal AA protocol for Karachi, develop a GIS-based trigger map and enhance coordination between the NDMA, PDMA Sindh, KMC/KWSB and district authorities.

Keywords: Anticipatory Action; Disaster Risk Reduction; Early Warning Systems; Geographic Information Systems (GIS); Urban Flooding

1. Introduction

Karachi has a population of over twenty million and contributes a significant proportion of the economic activity of the country, but its infrastructure has not been able to keep pace. The annual flooding of the city during the monsoon season is caused by high intensity rainfalls, unmaintained solid waste management and encroached stormwater drains coupled by unplanned urban development along natural drains. Although the weather forecast is fairly accurate, the response system of Karachi tends to be triggered only when the flood is already in the streets, leading to a delay in evacuation, pumping and distribution of relief in the city. Such a reactive response turns a predictable risk into a regular humanitarian and economic crisis.

Another way to do it is to do Anticipatory Action (AA), which is action in advance of a hazard's impact that is planned and resourced in advance of the event [3]. The principles of AA have already been described at national level by NDMA along with its National Disaster Response Plan [4] but the same has not been operationalized in a GIS enabled model in the city of Karachi. The paper describes the flood risk in Karachi and outlines the institutional and technical challenges of taking early action, before proposing a trigger-based approach for building the capacity to transition from reactive flood response to proactive, forecast-based actions, with the help of GIS.

2. Regional Context & Hazard Profile

Karachi is located at the southern coast of Pakistan and gets the bulk of its annual rainfall during a brief and intense monsoon period from July to September. It has a natural stormwater system, where the water flows into two seasonal rivers: Lyari and Malir, which are both nullahs. According to the Karachi Water and Sewerage Board records, there are 64 major nullahs which discharge water into these rivers, however, a large portion of these are encroached by informal and formal constructions to the extent that it has affected their capacity of carrying water, particularly along the major nullahs like Gujjar and Orangi nullah [5].

The City's hazard profile is demonstrated in two events. Karachi had 484 mm of rainfall in August 2020, which is the highest in nearly 90 years with 223.5 mm of rain falling in a span of 12 hours, affecting an estimated fifteen million people and causing the deaths of over forty residents [1], [6]. During the month of July 2022, a period of heavy rainfall of

more than 340 mm was recorded from 10th to 11th July, resulting in additional flooding and 14 fatalities [2]. Both events were similar in that the rain fell above the drainage capacity, the nullahs backed up into the streets, and low-lying settlements were the hardest hit.

From a disaster risk reduction perspective, the hazard is the event of heavy rain, the exposure is the people, roads and assets that are located on flood-prone or drainage-adjacent land, and the vulnerability is the diminished ability of the exposed people and systems to resist or recover from flooding under the local disaster risk circumstances of Karachi.

Table 1. Comparison of the August 2020 and July 2022 Karachi flood events.

Indicator	August 2020	July 2022
Rainfall recorded	484 mm (highest in ~90 years)	342.4 mm
Peak intensity	223.5 mm within a 12-hour spell	Heavy spell, 10–11 July
Reported deaths	41	14
Estimated people affected	~15 million residents	Not separately reported
Primary failure mode	Rainfall exceeded drainage capacity; nullahs backed up	Same pathway repeated within 23 months

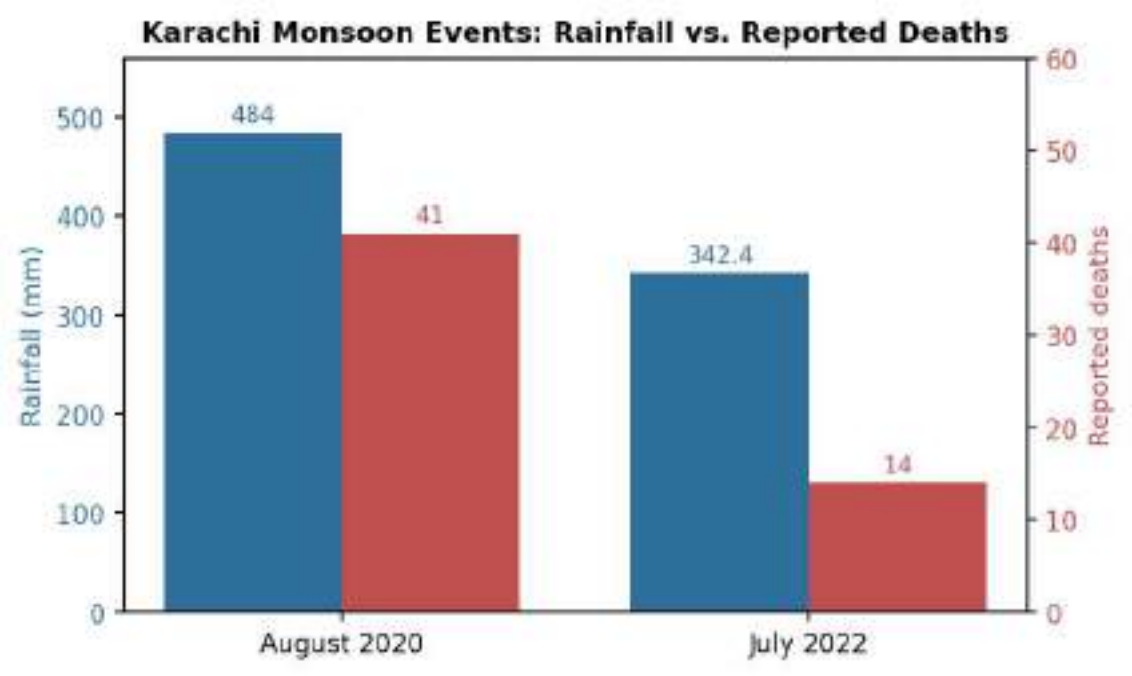

Figure 1. Rainfall totals and reported deaths for the August 2020 and July 2022 Karachi monsoon events [1], [2], [6].

3. Risk & Vulnerability Assessment

The socio-economic impacts of urban floods in Karachi are much deeper reaching than the immediate damage to people. Water-logged roads cause delays in transportation and trade for several days which impact on the economy of the metropolitan area where most trade and manufacturing of Pakistan take place. The informal sector, including daily-wage earners, informal vendors and transport workers make up a significant proportion of the city's workforce, and are deprived of income each day the city is flooded, with little formal safety net available to provide for these losses. Small businesses and households in katchi abadi areas, which are typically located near nullahs and low-lying areas, are more vulnerable to structural damage, as they also have the lowest capacity to cover repair expenses or relocate.

Flooding also negatively impacts food security indirectly: when markets are inundated, supply lines are cut off, and retailing facilities are submerged, food prices in the short-term rise and low-income groups can't access the food. Floodwater is likely to contain sewage, presenting a high public health risk in a city with a high degree of stormwater and sewage connection.

There is no uniform distribution of the vulnerability. Norms may limit women's mobility to access shelter or health facility during and after floods, often making them the primary carers during such periods. Children, elderly residents, and people with disabilities are at increased risk from the rising water, collapsing walls, which was a major cause of fatalities from the 2020 event [1] and loss of medical services. The fact that people living in informal settlements often do not have a formal address makes risk mapping and targeting of assistance more complicated. Together, these factors indicate that the same amount of rainfall has vastly different impacts if it happens in different places and strikes different people, thus underscoring the importance of using an exposure and vulnerability approach, not just a rainfall-based approach, for triggers of anticipatory action.

4. Community Resilience Factors

In Karachi, neighborhoods have a significant informal capacity for resilience, despite the lack of a formal system. In the event of flooding, local philanthropic and volunteer networks, from mosque committees to existing welfare groups, more often than not deploy rescue boats, ambulances and relief supplies before formal agencies, as they did during the 2020 and 2022 floods. Union council officials and local elders know the specifics of streets that flood first, safe ground, and who is most vulnerable, which are not always known at the City level. Long-term residents of the flood-prone katchi abadis have also evolved informal coping strategies such as raised plinths (slightly elevated floors on buildings), short-term relocation with relatives and community-led pre-monsoon cleanup of drains. Resilience building in Karachi does not need to be done from scratch; it needs to link up this social capital and existing local knowledge into a formal and GIS based chain of early action, so community networks are called into play on purpose, not by accident.

5. Scientific & Institutional Gaps

Karachi has several gaps that limit its ability to implement anticipatory action. There is lack of comprehensive, up-to-date digital information on the dimensions of nullahs, blockages, and flow capacity, which could be used to input a hydrological model in real time. The level of development of impact-based forecasting is not as advanced as that of rainfall forecasting itself, which is the translation of a rainfall forecast into a predicted flood at a specific location. The use of GIS and AI/ML in flood-risk modelling is still at an

early stage in disaster institutions in Karachi and there is no integration of GIS with the NDMA, PDMA Sindh, KMC and KWSB systems.

The institutional coordination is also disjointed; drainage being managed by KMC/KWSB, provincial disaster coordination by PDMA Sindh, and national guidance by NDMA, no single decision chain is agreed upon and is triggered on the basis of a disaster. District level capacity gaps continue to exist such as staff not being trained to interpret forecast products or GIS-based decision-support tools. The precondition for any protocol specific to Karachi is closing these gaps because triggers can only be as effective as the data and co-ordination that underlies them. Table 2 summarizes how responsibility is currently split across the four tiers that would need to act together under an anticipatory action protocol.

Table 2. Institutional roles relevant to anticipatory flood action in Karachi.

Tier	Primary responsibility
NDMA	National guidance, coordination and early-warning architecture
PDMA Sindh	Provincial warning, coordination and resource mobilization
KMC / KWSB	Drainage operations, pumps and city-level preparedness
DDMA / District	Local activation, shelters, evacuation and community communication

6. Mitigation Strategies & Best Practices

Even with structural measures, it is not enough to achieve a sustainable future. These include de-silting and widening of priority nullahs (already being done on the Gujjar and Orangi drains), removal of encroachments on drainage rights-of-ways, the upgrading of pumping stations and the integration of sustainable urban drainage principles into new development approvals.

The heart of anticipatory action is non-structural measures. They encompass establishing a locally calibrated trigger-to-action ladder, pre-positioning of pumps, boats and relief stock at known hotspots in advance of forecast threshold, as well as conducting annual pre-monsoon simulation exercises with NDMA, PDMA Sindh and district authorities. Relevant precedent can be found internationally: anticipatory action plans through global humanitarian networks now exist in dozens of countries and financing is forecasted and released automatically when a forecast threshold is hit, as opposed to the delays usually associated with post-disaster appeals [7], [8]. If applied in Karachi it would mean that funding and equipment be allocated to the different phases of the trigger ladder, from Watch to Evacuate, before the onset of the monsoon season. Table 3 sets out an illustrative version of this ladder; the exact thresholds would need to be calibrated against historical rainfall, drainage capacity and flood maps before adoption.

Table 3. Illustrative Karachi trigger-to-action ladder (thresholds require local calibration).

Stage	Indicator	Action
Watch	Forecast indicates elevated heavy-rain potential	Verify hotspots; pre-check pumps; brief agencies
Alert	Forecast confidence increases / local indicators worsen	Pre-position resources; test communications
Warning	Rainfall / water levels indicate imminent flooding	Activate district operations; traffic controls; dewatering
Evacuate	Observed inundation threatens life	Open shelters; evacuate priority areas; emergency response

7. Risk Communication & Early Warning

If a forecast isn't accurate, it offers no protection unless it is communicated to residents at risk in a manner, they can take action on. A multi-pronged Karachi early warning chain

must include multiple opportunities to reach more people: SMS and mobile app notifications for speed and scalability; TV & radio bulletins; and, importantly for regions with lower smartphone coverage, mosque loudspeaker announcements & union council networks, which convey a sense of trust that cannot be replaced by digital messages.

Warnings need to be gender-specific and remember that in some communities women may not receive warnings as soon as other household members do, and they might require specific instructions on evacuation planning for themselves and their dependents. A warning must not only alert people to flood risk, it must also include what actions are possible and what the timeframe is to take the action. A warning needs to be accompanied by operational plans for evacuation, bringing people to safe ground and to accessible shelters, otherwise a warning is little more than cause for anxiety to residents. When a warning is sounded, it is believed, understood, and acted on because it has been experienced in the community prior to the monsoon.

8. Policy Recommendations

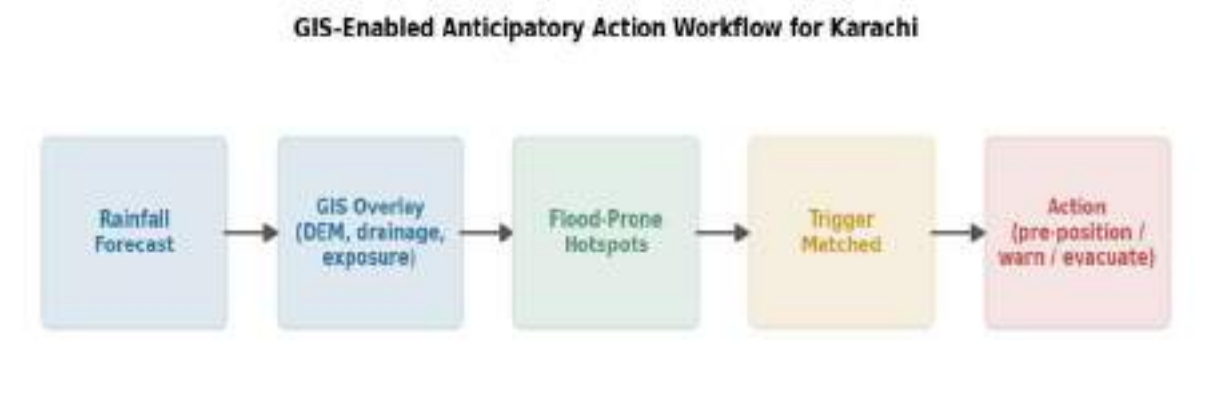

Figure 2. Proposed GIS-enabled workflow linking rainfall forecasts to location-specific anticipatory action.

Six priorities would help move Karachi towards an operational anticipatory action system. First, NDMA and PDMA Sindh should establish an AA protocol specific for Karachi, which will outline various trigger points, the agencies responsible, and pre-agreed actions to take at each stage. Second, a GIS based trigger map shall be created, which involves overlaying a rainfall forecast with digital elevation, drainage networks and population exposure to highlight priority areas for pre-positioning. Thirdly, introduction of a pilot

telemetry system on priority nullahs commencing from Gujjar and Orangi drains, and disseminating real time water level data to an operational dashboard shared between NDMA, PDMA Sindh and KMC/KWSB.

Fourth, resources and finances should be pre-arranged, and specific equipment, personnel and financial resources are to be released at each trigger point ahead of the onset of the monsoons, not in response to flooding. Fifth, the formal integration of union councils, mosque networks and community volunteers into the warning dissemination chain with digital warnings should be increased to enhance last mile warning capacity. Sixth, drainage planning should be redone utilizing current topographic and land use maps, and new development must be approved, taking natural drainage into account and not blocking it. These measures apply the existing principles of NDMA at the city level and are consistent with other international guidelines for DRM, including the Sendai Framework for Disaster Risk Reduction which stresses mitigating existing risk and avoiding the creation of new risk through improved planning informed by better knowledge [9].

9. Conclusion

Karachi's losses due to recurrent flooding is not just a forecasting problem because meteorological warnings were issued days ahead of the 2020 and 2022 events. The problem is the disconnect between forecast and response and the lack of a pre-agreed, GIS-based system that translates a warning to a location-specific response with resources in place before water arrives at communities. If implemented through a locally calibrated trigger ladder, the integration of GIS data, pre-arranged finance and a coordinated institutional chain from NDMA to PDMA Sindh, KMC/KWSB and district authorities, Anticipatory Action is a proven, flexible mechanism of bridging the gap for Karachi. Community networks and local knowledge exist without any formal support and are already capable of coping, so they can be a place from which they can be developed instead of a place where they must be invented from scratch. While Anticipatory Action does not prevent the monsoon from happening, it can significantly decrease the needless loss of life and livelihood in Karachi that it's had several times before, moving the city's disaster management from reactive response to real risk reduction.

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PARTICIPANT RESEARCH PAPER

Leveraging Big Data and Remote Sensing for Disaster Risk Management in Karachi: Opportunities, Gaps, and Policy Pathways

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Abstract

Pakistan's second-largest coastal city of Karachi experiences recurrent urban flooding, cyclical threat of cyclone and storm-surge impact, and increasingly extreme heatwaves due to rapid unplanned urbanization and climate change, which pose significant risks to the city's social and economic development. This paper explores the role of big data analytics and remote sensing in disaster risk management (DRM) in Karachi by examining the potential of satellite radar, land surface temperature, and related platforms to generate actionable insights for municipal authorities and emergency responders. With support from relevant publications of the National and Provincial Disaster Management Authorities (NDMA, PDMA-Sindh) and the peer-reviewed scientific literature on remote sensing, the paper demonstrates that while significant volumes of satellite data on urban flooding, land-cover transformation, and surface heat-islands are already being generated for the region, these are scarcely leveraged in current DRM practices due to critical scientific, institutional and technological gaps. It highlights several areas of DRM in Karachi that could benefit from big data and remote sensing, including flood forecasting, early warning, and community resilience, and offers a set of policy recommendations to promote multi-hazard DRM and risk governance in the city.

Keywords: Big data; Disaster risk management; Karachi; Remote sensing; Urban flooding

1. Introduction

As Pakistan's largest coastal metropolis and economic center, Karachi has a large and rapidly growing urban population and is at high risk of exposure to climate-related hazards such as urban flooding, coastal cyclones, and extreme heatwaves. At the same time, the city's disaster governance mechanisms are challenged to respond to the diverse and complex disaster risks that it faces. This paper builds upon the findings of remote sensing studies on flood hazards and surface heat islands in Karachi, Pakistan, and seeks to identify how big data and remote sensing could be integrated into the city's disaster risk management (DRM) cycle to support more effective and timely responses to flood, heatwave, and cyclone hazards. It attempts to contribute to disaster governance in Karachi by identifying critical institutional and policy gaps in leveraging remote sensing data for disaster risk management, particularly in the areas of flood forecasting and early warning.

Figure 1. The disaster risk management cycle in Karachi, indicating input areas for big data and remote sensing.

2. Regional Context & Hazard Profile

The natural hazard exposure in Karachi is determined by the city's location on the delta of the Lyari and Malir rivers that empty into the Arabian Sea. With most of its area comprising low-lying coastal land, any significant precipitation can lead to severe urban flooding, particularly in the informal settlements on the banks of the rivers, as seen during the 2022 and 2025 monsoon seasons. Flood hazard is compounded by the city's vulnerability to extreme weather events such as heatwaves, downpours, and cyclones (UNICEF 2025). For example, During Tropical Cyclone BIPARJOY in June 2023, Karachi and other coastal areas of Sindh were exposed to risks from heavy rainfall, strong winds, storm surge and urban flooding (PDMA 2023). The city scores particularly high on exposure to climate change impacts, with multiple studies reporting an increase in surface temperature of 1.3°C over the past 22 years on average for night-time observations (Atif et al. 2020; Zubair et al. 2023; Afzal et al. 2025).

Figure 2. Timeline of major hazard events and satellite data activations in Karachi, 2022-2025

For this study, the disaster risk management cycle in Karachi was considered as consisting of the following key elements: hazard identification and forecasting, exposure assessment, vulnerability and capacity analysis, early warning and preparedness, response and recovery, and institutional coordination (see Figure 3). For this study, flood, coastal storm, and heat-wave hazards were prioritized based on their likelihood and potential impact on the population and infrastructure.

Figure 3. River Systems in Karachi

3. Risk & Vulnerability Assessment

Using remote sensing and big data, it is possible to estimate the potential impact of different flood events on the population and infrastructure with a high degree of accuracy. Multiple peer-reviewed studies on the application of remote sensing in disaster risk management in Karachi have demonstrated the value of satellite-derived land-use land cover (LULC) change analyses for hazard assessment. As can be seen in Figure 4 below, the LULC trends in Karachi indicate increased impervious surface cover and decreased vegetation, contributing to increased exposure to flooding and heat-stress.

The vulnerability of the population to climate-induced hazards in Karachi is affected by a range of factors, including economic status, access to services, and social support networks. Socio-economic vulnerability appears to be most acute in the katchi abadi (informal settlements) along the Lyari and Malir rivers, where the impacts of flooding are compounded by poor sanitation and lack of resilience infrastructure such as community-level drainage systems. The increased exposure and vulnerability of these populations to hazards such as flooding contribute to their overall risk, which is elevated during heatwaves and peak monsoon seasons. In addition, the vulnerability of these communities to health shocks is increased: for instance, it has been reported that urban flooding in Karachi facilitates the spread of water-borne diseases such as cholera (Taseen et al. 2022). The vulnerability of poor populations to climate change impacts is further exacerbated by gender inequalities. For instance, women and children from disadvantaged communities are disproportionately affected by disaster impacts and have limited access to relief resources and early warning information (UNICEF 2025). Similarly, the lack of community-level disaster response plans means that evacuation and emergency shelter options are inadequate and inaccessible to many vulnerable groups, especially during heatwaves (Figure 4).

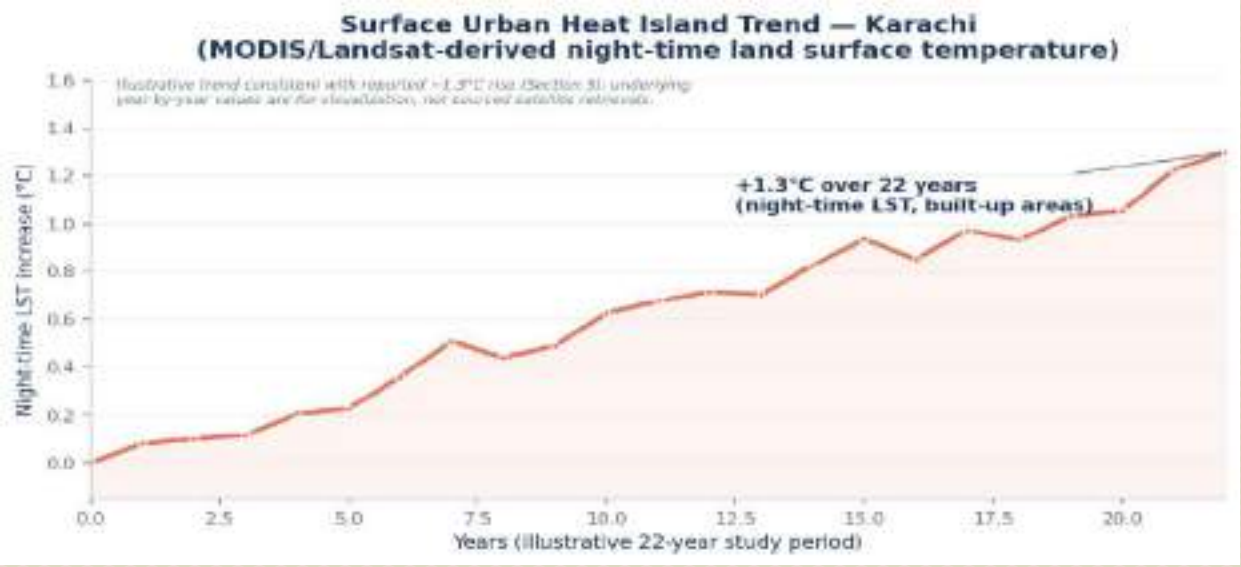

Figure 4. Surface urban heat island trend in Karachi based on MODIS/Landsat-derived night-time land surface temperature.

4. Community Resilience Factors

Despite the city's inadequate institutional disaster risk governance mechanisms, it is possible to observe several community-level resilience factors that contribute to reducing the disaster impact in vulnerable neighborhoods. For instance, in many low-income neighborhoods in Karachi, community members organize themselves to clear drainage and respond to flooding in their neighborhoods. Local knowledge about the likelihood and timing of floods informs people's preparedness and response behaviors, and in some cases, residents use mosques as a platform to share early warning information and coordinate collective response efforts when government authorities are unable to respond adequately (NDMA 2025b). Thus, community-level disaster resilience in these neighborhoods is informed by indigenous knowledge about flood patterns, as well as networks of mutual support that enable preparedness and response at the local level. At the same time, it must be noted that these factors operate in isolation from formal disaster management institutions, which do not engage with communities to understand their capacities or disseminate early warning information to them effectively.

5. Scientific & Institutional Gaps

The review of the literature on the use of satellite remote sensing in disaster management in Karachi reveals a number of scientific and institutional gaps that hinder the effective use of earth observation data in disaster risk management. On the scientific side, the main limitation is the lack of local capacity to process and apply big data analytics to disaster risk assessment and response. As noted by multiple studies, while earth observation data can be used to estimate the likelihood and potential impact of flooding with a high degree of accuracy, this potential is not leveraged due to limited technical expertise in local disaster management agencies (Copernicus Emergency Management Service 2025; Wagner et al. 2023; Afzal et al. 2025). For instance, while Sentinel-1 SAR-based flood mapping has been used extensively in Pakistan to support disaster response operations (up to 80% accuracy in 2022 flood mapping according to Wagner et al. 2023), local agencies do not have the capacity to analyze the raw satellite data and extract actionable insights for DRM. Similarly, while several peer-reviewed scientific studies have applied MODIS and Landsat-based analyses to estimate land surface temperatures and urban heat islands in Karachi (Atif et al. 2020; Zubair et al.

2023; Afzal et al. 2025), these findings have not been utilized by local authorities to support heat stress management.

A further scientific gap is the limited operational application of artificial intelligence (AI), machine learning (ML), and automated geospatial analytics for near-real-time disaster monitoring. While these approaches can support automated flood detection, heat-risk modelling, change detection, and predictive risk assessment, their use within local DRM institutions is limited. The challenge is therefore not only the availability of satellite data, but the ability to transform high-volume, multi-source data into reliable decision-support information.

Institutionally, fragmented data management and limited interoperability between disaster management agencies, local government, meteorological services, and research institutions impede the use of remote sensing. Satellite-based products, ground observations, administrative data, and historical disaster reports are often solved, limiting the development of integrated multi-hazard risk assessments. There is also a need for standardized data-sharing mechanisms, metadata practices, and institutional protocols to ensure that the regular incorporation of Earth observation products can take place in preparedness, early warning, response, and recovery functions.

These gaps suggest a wider “data-to-decision” disconnect in Karachi: while relevant Earth observation technologies and scientific studies are increasingly available, their benefits are not consistently leveraged for disaster risk reduction. Strengthening local technical capacity, institutional data governance, inter-agency collaboration, and the operational use of remote sensing and AI/ML are therefore critical for building a more evidence-based, technology-enabled DRM system (Figure 5).

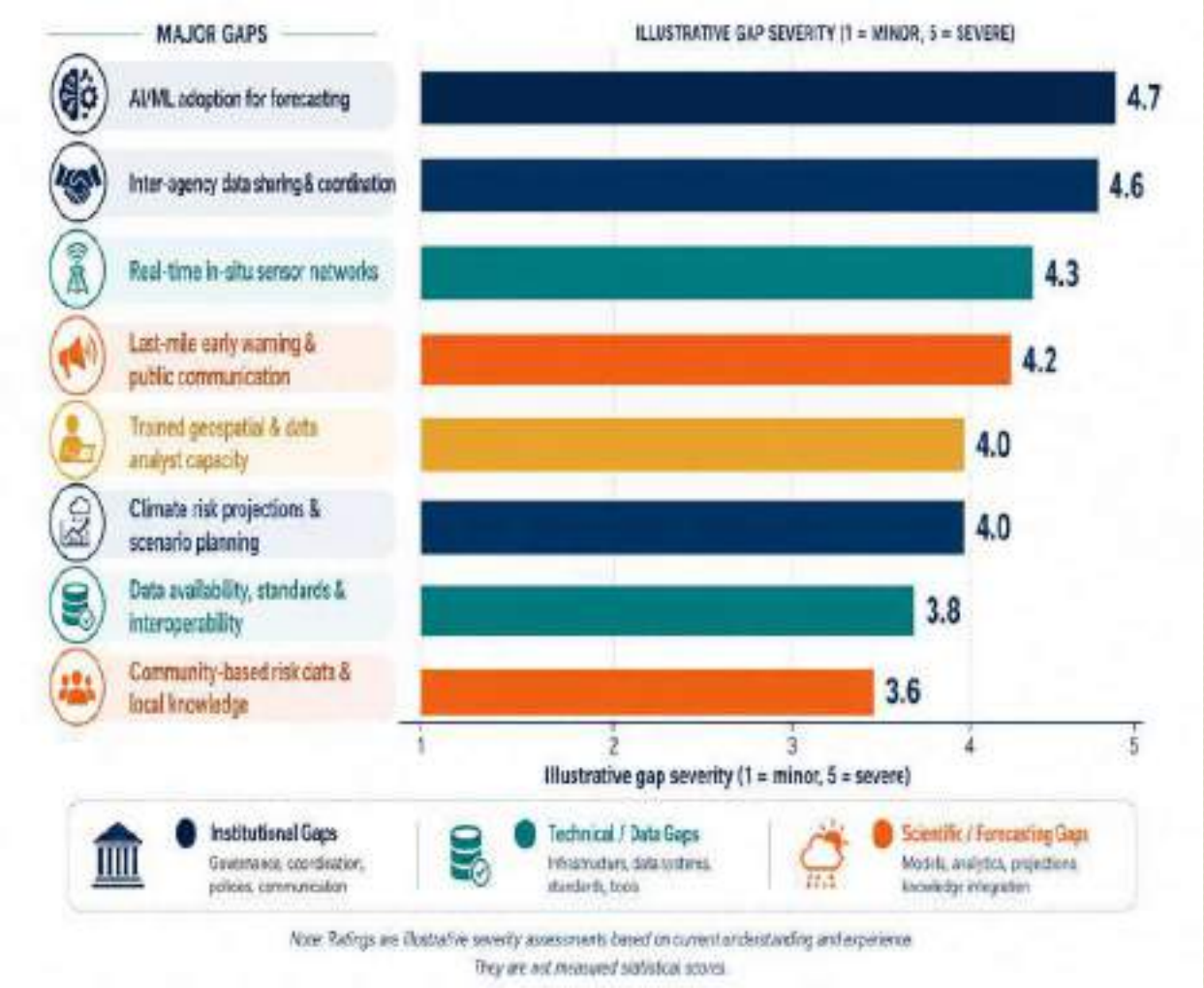

Figure 5. Reported severity of institutional and scientific gaps constraining Karachi's disaster risk management system.

6. Mitigation Strategies & Best Practices

The flood mitigation strategies that would be most effective for Karachi include structural and non-structural measures to reduce the impact of flooding on the population and infrastructure. The non-structural measures would involve institutional coordination and community engagement while structural measures would focus on improving the drainage system using satellite-estimated LULC information. In terms of institutional measures, the local authorities and the PDMA-Sindh could consider adopting a comprehensive risk governance strategy by formalizing the use of Sentinel-1/2 and MODIS products in the day-to-day operations as well as contingency planning. This would allow for continuous flood forecasting and early warning rather than relying on

international agencies such as the Copernicus Emergency Management Service (Figure 6). Some best practices could be drawn from other regional jurisdictions such as Jakarta and Chennai, which have implemented flood forecasting and early warning systems that combine satellite rainfall estimates with local ground truthing. In addition, other South Asian jurisdictions have started using drones to collect field survey images after a disaster, which could be considered as an option for post-flood needs assessment in Karachi. Other measures that could be adopted to improve flood forecasting and early warning in Karachi include the installation of local rain and river gauges to supplement the in-situ monitoring capabilities. To build local technical capacity for utilizing big data in disaster risk management, it may be useful to invest in training provincial and municipal disaster management personnel in geographic information systems (GIS) and remote sensing. Awareness-raising efforts among local communities about the flood risk governance framework and early warning systems can also be helpful in ensuring that residents know how to respond to flood warnings.

7. Risk Communication & Early Warning

When it comes to early warning, it is important to note that while authorities such as the Pakistan Meteorological Department (PMD) and the PDMA-Sindh issue rainfall and flood warnings, these are not reaching the most vulnerable communities in a timely manner, as evidenced by the number of casualties during the recent monsoon floods (Khan 2025; NDMA 2025a). In order to enhance early warning in flood-affected communities in Karachi, it is important to develop innovative risk communication strategies that make use of local knowledge and institutions while building trust with the formal authorities. This could involve using SMS/email notifications based on the flood extent forecast products provided by the Copernicus Emergency Management Service. Notifications would need to be targeted to the most vulnerable populations and issued well in advance of the flooding episodes. Gender-sensitive risk communication strategies should be used to ensure that women and children have access to the early warning information. This could involve leveraging local mosques, community councils, and, if available, local government units as a means of dissemination, as several communities reportedly accessed the early warning information through them during the 2025 monsoon season (NDMA 2025b).

8. Policy Recommendations

- Based on the findings of this study, the following policy recommendations are proposed to support multi-hazard disaster risk governance in Karachi:
- Establish a formal big-data platform for multi-hazard disaster risk management in Karachi, which would facilitate information sharing between the NDMA, the PDMA-Sindh, the KMC, and the PMD.
- Formalize inter-agency collaboration frameworks and clarify roles and responsibilities in relation to data collection, analysis, and dissemination.
- Build technical expertise in big data and remote sensing within the provincial and municipal disaster management agencies.
- Support the installation of ground monitoring equipment such as rain and river gauges to supplement the satellite observations and ensure that local-level forecasting and early warning becomes routine practice in Karachi.
- Ensure that early warning information is disseminated to the public in an accessible manner by creating localized versions of hazard maps and issuing SMS/email alerts in a timely manner.
- Explore public-private partnerships to ensure that disaster management agencies have technical expertise and analytical tools to harness the power of big data (Figure 6).

Figure 6. Summary of the six key policy recommendations proposed in this paper.

9. Conclusion

The disaster risk governance system in Karachi, Pakistan, has the capacity to leverage big data and remote sensing to enhance its flood forecasting, early warning, and emergency response capacities. The findings of this study indicate that while there is awareness of the potential of earth observation data in disaster management, it is not harnessed due to institutional, technical, and awareness-related challenges, which impede the implementation of data-driven disaster risk reduction strategies. It is recommended that in addition to building technical expertise among local disaster management agencies, policymakers invest in formalizing inter-agency collaboration frameworks, as well as community engagement mechanisms for building local resilience. In this regard, science-based early warning data, community knowledge, and modern technology should be viewed as complementary rather than competing resources, with the potential to contribute to more effective disaster risk governance in Karachi, Pakistan.

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PARTICIPANT RESEARCH PAPER

Building Collapse Risk in Pakistan: Structural Vulnerability, Construction Practices, Building-Code Enforcement, and Disaster Prevention

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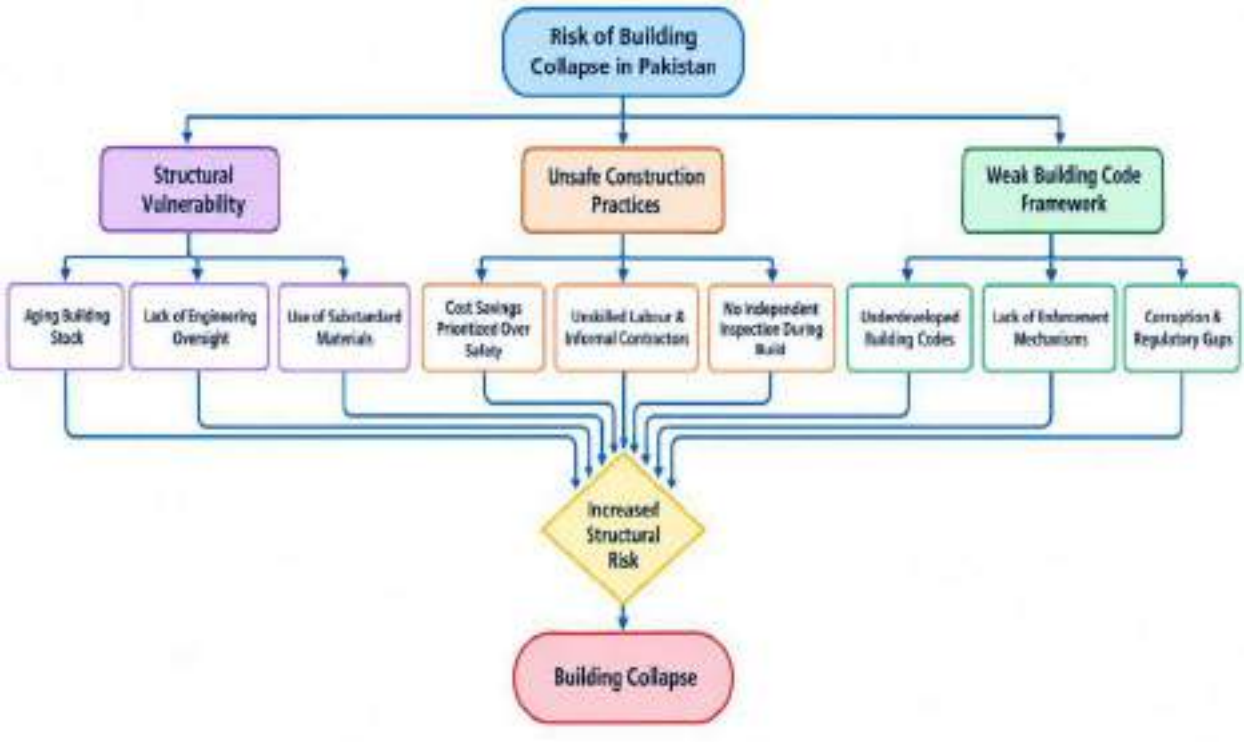
Abstract

One of the most common and preventable urban disasters in Pakistan is building collapse that takes lives of locals in common, non-seismic conditions not just during the earthquakes. A five-storey residential building known as Fotan Mansion in Lyari, Karachi collapsed killing 27 people on 4 July 2025, despite the Sindh Building Control Authority (SBCA) warning the building of danger in 2023 and the building still having approximately 12 families living inside (Dawn, 2025; Wikipedia, 2025). Within a year, on 30th June 2026, the roof of a private tuition centre in the Kahna area of Lahore collapsed and killed 14 children (Dawn, 2026a), while on 19th February 2026, a gas-explosion caused the collapse of a three-storey building in Soldier Bazaar, Karachi, which resulted in 16 deaths (France24, 2026), and on 30th July 2026, a three-storey building in Harbanspura of Lahore collapsed killing 11 children (The Nation, 2026). This paper explores how structural vulnerability, substandard construction practices, weak building-code enforcement are co-causing factors in the collapse risk of buildings in Pakistan, and suggests some structural-safety prevention measures in line with BCP 2021 by Pakistan Engineering Council and international building safety reform models, with the following four events from 2025 to 2026 being considered worked case studies

Keywords: Building Collapse; Building Code Enforcement; Structural Vulnerability; SBCA; Construction Practices.

1. Introduction

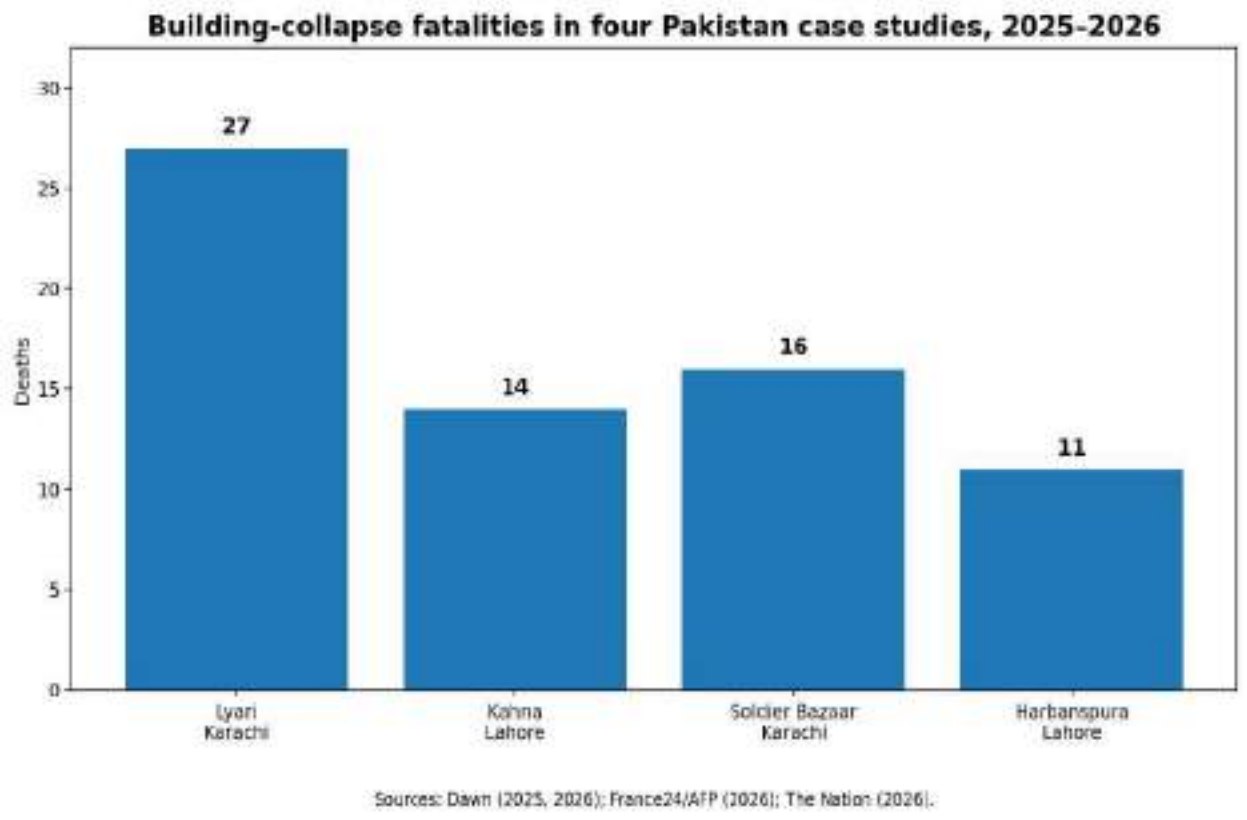
Natural hazards are rarely the cause of roof and building collapses across the cities of Pakistan, rather it is due to the age of buildings, their unauthorized alterations and poor construction practices that are not detected or rectified on time by safety regulation (CBS News, 2026). In the Pakistani city of Karachi, which has a population of more than 20 million, the lack of security has become a vital issue, with approximately 600 buildings declared unsafe by the Sindh government (France24, 2026; Anadolu Agency, 2025) in the city, which is infamous for its illegal extensions, old infrastructure, overcrowding and lack of proper enforcement. Unfortunately, such incidents have also happened in Lahore, Pakistan's second-largest city, due to other issues: lack of supervision of building construction of private business buildings and the use of inferior structural members. This paper examines three interdependent factors that contribute to the risk of buildings collapsing in Pakistan: structural vulnerability of Pakistan's building stock due to its age and lack of engineering; construction practices that are substituting cost savings with safety; and the lack of development and more importantly enforcement of building codes. The objectives are: (i) to describe the scale and pattern of the hazard based on the latest data from case studies; (ii) to present the evidence on the neighbourhood level for four collapse events that occurred in 2025–2026; (iii) to examine the vulnerability of various groups of residents and the socio-economic factors that hinder people from escaping unsafe buildings; (iv) to analyze the community's resilience and the gaps in institutions, such as the record of implementation of SBCA and other provincial disaster prevention institutions; and (v) to recommend policy measures based on the Building Code of Pakistan 2021 and international disaster prevention models.



2. Regional Context & Hazard Profile

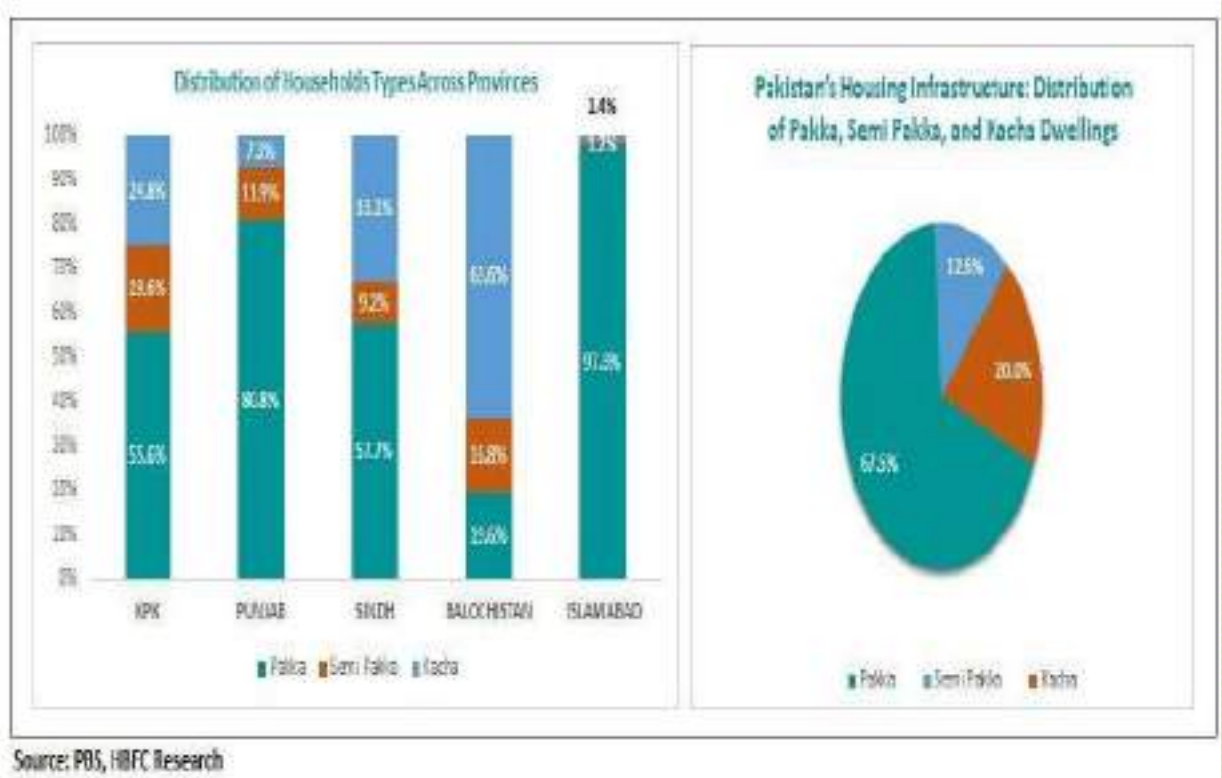
The building safety law in Pakistan is based on the Building Code of Pakistan (BCP) – Seismic Provisions 2007, which was developed by Pakistan Engineering Council (PEC) in response to the 2005 Kashmir earthquake (87,000 deaths, 780,000 buildings destroyed), and amended to BCP 2021 following the seismic hazard assessment that revealed many regions are more earthquake-prone than the 2007 building code assumed (PEC, 2021). But most crucially, the vast majority of the deaths that have been recorded since 2025 were not caused by seismic events, but by other causes: a gradual deterioration of the structures, by adding an extra floor at a building's façade, gas explosion in old gas piped buildings and the failure to follow the codes for construction of new buildings, which are not addressed by the seismic code; these are under the control of the municipal building control authorities (SBCA in Sindh and equivalent in Punjab, LDA, PHATA) respectively. As in the case of the collapse of the Fotan Mansion on 4 July 2025, which killed 27, the structure was declared unsafe by the SBCA as early as 2023, and authorities admitted that the structure's construction had violated building regulations, allowing for the addition of extra floors to the original building (Dawn, 2025;

Al Jazeera-sourced Anadolu Agency report, 2025). At the time, SBCA documents showed that there were a total of 588 buildings in the city that were considered to be dangerous, including 107 in the Lyari area — which is why, as one Dawn analysis put it, the Fotan Mansion tragedy was not a shock but a grim inevitability (Dawn, 2025).



Province/Region	Baked/brick/ block/stone	Unbaked brick/mud	Wood/ bamboo	What does this indicate for safety research?
Punjab	86.60%	11.84%	0.70%	Predominantly masonry-based housing stock
Sindh	61.15%	23.79%	12.32%	Greater diversity of construction materials
Khyber Pakhtunkhwa	67.16%	28.29%	2.72%	Significant traditional-material component

Balochistan	22.36%	61.02%	9.55%	Strong dependence on mud/unbaked construction
Islamabad	97.71%	1.53%	0.35%	Predominantly baked masonry construction



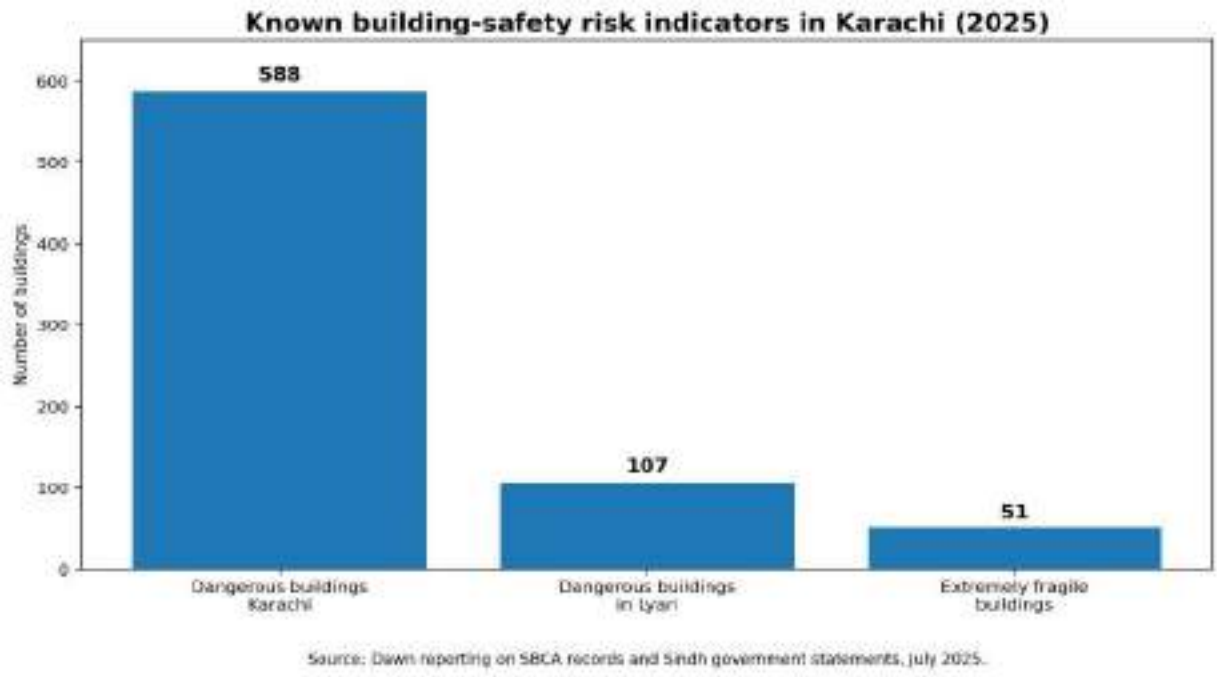
3. Risk & Vulnerability Assessment

The 2025-2026 case cluster reveals collapse risk linking through various unique pathways. The roof of a partially completed second floor of a private tuition centre in Kahna, Lahore, collapsed on the first floor where 14 children were killed and at least eight injured on 30 June 2026, marking children's exposure to collapsing roof as a risk parallel with that of older buildings (Dawn, 2026a; CBS News, 2026). A suspected gas explosion in a busy three-storey residential building in Karachi's Soldier Bazaar killed 16 people, including women and children, during the nighttime preparation of pre-dawn breaking fast Ramadan prayers on 19 February 2026, which is a typical feature of the city's dense, old

housing stock's susceptibility to gas-safety failures (France24, 2026; Gulf News, 2026). A run-down three-storey structure built using TR low-quality girders collapsed in the early hours of 30th July 2026 in Harbanspura area of Lahore killing 11, ranging in age from seven to 60, and thus, highlights the danger of collapse across the ages in the same household (The Nation, 2026). A recurring socio-economic trend is that the entire problem of structural vulnerability in Karachi has been blamed on the high level of corruption, regular violation of building laws and the lack of any authority supervision (Anadolu Agency, 2025). The majority of residents of declared-dangerous buildings, as frequently acknowledged by the SBCA, "don't leave" (Dawn, 2025) buildings when they have been noticed for evacuation as they have nowhere to go/relocate to. This means that the households that are at the highest risk of collapse are the same households that are the least likely to be able to get out of the situation on their own – something that formal warning notices cannot address. A channel of resilience that will need to be formalized and not just after tragedies.

Vulnerability dimension	Indicators that can be assessed	Suggested field evidence
Structural configuration	Irregular plan, soft storey, weak columns, inadequate lateral resistance	Visual/engineering inspection
Building age	Construction before applicable seismic/building-code provisions	Construction records
Alterations	Removal of walls, additional floors, extensions	Approved plans vs current structure
Site conditions	Foundation problems, unstable soil, proximity to hazards	Site inspection/geotechnical assessment
Adjacent-building	Very small gaps, pounding	Site survey

interaction	potential, shared walls	
Non-structural vulnerability	Unsafe ceilings, partitions, parapets, heavy fixtures	Building inspection
Maintenance condition	Cracks, corrosion, water damage, deterioration	Periodic inspection
Emergency performance	Exit availability, accessibility, fire-safety provisions	Safety audit



4. Community Resilience Factors

The neighbourhoods of Pakistan demonstrate substantial real resilience capacity during immediate aftermaths of collapse events, despite weak formal safety nets. While a local volunteer or neighbor is invariably the first responder, extended search and rescue operations, often spanning multiple days like the Lyari operation which lasted 50 hours till the final body was recovered (The Express Tribune, 2025; Wikipedia, 2025), have been done by rescuers like Rescue 1122 in Punjab and comparable rescue services in Sindh.

Community and civil-society pressure has also led to institutional accountability: the public outcry following the collapse of the Lyari, was a direct cause for the suspension of the SBCA Director General and a city-wide demolition and inspection drive of hundreds of at-risk structures is a case in point (Dawn, 2025; ARY News, 2025). This demonstrates that organised community and media pressure can lead to regulatory action, not only when enforcement is routine, but also after tragedy.This indicates that there is a resilience channel, which is not just through routine enforcement — it's through organised community and media pressure.

Resilience stage	Community capacity	Building-safety relevance	Desired outcome
Before disaster	Identify visibly unsafe buildings	Community reporting and inspection requests	Risk identified before
Before disaster	Know evacuation routes	Reduces exposure during emergencies	Faster evacuation
Before disaster	Maintain emergency contacts	Links residents with authorities	Faster intervention
During warning	Follow evacuation instructions	Prevents continued occupancy	Lower casualty risk
During emergency	Community coordination	Helps children, elderly and vulnerable residents	Reduced exposure
Immediately after event	Report damaged buildings	Prevents re-entry into unsafe structures	Secondary casualties avoided
Recovery	Participate in	Encourages safer	Reduced future

	reconstruction decisions	rebuilding	vulnerability

5. Scientific & Institutional Gaps

Technical codes are not the main issue in the building-safety system in Pakistan; it is the weakness of the institutions. SBCA itself admitted that Fotan Mansion was catalogued as dangerous in 2022-2023, but after a police investigation, six of the SBCA directors and the owner of the building were among 14 people found guilty of gross negligence, as the police found that though the building was known to be dangerous, no serious preventive measures were taken (ARY News, 2025). In more structural contexts, building codes are not compulsory throughout Pakistan: Among the research findings from the rural and peri-urban construction, it was found that no local council has officially adopted the national building codes and that legal, regulatory, technical, and financial barriers, combined with the ambiguity that ensued after the 18th Constitutional Amendment devolved planning powers to provinces, left code adoption inconsistent across jurisdictions (Usman & Ibrahim, 2016, cited in building-codes research, 2022). There is also incongruity regarding enforcement capacity, as SBCA's own records have official figures of 588–600 buildings in Karachi as officially dangerous, including more than 100 in Lyari alone, but SBCA's own public statements report that they cannot force the evacuation of residents without cooperation from the law-enforcement and social-welfare bodies, and have no relocation housing available (Dawn 2025; Pakistan Today 2026). Thus, the building-safety institutions operating in Pakistan at present are essentially a system of documentation, hence a system for cataloguing danger, but not one to prevent it.

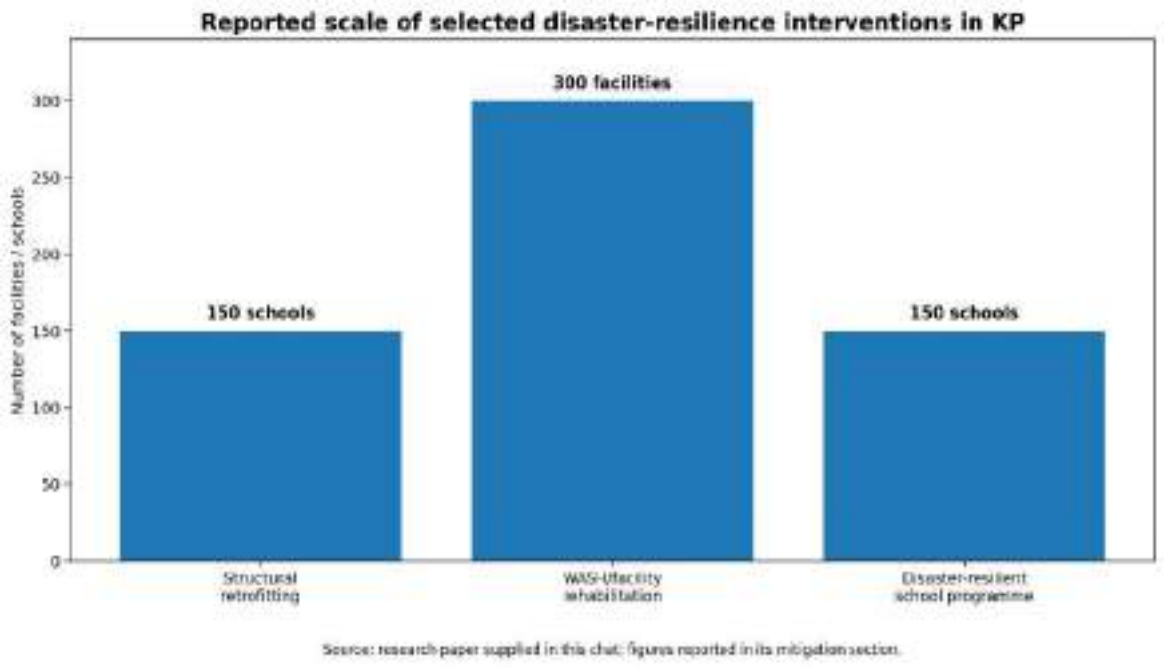
6. Mitigation Strategies & Best Practices

After the Lyari tragedy, the Sindh authorities had initiated a demolition drive targeting illegally constructed and under-construction buildings with financial assistance being provided from the property owner and recovery of the cost via tax dues if the owner fails to pay, and an inquiry was also launched by the Sindh High Court, which was asking the authorities to carry out inspections of all 588 unsafe buildings and review the rules of the Sindh's Building Control Authority (SBCA) (Wikipedia, 2025; ARY News, 2025). It is a

workable version of this template but a standing, pre-emptive annual inspection and demolition cycle (as opposed to a response that kicks in only after mass-casualty events) would turn documentation into prevention. But there should also be structural audits and verification of application of BCP 2021 requirements before occupancy certificates are issued, especially for buildings with new or unauthorized floors installed (PEC, 2021); and structural verification by PEC that the municipal building-control personnel are considering and applying the BCP 2021 requirements, instead of the obsolete seismic only baseline (BCP 2007) (PEC, 2021). However, Bangladesh's regulatory changes since the Rana Plaza building collapse in 2013, which resulted in a nationwide programme of mandatory structural, fire and electrical safety inspections for thousands of clothing factories, based on the Accord/RMG Sustainability Council model, provide a directly relevant blueprint for Pakistan: independent, published, building-by-building safety audits with binding remediation timelines and the public disclosure of results, rather than internal agency notices, which residents can choose to ignore. Similarly, Nepal's subsidy-based rebuilding programme, following its 2015 earthquake, took a different approach by tying a mandatory condition (engineer certified safety standards) to the release of subsidy money, a model that could be replicated for evacuees from and retrofits of buildings that are listed as being unsafe by SBCA.

Intervention	Location	Scale	Reported outcome/significance
Structural retrofitting	Khyber Pakhtunkhwa	150 schools	Schools strengthened against disaster risks
WASH/facility rehabilitation alongside structural work	KP	300 facilities	Structural and functional resilience addressed together
Disaster-resilient school programme	8 KP districts	150 schools	Improved learning environment for 31,000 students

Development of seismic-retrofitting guidance	Pakistan	National application intended	Standardized approach being developed for vulnerable schools



7. Risk Communication & Early Warning

Existing practice is to distribute written evacuation warnings to people living in buildings that are at risk, which works only partially well if people have no assistance for relocating from the building or enforcement support to help them evacuate (S. B. C. A., 2025). Public, geo-tagged disclosure of all officially dangerous buildings (which are already catalogued internally by SBCA and equivalent Punjab authorities) to help prospective tenants, buyers and financiers verify a building's safety status before they move in, thereby closing the information gap which currently lets families move in to buildings that are already known to be dangerous. Similarly, the use of ward level committees, mosque announcements and local media, which are working effectively in providing flood warnings in Punjab can be extended to announce timelines of demolition and relocation with concrete housing options to provide advance warning to the residents of the affected areas with concrete housing options.

8. Policy Recommendations

- Ensure that BCP 2021 provisions are mandatory and enforceable for all provincial and municipal building-control authorities, and eliminate the obscurity surrounding code adoption post-18th Amendment that currently exists at the local level.
- Replace SBCA's dangerous-building register from a documentation exercise with a set schedule for demolitions and relocation, inclusive of a published owner liability, and a program of transitional housing for low-income residents.
- Implement independent structural inspections before issuing occupancy certificates, similar to the factory inspection system in Bangladesh after the Rana Plaza collapse, particularly for buildings that are not registered for the added floors.
- Correlate any subsidy for relocation and/or reconstruction by government to structural compliance as assessed by engineers – as done in Nepal after the 2015 earthquake in Nepal, which required mandatory structural compliance by the owner.
- Create a public, agency-tags-only dangerous building register that tenants, purchasers and financiers can check for themselves, without relying on agency notifications.
- Just as the precedent of the Lyari inquiry led to the naming of the responsible officials in an FIR, then make criminal-liability accountability timelines for building-control officials who knowingly allowed the occupation of declared-dangerous buildings.

9. Conclusion

The cause of building collapse is predominantly a governance failure, and has nothing to do with the natural hazard, but rather inherent structural vulnerability in Pakistan. The three collapses of Lyari, Kahna, Soldier Bazaar and Harbanspura in 2025-2026, combined, resulted in the deaths of at least 68 people in structures that were either already known to be unsafe or were built with seemingly poor construction practices, with evacuation warnings, over-age buildings and unauthorized construction, etc., all present long before the collapse. What Pakistan lacks is the capacity to enforce the Building Code of Pakistan 2021 and the subsidy-linked retrofitting programme in Nepal, which

would also include public accountability mechanisms, along with the capacity to enforce the dangerous-buildings registry established by SBCA. Making documentation a prevention process, via compulsory audits, public registers, and funded and accountable relocation, is the most realistic strategy to curb Pakistan's annual death tolls caused by buildings collapsing.

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PARTICIPANT RESEARCH PAPER

Community-Based Disaster Risk Reduction: Approaches and Effectiveness — Evidence from Pakistan

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Abstract

Community-based disaster risk reduction (CBDRR) has become a cornerstone of global disaster risk management since the 1990s, when agencies such as the Asian Disaster Preparedness Center (ADPC) began shifting communities from passive recipients of relief toward active partners in hazard mapping and preparedness planning. This paper traces that global shift into the Pakistani context, examining the approaches used to implement CBDRR nationally and the evidence for their effectiveness. It situates Pakistani practice within the Sendai Framework for Disaster Risk Reduction 2015–2030 and the International Federation of Red Cross and Red Crescent Societies' people-centred early warning model, and within national instruments including the National Disaster Management Act 2010 and the National DRR Policy 2013. Drawing on documented Pakistani programmes the Aga Khan Development Network's FOCUS Humanitarian Assistance CBDRM model, UNDP's CBDRM initiative in Chitral, Concern Worldwide's Emergency Response Teams in Sindh, and UNDP's GLOF-II early warning programme in Gilgit-Baltistan (GB) and Khyber Pakhtunkhwa (KP) the paper assesses hazard and vulnerability profiles, community resilience assets, institutional gaps and early warning practice across the country. It finds that CBDRR is most effective where it is multi-hazard, sustained over time and built on genuine community ownership and gender inclusion, though rigorous impact evidence remains limited. The paper closes with recommendations to mainstream CBDRR into routine development planning and formal disaster governance.

Keywords: Community-Based Disaster Risk Management; Disaster Risk Reduction; Early Warning Systems; Pakistan; Vulnerability.

1. Introduction

Community-based approaches to disaster risk reduction recognize local communities as key actors in identifying risks, strengthening preparedness, and developing locally appropriate resilience measures. The approach gained international traction from the 1990s onward as agencies including the ADPC recognized that community involvement in hazard mapping and preparedness was more sustainable than externally imposed, top-down disaster response. This global shift arrived in Pakistan in the late 1990s and accelerated sharply after the 2005 Kashmir earthquake and the 2010 floods exposed the country's weak preparedness and response capacity, prompting the creation of the National Disaster Management Authority (NDMA) and a policy shift from reactive relief toward anticipatory risk reduction. Since then, government agencies, UN bodies and non-governmental organisations have implemented CBDRR programmes across Pakistan's most hazard-prone areas, from flood-exposed plains in Sindh to glacier-fed valleys in GB and KP. Despite this growth, independent reviews have repeatedly noted that the evidence base on what actually works, and why, remains thin. This paper's objective is to trace CBDRR from its global conceptual origins to its application across Pakistan, evaluate the evidence for effectiveness, and identify the institutional conditions needed to scale successful practice. The scope focuses on key hydro-meteorological and geophysical hazards, including floods, GLOFs, earthquakes, and droughts, informed by national and global DRR policies and programme-level evidence.

2. Regional Context & Hazard Profile

Following UNDRR terminology, a hazard is a potentially damaging physical event or process; exposure refers to people and assets situated in hazard-prone areas; vulnerability describes the characteristics that increase susceptibility to harm; and risk is the combination of hazard, exposure and vulnerability over a given period. Globally, the Sendai Framework was adopted precisely because disaster losses were continuing to rise despite decades of relief-focused response, and it set targets to substantially reduce mortality, the number of people affected, and economic losses by 2030. Pakistan's own hazard profile is genuinely multi-hazard and illustrates why this shift mattered: the 2005 earthquake killed more than 73,000 people in KP and Azad Jammu and Kashmir; the 2010 floods affected roughly 20 million people nationwide; the 2022 floods displaced over

30 million people and submerged a third of the country at their peak; and GB and KP face a rising trend of glacial lake outburst floods (GLOFs), with studies identifying over 3,000 glacial lakes in the two regions, of which dozens are considered hazardous and around 7 million people are at risk. Southern Sindh and parts of Balochistan additionally face recurrent drought, most severely documented in Tharparkar. Pakistan faces a wide range of hazards across different provinces. This makes a community-based approach important, as disaster risk reduction needs to be adapted to local hazards, vulnerabilities, and community capacities rather than following a one-size-fits-all approach.

3. Risk & Vulnerability Assessment

Vulnerability in Pakistan's disaster-prone communities is shaped by overlapping socio-economic and geographic factors that echo global patterns identified in the DRR literature: poverty, informal settlement, weak infrastructure and limited access to information all compound exposure to hazards. In rural, agriculture-dependent districts of GB, KP and interior Sindh, subsistence farming leaves households with little buffer against recurrent flood or drought losses. In rapidly urbanising cities such as Karachi, informal and poorly drained settlements bear the brunt of monsoon flooding, while displaced and low-income populations face the greatest secondary health and livelihood impacts after major floods. Gender is a consistent vulnerability driver nationally: women and girls are typically responsible for household water and fuel collection, face greater mobility constraints during evacuation, and remain under-represented in formal disaster-management decision-making, even though evaluations of CBDRM in Pakistan identify women's empowerment as one of the strongest secondary benefits where programmes deliberately target inclusion. Remote and high-altitude communities in GB and Chitral face compounded exposure from poor road access, limited health infrastructure and weak last-mile connectivity to district-level early warning systems. Displacement, waterborne disease and disrupted education and livelihoods are recurring impact pathways documented across both flood-plain and mountain contexts, reinforcing the case for vulnerability assessments that are hazard-specific, gender-disaggregated and locally validated rather than generic.

4. Community Resilience Factors

Community-based disaster risk management recognizes that local communities have valuable knowledge of their hazards and the capacity to take meaningful action. This approach has been implemented at significant scale across Pakistan. FOCUS Humanitarian Assistance, an agency of the Aga Khan Development Network, pioneered CBDRM in Pakistan in 1999 and has since trained over 36,000 community volunteers, more than half of them women, as first responders under an institutionalized Community Emergency Response Team (CERT) structure, alongside producing hazard and risk maps for 658 villages covering over 600,000 residents in Gilgit-Baltistan and Chitral. This model proved its worth in real emergencies, including the 2015 Chitral floods, when more than 700 trained volunteers were mobilised for search-and-rescue and relief distribution within days. In Chitral, a separate Norwegian-funded UNDP programme trained 751 people and established 40 village disaster management committees comprising 489 members, who went on to implement structural mitigation works such as protective dykes with a 20 percent community cost contribution. In Sindh, Concern Worldwide's Emergency Response Teams — mixed-gender groups of around 50 trained community volunteers per village — have delivered first aid, search-and-rescue and firefighting response independent of external agencies during real incidents. These cases show that resilience is strongest where CBDRR builds on, and formally institutionalises, existing community leadership rather than replacing it with externally managed structures.

5. Scientific & Institutional Gaps

Despite two decades of CBDRR investment, a 2013 review of the Pakistani evidence base found that the impact of community-based programmes remained poorly documented, constraining learning and replication nationally. Institutional gaps include limited integration of DRR into local development planning, fragmented coordination between federal, provincial and district disaster management authorities, andF inconsistent continuity when donor-funded projects conclude. Scientifically, hydro-meteorological monitoring networks remain sparse outside a small number of donor-funded project areas, and uptake of low-cost digital tools mobile-based reporting, automated sensors and satellite data for community-level monitoring is uneven across provinces. Capacity gaps persist in translating technical hazard data into locally understood risk information, and financing structures often favour short, project-based

interventions over the sustained multi-year engagement that reviews identify as a precondition for lasting impact. Another important gap is the limited participation and leadership of women in formal disaster-management processes. Strengthening women's involvement in decision-making can improve preparedness, resilience, and the overall effectiveness of disaster risk reduction.

6. Mitigation Strategies & Best Practices

Effective CBDRR integrates both structural and non-structural measures, informed by participatory hazard mapping and community-based risk assessments. This approach, promoted regionally by the Asian Disaster Preparedness Center (ADPC) since the 1990s, has contributed to a shift from predominantly passive, response-oriented approaches toward greater community participation in identifying local hazards, resources, vulnerabilities, and capacities. In Pakistan, this method underpins FOCUS Pakistan's hazard and risk mapping of 658 villages in GB and Chitral, used directly by provincial governments for planning and budget decisions. Structural best practices include small-scale flood-proofing and drainage improvements, community-funded protective dykes and retaining walls (as in Chitral), and, at larger scale, the UNDP-supported GLOF-II programme's construction of engineering structures such as check dams, mini dams and slope stabilisation works across GB and KP. Non-structural best practices include village disaster management committees, trained Emergency Response Teams, and ADPC-supported community flood monitoring in Hyderabad, Sindh, which linked local flood markers and rain gauges to a functioning early warning system. Across these examples, the strongest outcomes are associated with work that is multi-sectoral and multi-hazard, sustained over multiple years, and built on genuine community ownership rather than externally imposed technical solutions — consistent with the Sendai Framework's priorities on strengthening disaster risk governance and investing in disaster risk reduction for resilience.

7. Risk Communication & Early Warning

People-centred early warning is widely regarded as the linchpin connecting technical hazard monitoring to community action, and both the Sendai Framework and Pakistan's National DRR Policy identify multi-hazard early warning as a strategic priority. The International Federation of Red Cross and Red Crescent Societies has long argued that

warnings have little value unless the people most at risk are trained to act on them, requiring a combination of top-down scientific monitoring and bottom-up community networks. Pakistan's clearest large-scale application of this principle is the Green Climate Fund-financed GLOF-II project, which is installing roughly 50 automated weather stations and over 400 river discharge gauges across ten districts of GB and KP, aiming to give all households in targeted communities the ability to receive and act on warnings, with more than half of beneficiaries being women. At the community level, FOCUS Pakistan's Disaster Assessment Response Teams provide rapid, locally led hazard assessment immediately after an event, while trained Community Emergency Response Teams translate warnings into evacuation and first-response action. Good practice nationally includes running regular evacuation drills so that warning protocols are trusted and rehearsed rather than merely theoretical, and ensuring dissemination channels deliberately reach women, who are frequently present in the household when a warning first arrives.

8. Policy Recommendations

First, NDMA and provincial disaster management authorities should mandate the integration of CBDRR into local government development planning, addressing the long-standing gap between DRR policy and mainstream development budgeting identified in national and independent reviews. Second, village- and community-level disaster management committees and Emergency Response Teams should receive multi-year, rather than single-project, funding commitments, given the evidence that sustained engagement produces stronger and more durable outcomes than short donor cycles. Third, community-based early warning systems should be formally linked to district- and provincial-level monitoring networks, following the two-way, people-centred model already being scaled through the GLOF-II project Fourth, women's meaningful participation in village disaster management committees and emergency response teams should be incorporated as a funding requirement rather than treated as an optional programme target. This would help institutionalise gender-responsive approaches within CBDRR interventions and strengthen women's representation in local disaster risk governance. Fifth, a standardised national monitoring and evaluation framework for CBDRR programmes should be developed, aligned with relevant Sendai Framework

indicators, to strengthen systematic measurement of outcomes and address persistent gaps in evidence regarding programme effectiveness. Finally, successful hazard-mapping models such as FOCUS Pakistan's village-level risk maps should be extended to all high-risk districts and formally adopted as a standing input into provincial development budgeting, rather than remaining project-specific.

9. Conclusion

Community-based disaster risk reduction evolved from a global conceptual shift in the 1990s into an increasingly important component of Pakistan's disaster management architecture following the 2005 earthquake. The evidence reviewed in this study indicates that CBDRR can contribute to measurable improvements, including strengthened volunteer networks, functional early warning systems, and community-led mitigation measures, particularly when interventions adopt a multi-hazard approach, are sustained over time, and promote meaningful community ownership. At the same time, the evidence base on CBDRR effectiveness in Pakistan remains thinner than the scale of investment would suggest, and institutional integration into routine development planning is still incomplete. Aligning Pakistani practice more closely with the Sendai Framework's governance and preparedness priorities, and with the country's own National DRR Policy, while institutionalising sustained funding, gender inclusion and rigorous monitoring, offers the clearest path to converting scattered local successes into durable, nationwide disaster resilience.

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PARTICIPANT RESEARCH PAPER

Climate-Induced Migration and Displacement: Policy Challenges and Humanitarian Responses

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Abstract

Climate-induced migration and displacement has become one of the defining humanitarian and policy challenges of the twenty-first century. Rising global temperatures are intensifying sudden-onset hazards such as floods, cyclones and heatwaves, and accelerating slow-onset processes such as drought, sea-level rise and land degradation, together reshaping where and how people can safely live. The Internal Displacement Monitoring Centre recorded 29.9 million disaster-related internal displacements in 2025 alone (IDMC, 2026), while the World Bank's Groundswell model projects that up to 216 million people could be forced to move within their own countries by 2050 without decisive climate and development action (World Bank, 2021). Pakistan, ranked among the world's most climate-vulnerable countries, illustrates the scale of the challenge: the 2022 floods displaced roughly 7.9 million people and affected 33 million more (NDMA & NIDM, 2025). This paper examines the regional hazard profile, vulnerability drivers, community resilience factors, institutional and scientific gaps, and existing legal-policy frameworks governing climate displacement, before proposing evidence-based recommendations for governance, early warning, and humanitarian response. It concludes that closing the international protection gap and mainstreaming displacement risk into national Disaster Risk Reduction (DRR) and climate adaptation planning are essential to prevent climate mobility from becoming an unmanaged crisis.

Keywords: Climate Adaptation; Disaster Risk Reduction; Early Warning Systems; Humanitarian Response; Internal Displacement

1. Introduction

Human mobility has always responded to environmental conditions, but the pace and scale of anthropogenic climate change is now producing displacement of an unprecedented order. The Intergovernmental Panel on Climate Change (IPCC) identifies migration and displacement as major indirect consequences of climate change, transmitted through extreme weather events, water and food insecurity, and the gradual loss of habitable land (IPCC, 2022). Unlike conflict-driven displacement, climate displacement is frequently repeated, protracted, and difficult to attribute to a single cause, which complicates both its measurement and its governance.

The problem is acute for Pakistan and South Asia, where dense floodplain populations, glacier-fed river systems, and a narrow agrarian resource base intersect with rapidly intensifying monsoon variability and heat extremes. This paper's objective is to critically analyse the policy and institutional challenges surrounding climate-induced migration and displacement, and to assess the adequacy of current humanitarian responses. The scope covers internal and cross-border dimensions, drawing on global data and the Pakistan case, and concludes with policy-relevant recommendations consistent with the Sendai Framework for Disaster Risk Reduction and national DRR priorities (UNDRR, 2015).

2. Regional Context and Hazard Profile

Four analytical terms anchor this paper. Hazard refers to a potentially damaging physical event, such as a flood, cyclone or drought. Exposure describes the people, assets and livelihoods situated where a hazard may occur. Vulnerability is the set of conditions that determine the susceptibility of exposed populations to harm, including poverty, weak housing, and limited access to information or assets. Risk is the probable loss arising from the interaction of hazard, exposure and vulnerability over time (UNDRR, 2015). Displacement occurs when accumulated risk crosses a threshold beyond which remaining in place is no longer viable, whether abruptly, as in a flash flood, or gradually, as in prolonged drought or coastal erosion.

Globally, disaster displacement has trended upward over the past decade, with the 2026 Global Report on Internal Displacement recording 82.2 million people living in internal displacement worldwide by the end of 2025, of which a growing share is attributable to weather-related hazards (IDMC, 2026). The World Bank's Groundswell modelling

projects that South Asia alone could generate up to 40 million internal climate migrants by 2050 under a pessimistic emissions and development scenario, driven principally by water scarcity, declining crop yields and sea-level rise in the Indus and Ganges-Brahmaputra deltas (World Bank, 2021). Pakistan exemplifies this trajectory: the 2010 floods affected 17,600 villages and displaced millions (NDMA & NIDM, 2025), and the 2022 floods, intensified by an exceptionally heavy monsoon and glacial melt, submerged a third of the country, displaced an estimated 7.9 million people, and affected 33 million more across Sindh, Balochistan, Khyber Pakhtunkhwa and Punjab (NDMA & NIDM, 2025; CRS, 2022).

3. Risk and Vulnerability Assessment

The socio-economic impacts of climate displacement extend far beyond the immediate loss of shelter. In Pakistan's 2022 floods, more than 800,000 homes and roughly 800,000 hectares of standing crops were destroyed, and over 750,000 livestock were lost, eroding the asset base of rural households that depend on agriculture and livestock for both food and income (NDMA & NIDM, 2025). Displacement therefore compounds food insecurity: displaced households lose not only current-season harvests but also seed stock, irrigation access and land tenure security, which can delay recovery for years and, in some cases, convert a temporary movement into permanent resettlement in informal urban peripheries.

Vulnerability is distributed unevenly across the population. Women and girls face heightened risks of gender-based violence, loss of privacy and disrupted access to reproductive healthcare in displacement camps, while pregnant women and infants are disproportionately affected by waterborne disease outbreaks that follow prolonged flooding. Children experience interrupted schooling, and evidence from the 2022 floods pointed to elevated risks of child labour and early marriage among displaced families under acute economic stress (UNOCHA, 2023). Elderly people, persons with disabilities and religious or ethnic minorities frequently have the least capacity to relocate independently and the least access to information about relief entitlements. Landless tenant farmers and daily-wage labourers, who form a large share of Pakistan's rural workforce, typically have negligible savings and no formal land title, making them the first to be displaced and the last to receive compensation or resettlement support.

Exposure is also spatially concentrated: informal settlements along riverbanks, canal embankments and low-lying urban peripheries in cities such as Karachi and Hyderabad absorb large secondary movements of displaced rural populations, layering climate risk onto existing urban vulnerabilities such as inadequate drainage, insecure tenure and limited basic services. Research on displaced households following the 2011 and 2022 floods found that most families who relocated to cities intended to remain permanently rather than return to increasingly unviable agricultural land, indicating that climate displacement in Pakistan is evolving from a temporary emergency response into a longer-term urbanisation pressure (MPI, 2026).

4. Community Resilience Factors

Despite severe losses, affected communities consistently draw on social capital to cope with displacement. Extended kinship networks provide the first line of shelter and support, with displaced families frequently hosted by relatives in nearby towns before, or instead of, entering formal relief camps. Biradari (kinship-clan) networks and village-based mutual aid arrangements have historically underpinned informal early recovery in rural Sindh and Punjab, mobilising labour, credit and shared resources faster than formal humanitarian pipelines can reach remote areas (IOM, 2026).

Indigenous and local knowledge also plays a protective role: longstanding riverine communities retain intergenerational knowledge of flood patterns, safe evacuation routes and seasonal cropping adjustments that can reduce loss even where formal warning systems are weak. Community-based organisations and local philanthropic and religious networks were among the fastest responders during the 2022 floods, often reaching households before government or international agencies (UNOCHA, 2023). Strengthening, rather than substituting, these informal networks by linking them to formal early warning and cash-assistance mechanisms represents a cost-effective resilience pathway that existing humanitarian architecture has yet to fully exploit.

5. Scientific and Institutional Gaps

Significant gaps constrain evidence-based planning for climate displacement. Displacement data remain fragmented; IDMC itself has flagged a threefold increase in countries with reduced displacement-data availability in 2025 compared with 2024, undermining the evidence base needed for anticipatory planning (IDMC, 2026).

Attribution science linking specific displacement events to climate change has advanced, but translating attribution findings into operational risk models at the district level remains limited in Pakistan, where hydro-meteorological monitoring networks and flood-forecasting infrastructure are under-resourced outside major river systems.

Institutionally, disaster management in Pakistan operates under a devolved structure in which Provincial Disaster Management Authorities (PDMAs) hold significant autonomy while NDMA coordinates at the federal level; this arrangement has, at times, produced unclear lines of authority and inconsistent inter-provincial coordination during major floods. Adoption of Artificial Intelligence and Machine Learning-based forecasting, satellite-based flood mapping and GIS-enabled vulnerability assessment remains nascent, and capacity gaps persist among district-level officials tasked with translating national frameworks into local action. At the international level, no binding global treaty specifically protects people displaced across borders by climate change; internally displaced persons are covered only by the non-binding UN Guiding Principles on Internal Displacement, while cross-border climate displacement continues to fall into a recognised legal protection gap (Nansen Initiative, 2015; African Union, 2009).

6. Mitigation Strategies and Best Practices

Structural measures, including embankment reinforcement, canal desilting, resilient housing design and nature-based flood buffers such as riverine forest restoration, reduce exposure where properly maintained, though the 2022 floods exposed the limits of ageing embankment infrastructure (NDMA & NIDM, 2025). Non-structural measures are equally critical: land-use zoning that restricts new construction in high-risk floodplains, updated hazard maps incorporating climate projections rather than historical data alone, and mandatory disaster-risk assessment in urban planning approvals can materially reduce future displacement.

Internationally recognised good practice includes Bangladesh's cyclone preparedness programme, which combines a dense volunteer network with community-based shelters to have dramatically reduced cyclone mortality over recent decades, and the Philippines' forecast-based financing mechanisms that release pre-positioned funds ahead of typhoon landfall (IOM, 2026). Within Pakistan, the National Flood Response Coordination Centre established in 2022 and the Benazir Income Support Programme's rapid cash-

transfer mechanism for flood-affected families demonstrate the value of pre-existing social protection infrastructure that can be scaled quickly during a crisis (CRS, 2022). Embedding capacity-building, drills and public awareness campaigns into annual DRR calendars, rather than treating them as post-disaster activities, would further institutionalize preparedness.

7. Risk Communication and Early Warning

Effective early warning requires more than accurate forecasting; it requires a functioning last-mile communication chain that converts a technical alert into household-level action. People-centred early warning systems must reach populations with low literacy, limited connectivity and multiple local languages, and must be gender-sensitive, recognising that women, who are often responsible for children and elderly relatives during evacuation, face distinct mobility constraints and information access barriers (UNDRR, 2015).

In Pakistan, warning dissemination through cell-broadcast SMS, community sirens, mosque loudspeaker announcements and local radio has improved but remains inconsistent across rural districts with weak telecommunications infrastructure. Community engagement in designing evacuation protocols, rather than issuing top-down instructions, increases trust and compliance; village-level disaster committees that pre-identify safe routes and shelter points before the monsoon season have shown higher evacuation rates in pilot districts. Aligning warning messages with clear, actionable guidance, rather than technical severity classifications alone, and integrating informal community networks discussed above into formal dissemination chains would close much of the last-mile gap identified after recent flood seasons.

8. Policy Recommendations

Addressing climate-induced migration and displacement requires integrated governance that connects DRR, climate adaptation and migration management rather than treating them as separate policy domains. The following measures are recommended:

- Mainstream displacement risk into National Adaptation Plans and provincial DRR strategies, with explicit planning for both sudden-onset evacuation and slow-onset, planned relocation scenarios.
- Strengthen legal and institutional protection for internally displaced persons by operationalizing the UN Guiding Principles domestically, including clear

entitlements to documentation, land tenure regularization and access to services in displacement and return.

- Invest in interoperable early warning infrastructure and AI/ML-based flood and drought forecasting, paired with clearly assigned institutional ownership between NDMA, PDMAs and technical agencies to prevent handover failures.
- Expand forecast-based financing and shock-responsive social protection, using systems such as BISP to trigger pre-emptive cash transfers ahead of predicted disasters rather than only after displacement occurs.
- Support Pakistan's continued engagement with international mechanisms, including the Platform on Disaster Displacement and the Global Compact for Migration's Objective 2 (PDD/UNOPS, 2026; United Nations, 2018), to advocate for stronger international burden-sharing and, where relevant, humanitarian pathways for cross-border climate displacement.
- Institutionalized community participation and gender-sensitive planning in resettlement and relocation programs, ensuring free, prior and informed consent and durable livelihood restoration rather than one-time compensation.

9. Conclusion

Climate-induced migration and displacement is no longer a future risk but a present and escalating reality, as the scale of Pakistan's 2022 floods and the global rise in disaster displacement demonstrate (NDMA & NIDM, 2025; IDMC, 2026). The evidence reviewed here shows that vulnerability is shaped less by hazard magnitude alone than by pre-existing socio-economic inequality, weak last-mile communication, and institutional and legal gaps that leave displaced populations without durable protection. Community social capital, indigenous knowledge and informal networks already provide substantial, under-recognised resilience capacity that formal systems should integrate rather than bypass.

Building resilience to climate displacement demands an integrated approach that combines science-based early warning, inclusive and participatory planning, stronger institutional coordination, and evidence-based national and international policy frameworks (UNDRR, 2015). For Pakistan and comparably exposed countries, the priority is to move from reactive, post-disaster humanitarian response toward anticipatory,

risk-informed governance that protects displaced populations' rights and livelihoods before, during and after displacement occurs.

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PARTICIPANT RESEARCH PAPER

Climate-Resilient Infrastructure for Disaster-Affected Areas: A Case Study of Umerkot District, Sindh, Pakistan

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Abstract

Climate change continues to escalate the frequency, intensity, and unpredictability of hydrometeorological hazards across Pakistan. The catastrophic 2022 monsoon floods underscored the country's extreme climate vulnerability, impacting approximately 33 million people, destroying critical infrastructure, and causing severe socioeconomic disruptions. Sindh Province bore a disproportionate share of this damage.

Umerkot District, situated in southeastern Sindh at the edge of the Thar Desert, represents a critical micro-setting for analyzing multi-hazard vulnerability and climate-resilient infrastructure. Characterized by a population of 1,073,146 growing at 2.55% annually, an average annual rainfall of just 179.3 mm, and extreme temperature fluctuations, Umerkot faces a severe flood–drought dynamic. All Union Councils in the district are classified as drought-vulnerable, while intense monsoon downpours routinely cause flash and localized flooding across low-lying rural settlements.

This research paper examines how climate-resilient infrastructure—when integrated with Community Based Disaster Risk Reduction (CBDRR), Geographic Information System (GIS) hazard mapping, and robust Operation and Maintenance (O&M) protocols—can effectively mitigate disaster risk.

The findings demonstrate that physical assets alone cannot guarantee long-term resilience. Instead, infrastructure must function within a holistic framework connecting risk-informed site selection, resilient engineering, community ownership, and institutional coordination with district and provincial disaster management authorities.

Regional Context and Hazard Profile

Climate Change and Disaster Risk in Pakistan

Despite contributing less than 1% to global greenhouse gas emissions, Pakistan consistently ranks among the world's most climate-vulnerable nations. The country experiences a complex matrix of climate hazards, including riverine and flash floods, prolonged droughts, extreme heatwaves, glacial lake outburst floods (GLOFs), and tropical cyclones.

The 2022 Post-Disaster Needs Assessment (PDNA) estimated total damages and economic losses from the 2022 floods at over USD 30 billion, with reconstruction needs exceeding USD 16 billion. A critical insight from the 2022 disaster was that rebuilding damaged assets using traditional, unreinforced approaches merely recreates pre-existing vulnerabilities. Achieving long-term climate adaptation requires integrating disaster risk reduction into the design, site selection, and construction phases of physical infrastructure.

Umerkot District: Geographic and Socioeconomic Context

Umerkot District is located in southeastern Sindh, forming a transition zone between the irrigated plains of the lower Indus Basin and the hyper-arid Thar Desert.

Diagram 1: Umerkot District Hazard Matrix

Hyper-Arid / Thar Desert Zone:

- **Rainfall Baseline:** Sparse annual rainfall averaging 179.3 mm.
- **Primary Stressors:** Chronic water scarcity, intense drought exposure, and severe extreme heat.
- **Livelihood Reliance:** High dependency on pastoralism and livestock survival.

Total Exposed Population: 1,073,146 inhabitants.

Highly Exposed Settlements: 4,509 settlements across 23 priority Union Councils.

Severe Human Impact: 151,008 children facing acute malnutrition.

Environmental Zones & Stressors	Multi-Hazard Vulnerability Convergence

O **Low-Lying Agricultural Zone: Topography:** Flat terrain with poor natural drainage networks.

O **Primary Stressors:** Extreme vulnerability to floodwater accumulation and localized standing water during intense monsoons.

O **Livelihood Impacts:** Rapid destruction of standing crops, mud-brick (*kacha*) housing, and household assets.

The district's socio-demographic and environmental baseline is defined by key verified indicators:

- **Total Population:** 1,073,146 inhabitants (Government of Sindh Demographic Profile).
- **Population Growth Rate:** 2.55% per annum, intensifying pressure on land, surface water, and basic services.
- **Climate Classification:** Hot and semi-arid.
- **Average Annual Rainfall:** 179.3 mm, characterized by extreme spatial and temporal variability.
- **Drought Exposure:** 100% of Union Councils (UCs) are officially designated as drought-exposed under the District Disaster Management Plan (DDMP).
- **Climate Vulnerability Scale:** An assessment conducted by the International Organization for Migration (IOM) Displacement Tracking Matrix (DTM) identified 4,509 settlements across 23 UCs as highly vulnerable to recurrent climate shocks.
- **Malnutrition Burden:** UNICEF (2023) reported 151,008 children suffering from acute malnutrition across Umerkot, highlighting the direct link between environmental stress, food insecurity, and human vulnerability.

The Flood–Drought Paradox

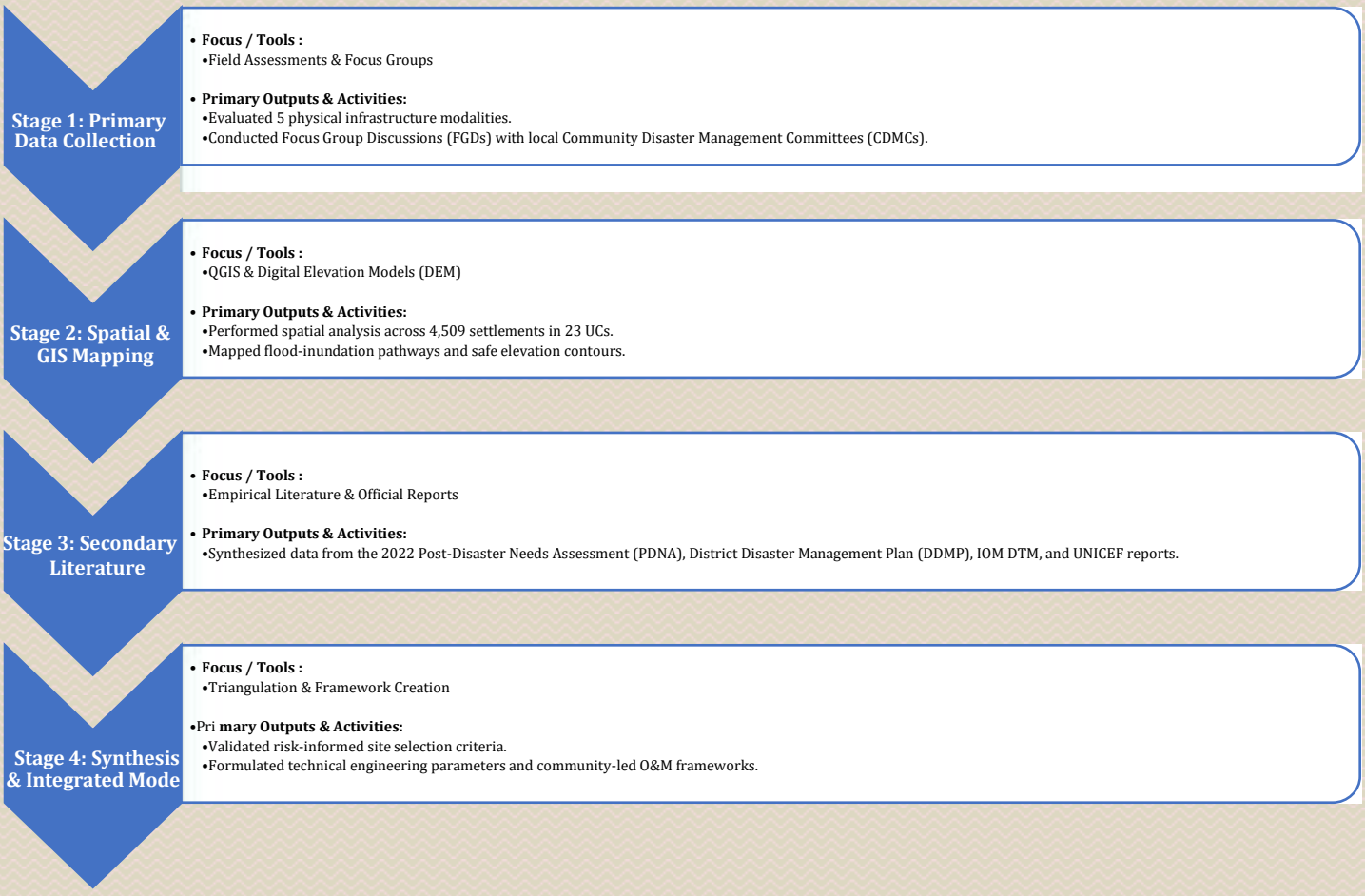
Umerkot presents a stark multi-hazard environment. While chronic water scarcity and drought dominate the district's long-term profile, intense monsoon cloudbursts trigger widespread localized inundation.

Flat terrain, low natural elevation, and inadequate drainage networks prevent rapid water runoff. Consequently, monsoon floods submerge agricultural land, destroy mud-brick (*kacha*) housing, disrupt access routes, and contaminate vulnerable groundwater sources. Communities in Umerkot must navigate a cycle of environmental stress: surviving long spells of severe drought, followed by acute, highly destructive flooding.

Research Methodology

This paper adopts a mixed-methods research design combining primary field data, spatial analysis, and secondary literature synthesis.

Diagram 2: Research Methodology Workflow



Primary Data Collection

Field Assessments: Field-level reviews of climate-resilient infrastructure projects implemented in rural Umerkot, including community evacuation shelters, elevated livestock structures, household- and community-level grain storage units, and Reverse Osmosis (RO) water purification units.

Focus Group Discussions (FGDs): Interactive sessions with Community Disaster Management

Committees (CDMCs), local leaders, women's self-help groups, and livestock owners to evaluate shelter accessibility, functionality during disasters, and operational challenges.

Spatial and Technical Mapping

QGIS Spatial Analysis: Integration of hazard maps, satellite imagery, and topographic Digital Elevation Models (DEM) to evaluate flood-inundation paths, safe elevation contours, and settlement exposure across the 23 priority Union Councils.

Secondary Empirical Literature

Triangulation of official government statistical reports, including the *Sindh Demographic Profile*, the *Umerkot District Disaster Management Plan (DDMP)*, the *2022 Post-Disaster Needs Assessment (PDNA)*, *IOM DTM Climate Vulnerability Reports*, and *UNICEF Emergency Nutrition Surveys*.

Literature Review

Integrating climate risk into physical infrastructure planning is widely recognized in academic and policy literature as essential for sustainable development.

The Evolution of Resilient Infrastructure

Early disaster management literature focused primarily on post-disaster emergency response and temporary relief. However, structural engineers and disaster risk scholars have shifted focus toward proactive risk reduction.

World Bank frameworks emphasize that resilient infrastructure investments yield a 4:1 benefit-cost ratio by reducing emergency repair costs, preventing economic disruption, and preserving community assets.

Community-Based Disaster Risk Reduction (CBDRR)

Scholarship on community resilience highlights that top-down engineering interventions frequently fail when detached from local socioeconomic realities.

Participatory risk assessment models demonstrate that physical assets (e.g., evacuation shelters or water plants) require strong local ownership, institutional integration, and clear community-led Operation and Maintenance (O&M) mechanisms to remain functional over time.

Multi-Hazard Adaptation in Semi-Arid Zones

Studies on Arid and Semi-Arid Lands (ASALs) in South Asia stress the necessity of dual-purpose or multihazard infrastructure. In semi-arid regions like Umerkot and the wider Thar Desert, infrastructure cannot be designed solely for flood protection or drought relief in isolation. Structures must be adaptable—serving as flood shelters during monsoon surges and as community centers, schools, or water distribution hubs during long dry seasons.

Multi-Dimensional Risk and Vulnerability Assessment

Flood and Heavy Rainfall Exposure

Rural housing in Umerkot consists largely of unfired mud-brick (*kacha*) structures that collapse under prolonged exposure to floodwaters. When localized flooding occurs, roads become impassable, cutting off rural villages from health services and emergency relief.

The loss of physical assets disproportionately affects low-income households with limited financial reserves or access to credit.

Livestock Vulnerability and Livelihoods

Livestock (cattle, goats, sheep, and camels) represents the primary financial asset, safety net, and nutritional source for pastoral communities in Umerkot. During the 2022 floods, livestock mortality was compounded by a lack of elevated dry ground, widespread contamination of grazing land, extreme weather exposure, and swift outbreaks of waterborne diseases (e.g., foot-and-mouth disease, hemorrhagic septicemia).

When households lose their animals, they lose both immediate subsistence and long-term economic stability.

Food Security and Storage Fragility

Traditional food storage methods rely on earth-and-straw silos or unprotected indoor spaces. Floodwaters easily enter these storage units, rotting stored grain, accelerating mold growth, and attracting pests.

The destruction of household food reserves creates acute food shortages immediately following a disaster, forcing families to rely on external humanitarian food distributions.

Water Scarcity and Contamination

Groundwater in Umerkot is naturally saline across vast swathes of the district, requiring deep tube-wells or specialized filtration. Flood events contaminate shallow wells and rain-fed ponds (*toba*) with pathogens, agricultural runoff, and fecal matter.

During drought periods, water sources dry up entirely, forcing women and young girls to walk several kilometers daily to fetch water. The lack of safe water directly contributes to high rates of waterborne diseases and exacerbates the district's severe child malnutrition challenge.

Quantitative Synthesis: Climate and Vulnerability Baseline

The following structured matrix synthesizes the empirical indicators for Umerkot District, linking demographic data directly to infrastructure planning requirements.

Table 1: Empirical Climate and Vulnerability Baseline of Umerkot District

Risk Dimension	Verified Baseline Statistic	Empirical Source	Infrastructure Design Requirement
Total Population	1,073,146 individuals	Government of Sindh Demographic Profile	Requires high-capacity, decentralized community infrastructure networks.
Demographic Growth	2.55% annual growth rate	Government of Sindh Demographic Profile	Mandates scalable design capacities for water, shelter, and sanitation facilities.

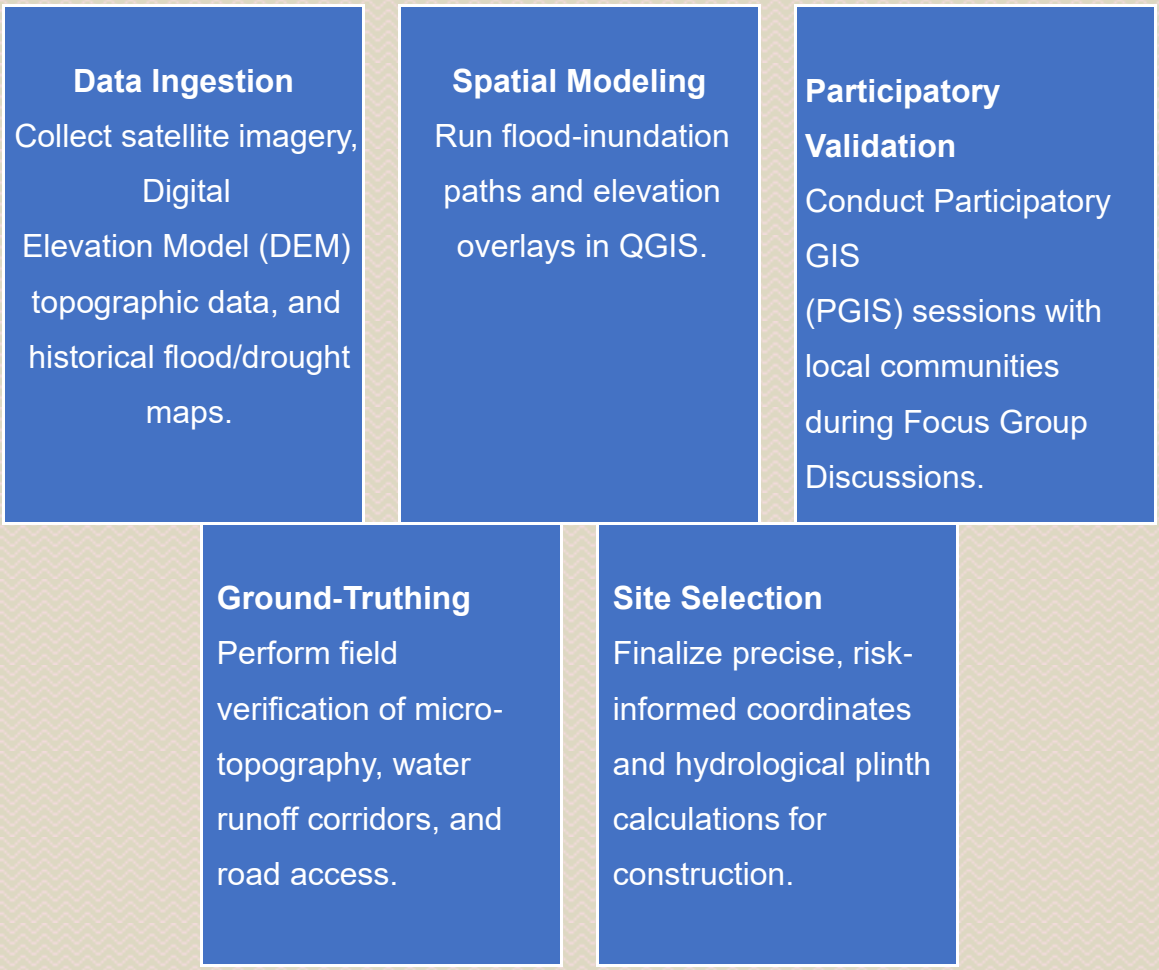
Mean Annual Rainfall	179.3 mm	Umerkot District Disaster Management Plan (DDMP)	Water infrastructure must incorporate dual-capacity flood drainage and rainwater harvesting.
Drought Risk Exposure	100% of Union Councils (UCs) exposed	Umerkot DDMP	Facilities must remain operational during prolonged dry periods and heatwaves.
Climate Hazard Exposure	4,509 settlements across 23 UCs assessed as highly vulnerable	IOM DTM Climate Vulnerability Assessment (2024– 2025)	Demands precise GIS hazard mapping for site selection to prevent constructing in high risk zones.
Child Malnutrition Burden	151,008 acute malnutrition cases in children	UNICEF Pakistan Emergency Report (2023)	Requires integrated food security protection, including elevated grain storage and safe water plants.
Primary Economic Base	Pastoral livestock & rain-fed agriculture	Field Surveys & Local Government Data	Demands structural protection for livestock and grain assets alongside human evacuation spaces.

Role of QGIS Hazard Mapping and Advanced Planning Technologies

Constructing infrastructure without spatial risk analysis increases the likelihood of facility failure. Integrating Geographic Information Systems (GIS), particularly open-

source software like QGIS, transforms disaster management from reactive construction to risk-informed planning.

Diagram 3: Integrated GIS Planning Workflow



QGIS Hazard Mapping Applications

Inundation Modeling: Overlaying Digital Elevation Models (DEM) with historic flood footprints to identify low-risk zones suitable for community shelters and high-risk zones that require drainage improvements.

Accessibility and Network Analysis: Mapping roads, bridges, and footpaths to ensure evacuation shelters remain accessible to isolated rural settlements during flood events.

Exposure Mapping: Spatial cross-referencing of settlement density, livestock populations, and existing water points against drought and flood hazard layers.

Participatory GIS (PGIS)

Combining technical satellite data with local spatial knowledge produces the most accurate risk maps. Community members identify localized micro-topography, historical water flow paths, and seasonal movement corridors for livestock.

When validated in QGIS, this participatory approach ensures that infrastructure investments align with local needs and hydrological realities.

Institutional, Technical, and Operational Challenges

Despite clear advantages, implementing climate-resilient infrastructure faces structural and operational hurdles.

Gaps in Risk-Informed Infrastructure Planning

Conventional infrastructure projects are frequently planned without comprehensive multi-hazard risk assessments. Engineering designs often rely on standardized blueprints that ignore local hydrological data, resulting in facilities constructed in flood-prone areas or with insufficient plinth heights.

District-Level Technical Capacity Constraints

District-level institutions, including District Disaster Management Authorities (DDMAs) and municipal engineering departments, often face resource and capacity constraints:

- Limited access to licensed or updated GIS software and technical geospatial analysts.
- Insufficient training in climate-resilient structural engineering and hydrological modeling.
- High staff turnover that disrupts institutional memory and project continuity.

Long-Term Operation and Maintenance (O&M) Deficits

A primary cause of infrastructure failure in development contexts is the absence of sustainable Operation and Maintenance (O&M) frameworks.

Projects frequently focus on initial construction while neglecting ongoing operational budgets, routine maintenance protocols, and community management structures. As a result, RO water plants and evacuation shelters can fall into disrepair within a few years of completion.

An Integrated Framework for Climate-Resilient Infrastructure

To address these challenges, this paper proposes an integrated operational framework connecting physical asset development with governance, technical analysis, and community ownership.

Pillar 1: Spatial Risk Assessment & Site Selection

Mandatory application of QGIS hazard mapping, DEM elevation profiling, and historical flood-line modeling prior to finalizing infrastructure locations.

Direct integration of participatory community mapping to capture local environmental knowledge.

Pillar 2: Climate-Proofed Engineering & Multi-Hazard Design

Engineering specifications adjusted for local climate risks: raised plinths, salt-resistant concrete formulations, wind-resistant roofing, and off-grid solar power systems.

Dual-purpose facility design: structures function as emergency shelters during crises and as community centers, vocational schools, or health clinics during normal periods.

Pillar 3: Comprehensive Livelihood Asset Protection

Infrastructure design that protects both human lives and productive economic assets (livestock, seed reserves, and potable water supplies).

Pillar 4: Community Ownership and Capacity Building

Establishing and training Community Disaster Management Committees (CDMCs) prior to construction.

Training local technical teams on basic maintenance, asset care, and operating financial reserve funds for ongoing repairs.

Pillar 5: Institutional Alignment & Governance Integration

Formalizing operational links between CDMCs, District Disaster Management Authorities (DDMAs), the Provincial Disaster Management Authority (PDMA Sindh), and Union Council administrations.

Integrating local infrastructure asset inventories directly into official District Disaster Management Plans (DDMPs).

Strategic Policy Recommendations

Based on empirical evidence and field analysis from Umerkot District, the following policy interventions are recommended for municipal authorities, provincial government bodies, and international development agencies:

- **Mandate Climate Risk Assessments in Building Codes:** Amend provincial building codes and public sector investment frameworks to require mandatory multi-hazard risk assessments and climate-proofing for all public infrastructure projects in Sindh.
- **Institutionalize GIS-Based Infrastructure Spatial Planning:** Allocate dedicated funding to equip District Disaster Management Authorities (DDMAs) with QGIS tools, hardware, and geospatial analysis training to ensure site selection is guided by spatial data.
- **Establish Localized Infrastructure Maintenance Funds:** Allocate a fixed percentage (minimum 10-15%) of initial capital expenditure budgets toward a dedicated, community-co-managed Operation and Maintenance (O&M) fund to support long-term asset functionality.
- **Expand Multi-Hazard Asset Protection Frameworks:** Replicate integrated resilience complexes—combining human evacuation space, elevated livestock platforms, hermetic grain storage, and solar water purification systems—across all highly vulnerable Union Councils in Sindh.
- **Strengthen Tripartite Institutional Coordination:** Formalize operational links between community committees (CDMCs), local government administration, and provincial authorities (PDMA) to streamline disaster response, asset maintenance, and emergency resource distribution.

Integration across the Disaster Management Cycle

The proposed integrated infrastructure framework directly supports all five phases of the disaster management cycle:

Table 2: Disaster Management Cycle Alignment

Phase	Operational Action of Resilient Infrastructure
1. Anticipatory Action	Spatial QGIS mapping identifies vulnerable populations and safe locations prior to disaster strikes.
2. Preparedness	Pre-positioned multi-purpose shelters and trained CDMCs enable rapid, organized evacuation.
3. Response	Elevated human shelters, solar RO plants, and livestock platforms protect lives and prevent asset loss during crises.
4. Recovery	Intact grain reserves and surviving livestock prevent post-disaster destitution and speed up economic recovery.
5. Adaptation	Robust physical structures withstand recurring extreme weather events, building long-term climate resilience.

Conclusion

Climate-resilient infrastructure is essential for mitigating disaster losses and supporting long-term climate adaptation in Pakistan's disaster-prone regions. The experience of Umerkot District demonstrates that infrastructure interventions are most effective when designed around local hazard dynamics, environmental conditions, and socioeconomic realities.

Constructing elevated evacuation shelters, livestock protection platforms, sealed grain storage facilities, solar RO water plants, and adaptable water management networks directly protects lives and essential livelihoods. However, physical infrastructure alone cannot ensure long-term resilience. Long-term success requires combining resilient engineering with QGIS spatial analysis, active community participation, robust operation and maintenance systems, and direct integration with district and provincial disaster management frameworks.

As climate-induced extreme weather events increase in frequency and severity across Sindh and Pakistan, investment strategies must move beyond reactive repair and

conventional construction. Adopting an integrated, risk-informed, and community-owned resilience model will safeguard vulnerable populations, protect economic assets, and build sustainable disaster resilience for the future.

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PARTICIPANT RESEARCH PAPER

Climate Change as a Driver of Rising Disaster Risk

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Abstract

Climate change is no longer a distant projection; it is an active multiplier of disaster risk across the globe. This paper examines how a warming climate amplifies the hazard, exposure, and vulnerability components of disaster risk, drawing on the global disaster record and two illustrative cases: the August 2026 Bhote Koshi glacial flood in Nepal and the escalating flood risk facing Pakistan's Gilgit-Baltistan region. Using data from the World Bank, the UN Office for Disaster Risk Reduction (UNDRR), and the Germanwatch Global Climate Risk Index, the analysis shows that recorded disasters have multiplied six- to tenfold since 1950, and that low-income, climate-exposed nations bear a disproportionate share of the resulting losses despite contributing least to global emissions. The paper identifies gaps in scientific monitoring, institutional capacity, and early warning coverage, and proposes an integrated response combining structural mitigation, community-based early warning, and adaptive governance. It concludes that disaster risk reduction can no longer be planned separately from climate adaptation.

Keywords: *Climate Change; Disaster Risk Reduction; Early Warning Systems; Glacial Lake Outburst Floods; Vulnerability*

1. Introduction

For most of human history, disasters were understood as discrete natural events an earthquake, a cyclone, a drought separated from one another by geography and time. That framing no longer holds. Climate change has become a background condition that shapes nearly every weather-related hazard, altering how often extreme events occur, how severe they are, and how far their consequences reach. Floods, heatwaves, storms, droughts, and wildfires are not new phenomena, but a warming atmosphere and ocean are systematically loading the dice in their favour. Furthermore, contemporary research suggests that climate change should be integrated as a constituent element of broader disaster risk reduction efforts rather than treated as an isolated challenge, given its role in exacerbating both inherent hazards and societal vulnerabilities (Kelman et al., 2015). The global escalation in disaster-related losses is driven less by the frequency of natural hazards themselves and more by the intensification of human exposure and socioeconomic vulnerability (Chapagain et al., 2024). Although empirical evidence suggests a global decline in vulnerability to certain climate-related hazards, this progress remains spatially heterogeneous and may be insufficient to counterbalance the concurrent growth in hazard intensity and societal exposure (Kreibich et al., 2022; Taylor et al., 2023). Furthermore, the emergence of compound events and systemic risks—where cascading effects ripple through socioeconomic structures—underscores that record-shattering extremes will increasingly constrain the efficacy of traditional adaptation strategies (Wen et al., 2023). Specifically, the accelerated retreat of mountain cryospheres has heightened the prevalence of glacial lake outburst floods, which now pose significant, localized threats to vulnerable downstream communities (Huggel et al., 2020; Laura, 2025). Consequently, effective mitigation requires disentangling climate-induced hazard amplification from non-climatic drivers such as rapid, unplanned urbanization and socioeconomic inequity which often exacerbate disaster risk independently of shifting weather patterns (Forino et al., 2015; Kelman, 2015; Valente et al., 2022).

This shift matters because disaster risk is not simply a function of nature; it is the product of hazard, exposure, and vulnerability acting together. Climate change intensifies the first of these while, through its interaction with poverty, rapid urbanisation, and fragile

ecosystems, also worsening the other two. The result is a widening gap between the disasters societies are prepared for and the disasters they now face. This systemic transformation is further evidenced by the emergence of cascading risk chains, where initial weather-related impacts trigger secondary failures in critical infrastructure and socioeconomic networks, often exceeding the predictive capabilities of conventional risk assessment models (AghaKouchak et al., 2018; Glasser, 2020). Consequently, disaster risk reduction frameworks must evolve to account for the non-linear intensification of hazard frequency and magnitude, as current planning often overlooks the catastrophic potential of these cascading interactions (McGlade et al., 2019; Shi et al., 2020). Furthermore, addressing these risks requires a strategic transition from structural defense systems toward nonstructural measures that proactively reduce the exposure of populations and ecosystems (Tabari et al., 2021). Such strategies must emphasize the identification and regulation of hazard zones, acknowledging that the global increase in disaster loss is fundamentally linked to human settlement patterns in high-risk areas (Handmer et al., 2012). This shift necessitates a departure from reliance on static, climate-insensitive infrastructure toward adaptive, nature-based solutions that can accommodate the increased frequency and intensity of hydrometeorological events (Eriksen et al., 2020; Shamsudduha, 2025). Integrating such methodologies ensures that risk assessments transcend traditional focus on physical phenomena, incorporating social vulnerability and economic development trajectories as critical variables (Aizaga et al., 2025; Ismail-Zadeh, 2021).

This paper sets out to examine that gap. Its purpose is to analyse the mechanisms through which climate change drives rising disaster risk, and to ground that analysis in recent, real-world evidence rather than abstract projection. The scope is deliberately both global and regional: global disaster statistics establish the scale of the trend, while two case studies the 2026 Nepal glacial flood and the compounding climate risks facing Gilgit-Baltistan, Pakistan illustrate how the trend plays out on the ground. The objective is to translate this evidence into practical recommendations for disaster risk reduction (DRR) policy and practice.

2. Regional Context and Hazard Profile

Disaster risk is conventionally understood through four interlinked concepts. Hazard refers to a potentially damaging physical event, such as a flood or heatwave. Exposure describes the people, assets, and systems located in places where hazards could occur. Vulnerability captures the conditions that determine how much harm exposed people and systems actually suffer. Risk is the product of all three: the likelihood and severity of loss arising from the interaction of hazard, exposure, and vulnerability. Recent disaster forensics research further emphasizes the necessity of adopting this dynamic perspective, as the role of anthropogenic climate change functions as a primary driver that continuously reconfigures the risk landscape over time (Huggel et al., 2018). In regions such as the Himalayas, this reconfiguration is characterized by complex interactions between steep topography and shifting meteorological patterns, which heighten the probability of extreme events like glacial-fed flash floods (Liu et al., 2025). Specifically, the rapid thawing of the cryosphere, driven by accelerated glacier and snowpack melting, induces cascading phenomena such as ice-rock avalanches, debris flows, and the sudden failure of glacial lakes (Slater et al., 2021; Wang et al., 2024). These avalanche-induced glacial lake outburst floods represent complex process chains, wherein rising climate variability reduces the structural stability of glaciers and bedrock, thereby heightening the frequency of these catastrophic downstream events (Lala et al., 2018). In the Third Pole, this destabilization is compounded by the rapid expansion of glacial lakes, which currently threaten thousands of buildings, critical hydropower infrastructure, and vast stretches of farmland (Zhang et al., 2023). The increasing probability of such events is further exacerbated by the transboundary nature of these drainage basins, where the projected doubling of hazardous glacial lakes in border regions threatens to overwhelm existing regional early warning and response capabilities (Allen et al., 2022). Recent events, such as the 2023 Sikkim flood, demonstrate how mass movements triggered by slope instability can generate massive tsunami-like surges that bypass standard defensive infrastructure (Sattar et al., 2025). These cascading events exemplify the definition of risk as a complex interaction between physical triggers, societal exposure, and the inherent vulnerability of critical infrastructure (Kirschbaum et al., 2019). These dynamics highlight the extreme connectivity of landslide-flood cascades, where climate change and socio-economic processes serve as external

drivers that amplify both the probability and magnitude of potential disasters (Terzi et al., 2018). Moreover, the integration of graph-theoretic frameworks allows for a more nuanced characterization of these hazard networks, mapping how spatiotemporal progression influences the cascading failure of mountain catchments (Ekkirala & Ramesh, 2026). This systemic reconfiguration of High-Mountain Asia, often termed the "Third Pole," is underscored by the degradation of extensive permafrost and glacier reservoirs, which collectively sustain essential water resources for nearly two billion people (Zen & 10, 2025). The destabilization of these high-altitude cryospheric systems triggers a complex web of geohazards, including ice and rock avalanches that destabilize slopes and significantly alter riverine morphology (Zen & 10, 2025). This process of landscape-scale homeostatic disruption is further intensified by the Tibetan Plateau's rapid warming measured at 0.42 °C per decade since 1980 which drives both the expansion of glacial lakes and the acceleration of river runoff (Kuang et al., 2025).

Global data illustrate how sharply this equation has shifted. Fewer than 50 disasters were recorded worldwide in 1950; since 2000, the world has recorded between 300 and 500 climate-related disasters every year, a six- to tenfold increase that cannot be explained by reporting improvements alone. Mountain and glacial environments illustrate the hazard side of this shift particularly starkly. In August 2026, a glacial collapse on the Nepal–China border released an ice-and-rock mass equivalent in energy to a magnitude-5.2 earthquake, damming the Bhote Koshi–Trishuli river system. When the resulting dam breached, river levels rose by roughly nine metres within thirty minutes, sweeping through the Rasuwa, Nuwakot, Dhading, Gorkha, and Chitwan districts and reaching settlements up to 80 metres above normal river level. As of two days after the event, more than 1,000 deaths had been confirmed and over 2,300 people remained missing, with the toll expected to rise. This was not an isolated event: the same river system had flooded fourteen months earlier, and Nepal has recorded comparable glacial lake outburst floods (GLOFs) in 2024 and twice in 2025, among more than 3,600 glacial lakes now mapped across the Himalayan region. This poses a profound existential threat, as the combination of cryosphere degradation and climate-induced extremes destabilizes the geomorphic integrity of these high-altitude landscapes, frequently triggering catastrophic landslides, debris flows, and avalanches (Immerzeel et al., 2020).

Furthermore, the “high-altitude amplification effect” in these regions has accelerated flood risks to levels two to three times higher than those observed in low-altitude environments (Li et al., 2026). This heightened geomorphological sensitivity implies that the frequency of such disasters is projected to rise further as climate warming facilitates chain reactions and cascading processes across vulnerable catchments ((IPCC), 2023). Such geohazards, which include dam failures triggered by phenomena such as piping, earthquakes, and rockfalls, are predicted to increase in magnitude and frequency as continuous ice recession fosters the formation and rapid expansion of unstable glacial lakes. The eastern Himalaya is increasingly identified as a critical hotspot where these hazards are expected to shift westward, intensifying the complex interplay between geological instability and long-term climatic trends (Sattar et al., 2022). This incident pose a wake-up call for developing country like Pakistan, which is known as a third-pole region. Furthermore, the escalating frequency of these floods underscores the imperative for comprehensive, cross-border hazard assessments that incorporate diverse dam breach scenarios to mitigate future socio-economic losses (Furian & Sauter, 2025). These management frameworks are urgently required, as transboundary flood episodes across the Himalayas have historically caused thousands of fatalities and billions of dollars in infrastructure damage (Wani & Malik, 2023). To address these systemic vulnerabilities, disaster risk reduction strategies must transition toward integrated monitoring protocols that account for both seismic triggering mechanisms and the degradation of ice-cored moraine dams (Shrestha et al., 2023).

Pakistan illustrates the same hazard profile at national scale. The country contributes under one percent of global greenhouse gas emissions yet was ranked the world's most climate-affected country in 2022 and remains among the five most vulnerable nations to long-term climate risk. Much of this exposure is concentrated in Gilgit-Baltistan (GB), often described as the “water tower” of South Asia because its rivers, fed by glacial melt from the Hindu Kush, Karakoram, and Himalaya ranges, sustain agriculture and water supply across the country. Recent heat anomalies have pushed daytime and night-time temperatures 3–5°C above the 1981–2010 average, with extremes of 48.5°C recorded in Chilas and 46.1°C in Bonji in July 2025. More than 3,000 glacial lakes are now mapped

across GB and Khyber Pakhtunkhwa, of which over 33 are classified as hazardous, placing more than seven million people at risk.

3. Risk and Vulnerability Assessment

The human and economic consequences of these hazards are magnified by exposure and vulnerability patterns that climate change itself helps to create. In Gilgit-Baltistan, settlements sit on valley bottoms and alluvial fans directly in the path of mountain-origin hazards, leaving residents with little time to escape when a GLOF or flash flood occurs. An estimated 26.7 percent of the region's population is considered susceptible to climate-induced disasters, a reflection of fragile mountain ecosystems, complex topography, scattered settlement patterns, and limited socio-economic capacity. Long-term climate records reinforce this picture: average temperatures across five GB weather stations rose by 0.19°C per decade, a cumulative 0.6°C between 1984 and 2019, while average precipitation fell by 6.2 millimetres per decade over the same period, a combination that accelerates glacial melt while reducing the buffering effect of stable rainfall patterns. This climatic trajectory promotes erratic glacier behavior and widespread instability throughout the Karakoram range, directly escalating the frequency of glacial lake outburst floods that threaten critical infrastructure and livelihoods (Ajani & Geest, 2021).

Vulnerability is not evenly distributed. Communities most dependent on natural resources herding, subsistence agriculture, and glacier-fed irrigation face the greatest livelihood disruption when hazards strike, and food security is often the first casualty of flood or drought damage to agricultural land. Encroaching settlement patterns compound the risk: increasing occupation of flood plains, interventions in stream beds, riverbank encroachment, and infrastructure built on steep slopes all raise the exposure of lives, livelihoods, and infrastructure to hazards that are themselves intensifying. At the global level, the Germanwatch Global Climate Risk Index confirms that this pattern is systemic rather than local: seven of the ten most climate-affected countries in 2024 were low-income or lower-middle-income nations, including St. Vincent and the Grenadines, Grenada, Chad, Papua New Guinea, and Niger countries that, like Pakistan, have contributed comparatively little to the emissions driving their own risk.

4. Community Resilience Factors

Despite this exposure, affected communities are not without resources. Indigenous and local knowledge systems in Gilgit-Baltistan have long served an informal early-warning function: residents have learned to read glacier sounds, changes in river flow, and animal behaviour as signals of impending hazards, knowledge accumulated over generations of living alongside these mountain systems. Social capital and community networks similarly shape how quickly households recover from disaster impacts, with tightly knit communities often mobilising local labour and resources for search, rescue, and rebuilding well before formal assistance arrives. These coping mechanisms represent a genuine resilience asset, yet they are typically informal, undocumented, and rarely integrated into official planning processes, leaving their protective value only partially realised.

5. Scientific and Institutional Gaps

Several gaps constrain the translation of resilience potential into reduced risk. First, monitoring coverage remains incomplete: at-risk valleys such as Roushan in Ghizer fall outside the boundaries of current government and UNDP glacial-flood projects, leaving their communities without formal warning systems despite comparable exposure. Second, the indigenous knowledge described above remains largely outside formal early-warning system (EWS) design, meaning technical monitoring and community observation operate in parallel rather than as an integrated system. Third, institutional and financing capacity has not kept pace with the scale of the hazard: climate adaptation funding has tended to follow population centres rather than the upstream, sparsely populated regions like Gilgit-Baltistan that generate the water and hazard exposure affecting the country as a whole. Finally, broader adoption of modern monitoring and modelling tools, including satellite-based glacial lake surveys and predictive analytics, remains limited relative to the pace at which glacial systems are changing, constraining the lead time available for both structural and community-based responses. To address these deficiencies, current research emphasizes the necessity of shifting from top-down disaster management toward inclusive, community-based risk modeling that incorporates both GIS-based spatial analysis and traditional coping mechanisms (Abbas et al., 2025).

6. Mitigation Strategies and Best Practices

Some of these gaps are already being addressed through structural and non-structural interventions. The GLOF-II Pakistan project, implemented by the UNDP between 2017 and 2024, combined engineering measures dams, spillways, and drainage works with community-based early warning systems across Gilgit-Baltistan and Khyber Pakhtunkhwa, offering a template for integrated risk reduction. Complementary approaches include bioengineering and ecosystem-based solutions such as afforestation and slope stabilisation, which reduce hazard intensity while restoring degraded mountain ecosystems, and infrastructural resilience measures that account for floodplains and slope stability in siting future construction. Globally, similar best practice emphasises combining hard infrastructure with nature-based defences and capacity building, rather than relying on either approach alone, alongside sustained investment in community preparedness and training.

7. Risk Communication and Early Warning

Early warning systems are expanding but remain uneven in coverage. New hydrological modelling, flood gauges, and weather stations are improving the ability to detect and respond to flood risk in real time across GB and KP, building on the infrastructure established through GLOF-II. However, the same coverage gaps noted earlier mean that last-mile communication ensuring warnings reach and are acted upon by the most exposed households remains inconsistent, particularly in valleys outside formal project boundaries. People-centred, gender-sensitive early warning requires not only technical detection capacity but also communication channels and formats that reach women, elderly residents, and remote settlements in time to act, and that build on, rather than bypass, the informal warning practices communities already trust. Furthermore, integrating geospatial intelligence such as satellite imagery, digital elevation models, and drone surveys with these community-based insights is essential to map overlapping risks in high-elevation valleys where environmental monitoring remains minimal (Javid & Ahmad, 2026).

8. Policy Recommendations

Four priorities emerge from this analysis. First, early warning coverage should be extended to every hazardous valley, not only those within existing project boundaries, closing gaps such as the one in Roushan. Second, indigenous knowledge should be

formally integrated with technical monitoring, combining community observation with instrumental data to produce faster, more localised alerts. Third, climate finance should be scaled and explicitly integrated with disaster planning, directing adaptation funding toward the upstream regions that generate a country's water supply and hazard exposure, not only its population centres. Fourth, investment in nature-based defences, afforestation, slope stabilisation, and ecosystem restoration should continue alongside hard infrastructure such as spillways and drainage works. Underpinning all four is a need for integrated governance that treats climate adaptation and disaster risk reduction as a single policy agenda rather than parallel tracks, with community participation embedded at every stage.

9. Conclusion

The evidence assembled in this paper points to a single conclusion: climate change is not a future threat to disaster risk but the trend line the world is already living on. The sixfold-to-tenfold rise in recorded disasters since 1950, the disproportionate burden carried by low-income and climate-exposed nations, and the accelerating glacial hazards documented in Nepal and Pakistan all describe the same underlying dynamic a warming climate steadily raising hazard, exposure, and vulnerability together. Reducing this risk will require science-based planning that keeps pace with changing hazards, recognition of social capital and indigenous knowledge as genuine resilience assets, wider adoption of monitoring technology, and integrated policy approaches that connect climate adaptation directly to disaster risk reduction. Every fraction of a degree of warming avoided, and every unit of investment made in resilience today, represents a tangible reduction in tomorrow's losses.

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PARTICIPANT RESEARCH PAPER

Climate-Disaster Supply Chain Resilience in Pakistan: Vulnerabilities, Community Resilience, and Policy Pathways for Flood-Prone Supply Chains

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Abstract

Pakistan's exposure to floods is increasing the strategic importance of resilient supply chains. Floods do not only damage physical infrastructure; they interrupt transport corridors, local markets, warehouses, fuel availability, communications, supplier capacity, health services and the delivery of essential goods. The resulting disruption can persist long after floodwaters recede. This paper examines climate-disaster supply chain resilience in Pakistan through three connected lenses: supply-chain vulnerability, community resilience, and policy pathways. It argues that Pakistan's response needs to move beyond a predominantly reactive humanitarian logistics model toward a proactive and decentralized resilience model that anticipates disruption, diversifies sourcing and transport, pre-positions critical stocks, strengthens local markets and community capacities, uses early-warning information to trigger operational decisions, and embeds climate risk into procurement and infrastructure planning. The paper proposes a practical resilience framework linking climate hazards and exposure to vulnerability, preparedness, absorptive capacity, adaptive capacity, recovery and learning. It concludes with policy and operational recommendations for government, humanitarian organizations, development partners and private-sector supply-chain actors.

Keywords: Climate change; floods; supply chain resilience; humanitarian logistics; disaster risk reduction; community resilience; Pakistan; procurement; last-mile delivery; climate adaptation.

1. Introduction

Climate change is increasingly being experienced not only as an environmental challenge but also as a disruption to economic and social systems. For Pakistan, recurrent flooding illustrates this relationship particularly clearly. Flood events can simultaneously affect roads, bridges, agricultural production, markets, energy, telecommunications, public services, health facilities and household livelihoods. When these systems fail together, the consequences are transmitted through supply chains.

The 2022 floods demonstrated the scale of this systemic exposure. The disaster affected approximately 33 million people and generated damages and economic losses exceeding US$30 billion. Such events highlight a critical strategic question: how can essential supply chains continue to function when the infrastructure and markets on which they depend are themselves exposed to the same hazard?

Traditional disaster logistics tends to emphasize the movement of relief commodities after an emergency occurs. Supply-chain resilience requires a broader perspective. It considers the ability of a system to anticipate disruption, prepare for it, absorb shocks, maintain critical functions, recover quickly and adapt based on lessons learned. This distinction is particularly important in flood-prone Pakistan, where repeated disruptions can turn a single disaster into a prolonged supply and livelihood crisis.

This paper therefore examines climate-disaster supply-chain resilience in Pakistan, focusing on three questions: (1) what are the principal vulnerabilities affecting flood-prone supply chains; (2) how can community capabilities contribute to resilience; and (3) what policy pathways can strengthen supply-chain continuity before, during and after floods?

2. Pakistan’s Flood and Climate Risk Context

Pakistan is highly exposed to climate-related hazards, including floods, droughts, heatwaves and changing precipitation patterns. Flood risk is particularly significant because population centres, agricultural areas, transport networks and economic activity are closely connected to river systems, monsoon rainfall and the Indus Basin. The National Climate Change Policy provides an important policy foundation for adaptation and disaster-risk reduction, including measures related to resilient infrastructure, early warning, risk mapping, institutional capacity and community participation. Pakistan’s National Adaptation Plan further strengthens the national

adaptation framework. However, translating climate policy into supply-chain continuity requires operational mechanisms that connect climate-risk information with procurement, inventory, transportation, warehousing and distribution decisions.

The strategic implication is that flood risk should be treated as a supply-chain risk rather than as an isolated emergency-management issue. A road closure, for example, can become a procurement problem if suppliers cannot deliver; a damaged bridge can become a health problem if medicines cannot reach a district; and loss of local markets can become a food-security problem if communities lose both purchasing power and access to goods.

3. Supply-Chain Vulnerabilities in Flood-Prone Areas

3.1 Physical infrastructure and transport

Roads and bridges are among the most visible points of vulnerability. Floodwater can sever primary routes and isolate communities, while damage to secondary roads can make conventional last-mile distribution impossible. Reliance on a single corridor increases concentration risk. Supply chains that have no mapped alternative routes may therefore experience disproportionate disruption from localized infrastructure failure.

3.2 Warehousing and inventory

Warehouses located in flood-exposed areas face direct damage as well as access constraints. Even where stocks remain physically intact, they may become unusable if transport links, electricity, security or communications fail. Resilience therefore requires more than maintaining a nominal level of inventory. It requires strategically located stocks, appropriate storage conditions, stock visibility, replenishment plans and defined emergency release procedures.

3.3 Procurement and supplier dependence

Floods can affect suppliers at the same time that they affect buyers. Local vendors may lose facilities, inventory, transport capacity or access to financial services. Excessive dependence on a small number of suppliers can therefore create a major bottleneck. Resilient procurement should incorporate supplier diversification, prequalification, framework agreements, realistic lead times, emergency contracting mechanisms and consideration of geographically dispersed sources.

3.4 Fuel, energy and telecommunications

Fuel shortages and power interruptions can amplify transport and warehousing constraints. At the same time, unreliable telecommunications can reduce visibility of inventory, supplier status and road conditions. This means that supply-chain resilience depends on interdependent systems rather than on logistics assets alone.

3.5 Last-mile distribution

The last mile is often the weakest link. National or provincial stocks may reach a relatively accessible hub while isolated settlements remain underserved. Flood-resilient planning should therefore identify community-level access constraints in advance and consider alternative modes, local transport providers, temporary distribution points and decentralized stocks.

4. Lessons from the 2010 Pakistan Super Flood: A Supply-Chain Resilience Perspective

The 2010 floods represent a critical turning point in Pakistan's disaster-management experience. The scale and geographic spread of the disaster exposed vulnerabilities not only in physical infrastructure but also in the systems required to move people, food, medicines, shelter materials and other essential commodities. More than 20 million people were affected, while approximately 100,000 square kilometres of territory were inundated. The floods also damaged roads, bridges, irrigation systems, agricultural land and communications infrastructure, creating a complex logistics environment in which access to affected communities became a major operational constraint.

From a supply-chain perspective, the most important lesson from 2010 was that physical infrastructure and supply-chain continuity are inseparable. Damage to transport infrastructure created bottlenecks that affected the movement of relief commodities and the connection between communities and markets. In Sindh alone, flood-related damage included extensive impacts on provincial roads and agricultural land. Subsequent rehabilitation demonstrated the economic importance of restoring transport connectivity: ADB reports that repaired sections of provincial roads subsequently experienced a substantial increase in truck traffic.

A second lesson was the importance of multiple logistics channels and operational flexibility. The national response required the simultaneous use of military assets, government agencies, humanitarian organizations, helicopters, aircraft, boats and

conventional road transport. The World Bank's contemporary assessment records the mobilization of more than 20,000 military personnel, helicopters, C-130 aircraft and more than 1,000 boats for rescue and relief operations. This demonstrates that when conventional supply routes fail, resilient disaster supply chains require alternative transportation modes that can be activated rapidly.

A third lesson concerns the importance of decentralized access and last-mile logistics. The 2010 response demonstrated that reaching an affected population is not equivalent to reaching an affected community. Large-scale national stocks and international assistance can be mobilized, but their effectiveness depends on the ability to move commodities through damaged infrastructure and eventually reach isolated households. The experience therefore supports a decentralized model involving regional stocks, local transport capacity, community networks and alternative access routes.

A fourth lesson was the importance of rapid assessment and information for resource allocation. The 2010 floods led to a formal Damage and Needs Assessment that estimated damages and losses at approximately PKR 855 billion, or US$10.1 billion, equivalent to about 5.8% of GDP. Such assessments are essential, but a modern resilience approach should complement post-disaster assessments with real-time information during the emergency. Supply-chain decisions increasingly require information on road accessibility, supplier capacity, inventory levels, market prices, fuel availability and changing community needs.

A fifth lesson is that disaster preparedness must move beyond contingency documents to operational readiness. Pakistan subsequently strengthened its disaster-risk-management approach, with the World Bank noting the shift from response-based disaster management toward more proactive risk management following the 2010 floods. The key challenge is ensuring that preparedness plans are converted into pre-agreed actions: which suppliers will be activated, where stocks will be positioned, which routes will be used, what alternative transport will be available, and who has authority to make emergency procurement and logistics decisions.

4.1 What 2010 taught us about supply-chain resilience?

The 2010 experience can therefore be summarized through six major lessons:

2010 Lesson	Supply-Chain Implication	Resilience Response
Roads and bridges failed	Conventional distribution routes became unreliable	Pre-identify alternative routes and transport modes
Communities became isolated	Centralized distribution was insufficient	Strengthen last-mile and decentralized logistics
Suppliers and markets were disrupted	Normal procurement assumptions became unreliable	Diversify suppliers and establish framework agreements
Relief demand changed rapidly	Static distribution plans became inadequate	Use real-time needs and market information
Multiple agencies responded simultaneously	Coordination became critical	Establish integrated logistics coordination mechanisms
Recovery took place over an extended period	Emergency logistics and recovery logistics overlapped	Plan for continuity from relief through recovery

4.2 From 2010 to 2022: Did resilience improve?

This is where I think your paper can become **much more interesting and analytical**.

Rather than simply saying *"Pakistan learned lessons from the 2010 floods,"* we should ask:

To what extent were the lessons of 2010 translated into stronger supply-chain resilience before the 2022 floods?

The comparison is compelling. The 2010 floods affected more than 20 million people, while the 2022 floods affected approximately 33 million people and generated more than US$30 billion in damages and economic losses. Transport and communications were among the sectors suffering the greatest damage in 2022.

The experience of 2010 demonstrated the consequences of supply-chain fragility; the experience of 2022 demonstrated that vulnerability remained systemic. The strategic challenge for Pakistan is therefore no longer simply to improve emergency response, but to institutionalize resilience before the next major climate shock.

5. Community Resilience as a Supply-Chain Capability

Communities are often treated as the final recipients of humanitarian assistance. This perspective can overlook their role as active participants in supply networks. Local communities possess knowledge of terrain, access routes, local markets, social networks, transport options and changing needs. These capabilities can become important resilience assets when formal supply chains are disrupted.

Community resilience is multidimensional, encompassing social relationships, local economic capacity, infrastructure, institutional trust and access to information. In flood-prone areas, strengthening local capacities can reduce dependence on centralized systems and improve the speed and appropriateness of response.

A resilient model should therefore integrate local suppliers, transporters, community-based organizations and local authorities into preparedness planning. This does not mean replacing national or international supply chains. Rather, it creates multiple interconnected pathways so that failure of one node does not cause complete system failure.

6. Conceptual Framework

This paper proposes a climate-disaster supply-chain resilience framework consisting of six stages:

Climate hazard → Exposure → Vulnerability → Resilience capacity → Supply-chain continuity → Recovery and adaptation.

Exposure describes the assets, suppliers, transport routes, markets and communities located within hazard-prone areas. Vulnerability reflects the degree to which these elements are susceptible to disruption. Resilience capacity includes preparedness, redundancy, flexibility, local capacity, collaboration, information visibility and financial resources.

The framework emphasizes that resilience is not synonymous with redundancy alone. Maintaining multiple suppliers or large inventories may be costly and may not protect the system if all alternatives are exposed to the same flood. The objective is therefore strategic diversity: geographic diversification, alternative routes, flexible contracts, decentralized stocks and reliable information.

A useful operational cycle is:

Anticipate → Prepare → Absorb → Adapt → Recover → Learn.

The learning stage is essential because repeated flood events should generate institutional improvements rather than repeated emergency improvisation.

7. Policy Pathways for Pakistan

7.1 Integrate climate risk into supply-chain planning

Government agencies, humanitarian organizations and major private-sector operators should incorporate flood-risk mapping into procurement, warehousing and distribution planning. Critical suppliers, warehouses, transport corridors and service points should be screened against hazard exposure and interdependency risks.

7.2 Establish decentralized and strategically pre-positioned stocks

Emergency stocks should be positioned according to population needs, hazard exposure and accessibility rather than administrative convenience alone. Regional and district-level pre-positioning can reduce dependence on a single central warehouse and shorten response times when major corridors are blocked.

7.3 Build resilient procurement systems

Procurement policies should support prequalified supplier pools, framework agreements, geographically dispersed sourcing, emergency purchasing protocols and supplier business-continuity requirements. Procurement planning should also distinguish between items that can be sourced locally and commodities that require national or international sourcing.

7.4 Develop resilient transport networks

Flood contingency plans should identify alternative routes and transport modes before an emergency. Agreements with local transporters can provide flexible capacity when conventional routes become inaccessible. Route planning should be linked to early-warning information and regularly tested through simulations or tabletop exercises.

7.5 Institutionalize community participation

Community organizations and local market actors should be incorporated into preparedness and distribution planning. Local knowledge can improve route selection, beneficiary communication, demand assessment and identification of viable local supply options. Community participation should be treated as a resilience investment rather than simply a consultation activity.

7.6 Link early warning to operational triggers

Early-warning systems have limited value if they do not trigger decisions. Agencies should establish predefined thresholds that activate actions such as stock repositioning, supplier confirmation, vehicle staging, route changes, staff movement or emergency procurement. This converts climate information into supply-chain action.

7.7 Strengthen public-private partnerships

Government, humanitarian organizations, logistics companies, fuel providers, telecommunications firms and local businesses often possess complementary capabilities. Formal coordination mechanisms can help establish contingency capacity, shared information protocols and emergency service arrangements before a crisis occurs.

8. Operational Resilience Framework

Risk	Preparedness Measure	Response Trigger	Resilience Outcome
Road/bridge disruption	Map alternate routes; pre-arrange local transport	Flood warning/route closure	Continuity of last-mile delivery
Supplier failure	Diversify and prequalify suppliers	Supplier capacity alert	Reduced procurement interruption
Warehouse exposure	Flood-risk screening; decentralized stocks	Rising flood risk	Protected inventory and faster access
Fuel shortage	Framework agreements and contingency stocks	Supply disruption warning	Transport continuity
Telecom/power failure	Backup communications and power	Network outage	Maintained visibility and coordination
Local market disruption	Local market mapping and	Market closure or price shock	Improved community access

	cash/local sourcing options		

9. Discussion

The central finding of this paper is that flood resilience cannot be achieved through a single intervention. Infrastructure investment is necessary, but infrastructure alone cannot guarantee supply continuity. A resilient supply chain is a network of physical assets, suppliers, institutions, information systems and communities.

Pakistan's recurring flood experience also suggests that preparedness should be understood as a continuous investment rather than a seasonal activity. Organizations that repeatedly establish temporary emergency arrangements after a disaster may incur higher costs and still face preventable delays. By contrast, pre-agreed supplier relationships, decentralized stocks, route contingency plans and early-warning triggers can reduce both response time and uncertainty.

A second implication concerns localization. Local actors are often the first and sometimes the only actors able to operate when external supply chains are disrupted. Strengthening local procurement and transport capacity can therefore contribute simultaneously to humanitarian effectiveness and local economic resilience. However, localization should be risk-informed; local markets themselves may be heavily exposed to floods, and local capacity can be overwhelmed during large-scale disasters.

Finally, policy coordination is essential. Climate adaptation, disaster management, infrastructure development, procurement reform and humanitarian logistics are frequently managed through different institutional structures. Supply-chain resilience requires these functions to be connected through shared risk information, joint planning and measurable continuity objectives.

10. Recommendations

1. Develop national and provincial flood-risk maps that identify critical supply-chain nodes, corridors, warehouses, suppliers and service facilities.
2. Require major public and humanitarian supply-chain systems to maintain documented business-continuity and flood-contingency plans.

3. Create geographically diversified supplier and transporter pools for critical commodities and services.
4. Expand strategic pre-positioning of essential commodities at appropriately selected regional and district locations.
5. Develop procurement framework agreements that can be activated rapidly when defined climate-risk thresholds are reached.
6. Establish operational protocols that convert early warnings into logistics actions, including stock repositioning and route changes.
7. Integrate local suppliers, transporters and community organizations into disaster preparedness exercises and contingency planning.
8. Use scenario-based stress testing to identify single points of failure across critical supply chains.
9. Develop public-private coordination arrangements for transport, fuel, telecommunications, warehousing and emergency services.
10. Track resilience through measurable indicators such as recovery time, alternative-route availability, supplier concentration, stock coverage, percentage of critical facilities above flood-risk thresholds, and time required to activate emergency procurement.

11. Conclusion

Pakistan's flood risk is increasingly a strategic supply-chain issue. The impacts of climate-related disasters propagate through transport, procurement, warehousing, energy, telecommunications, markets and communities. A response centered only on post-disaster relief is therefore insufficient.

Climate-disaster supply-chain resilience requires a shift toward anticipation, diversification, decentralization and continuous learning. The most resilient system is not necessarily the one with the largest inventory or the greatest number of assets; it is the system capable of maintaining critical functions when individual nodes fail.

For Pakistan, the policy opportunity is to connect climate adaptation with practical supply-chain management. This means integrating flood-risk information into procurement and infrastructure decisions, pre-positioning essential stocks, diversifying suppliers and routes, strengthening local markets and communities, and establishing operational

triggers linked to early-warning systems.

The strategic objective should be clear: **from reactive disaster logistics to proactive, climate-resilient supply-chain continuity.** Such a transition can reduce disruption, improve the speed and equity of emergency response, protect livelihoods and strengthen Pakistan’s wider capacity to adapt to a changing climate.

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- Recent Pakistan-focused literature on community resilience, flood impacts and rural–urban supply flows should be expanded and verified during the next research stage.

PARTICIPANT RESEARCH PAPER

Cloudburst Risk in Pakistan: Causes, Vulnerability, Early Warning and Disaster Risk Reduction

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Abstract

Cloudbursts generally are heavy and rapid rainfall events that can lead to serious flash flooding and landslides or debris flows in minutes, especially in steep and urbanized catchments. All this makes Pakistan vulnerable to it due to its complicated monsoon climate, mountainous geography, speedy urbanization, environmental degradation, and high social vulnerability. In the changing climate, the risk becomes more significant: recent research has shown that anthropogenic warming provided some background support to the exceptional rainfall setting associated with the 2022 floods and future projections suggest that extreme precipitation will increase in a number of hydroclimatic zones in Pakistan. The flash floods which occurred in Khyber Pakhtunkhwa, in 2025 again highlighted the challenge of safety to life posed by very high intensity and very short duration of rainfall. This paper assesses cloudburst risk through hazard-exposure-vulnerability approach, and explores impacts on livelihood, food security, infrastructure and vulnerable groups. It calls Pakistan to go beyond rainfall forecasting and shift towards "People-centred, Impact based early warning". Institutional coordination, improved high resolution data, responsible use of artificial intelligence and machine learning, and increased district level capacity are needed to convert scientific information to timely protective action.

Keywords: Cloudburst; Climate Change; Disaster Risk Reduction; Early Warning; Pakistan

1. Introduction

Cloudbursts are sudden and heavy falls of rain, generally associated with shower-type precipitation. Cloudburst is not a precise meteorological term but a colloquial term employed by the World Meteorological Organization. But the disaster-management aspect is not the label itself, it is the conjunction of very high intensity of rain, small spatial scale and short response time. This can happen very quickly as precipitation exceeds infiltration and drainage causing flash flooding and slope failures. The basin response time is very short and limited time is available for detection, warning and action to take place in flash flood situations. Pakistan is faced with multiple vulnerability pathways from heavy rainfall to disaster due to its geography. In mountainous regions of K-P, G-B, AJK and northern Punjab, there are steep slopes and narrow valleys that can result in increased runoff concentrations. Impervious surfaces, drainage limitations and exposure of homes, roads and critical systems are added to urban areas. Rural communities can also be at further risk due to crop damage, loss of livestock, damage to irrigation systems, and loss of access roads. The combination of 150 mm of rain falling in Buner in one hour on 15 August 2025, causing rapid flash flooding, and 509 fatalities as a result of flash flooding was demonstrated in 2025 in the province of Khyber Pakhtunkhwa. This paper aims to critically review the risk of a cloudburst event in Pakistan and suggest viable measures to mitigate the mortality, disruption of livelihood and economic losses in the event of a cloudburst. The goals are to: (i) outline the hazard and its regional characteristics; (ii) evaluate exposure and vulnerability; (iii) explore community and institutional resilience; (iv) examine scientific and institutional gaps; and (v) recommend integrated mitigation, early-warning and policy strategies.

2. Regional Context and Hazard Profile

Pakistan is a meso-regional country located on the intersection of various climatic and physiographic systems, such as the South Asian monsoon, western disturbances, Hindu Kush–Karakoram–Himalayas mountain system and vast lowland plains. In mountains, heavy rainfall may result in intense surface run-off, flash-floods, landslides and debris flows. In urban areas, short-duration, heavy rainfall events can overload storm-water infrastructure. Flooding can occur on low-lying land where the water may stay longer.

Understanding cloudburst risk should, therefore, be looked at in terms of four interrelated concepts. Hazard: A potentially damaging physical event; Exposure: People, infrastructure, livelihoods, ecosystems and assets in hazard prone areas; Vulnerability: Physical, social, economic, and environmental conditions that make people more susceptible to the hazards; Risk: When hazard and exposure and vulnerability interact. This framework aligns with current disaster-risk assessment processes that focus on people-centred disaster risk, governance, inclusiveness, and evidence-based decision-making.

While cloudbursts cannot be solely blamed on climate change, the impact of climate change is an important risk multiplier for cloudbursts. The record-breaking rainfall in 2022 over Pakistan was found to be due to both anthropogenic warming and internal climate variability in a new study released in 2024. Recent studies, based on the data of different climate models from the Coupled Model Intercomparison Project (CMIP6), suggest that the monthly maximum daily precipitation over Pakistan's hydroclimatic zones will also change, necessitating planning for changing extremes, not just historic rain thresholds.

The 2025 KP flash floods in particular are pertinent to the operational difficulties of short-duration extreme rainfall. The event highlighted that, despite the provision of weather information by forecasting institutions, communities' response time to receive the warning message and evacuate could be very short.

3. Risk and Vulnerability Assessment

Cloudburst risk is not only dependent on intensity of rainfall. The impact of the same rainfall on settlement, drainage, land cover, building quality, road access and poverty and preparedness can lead to very different consequences. The high density of population and economic activities in flood-prone areas, unplanned and informal urbanization and environmental degradation and unequal distribution of protective infrastructure are among the factors which make Pakistan very vulnerable.

Socio-economic impacts are likely to be immediate and cascading. Homes can be flooded or destroyed, roads and bridges severed, electricity and communications disrupted, schools and health facilities inaccessible, and markets disrupted. Crop losses, livestock deaths, and damage to irrigation resources can negatively affect income and food for rural residents. Poor households that have little savings could find that even a

relatively small disaster becomes a long-term livelihood crisis due to a scarcity of resources to recover from the disaster.

Short duration flood events have high food security vulnerability as they affect standing crops, topsoil, stored grain and the livestock shelter and local transport. Frequent events can also deter investments in agricultural activities and decrease household resilience.

There is also a strong spatial component to exposure. Limited buildable land in valleys may mean that mountain communities are situated right next to streams. Natural drainage paths may have been encroached upon and urban residents may reside or work along these paths.

So far as social group vulnerability is concerned, there is not a uniform distribution. Children, older people, disabled people, those living in poverty; slums and outdoor workers have less access and ability to respond to warnings. Gender also matters. Women might have limited access to transport and household resources and social responsibilities can make for a quick evacuation challenging. The National Climate Change Policy explicitly mentions special attention to be paid to women, children, older persons and people with disabilities in evacuation plans. Planning, therefore, should be Gender-sensitive and incorporate accessible shelters, safe sanitation, accessible communication channels and opportunities for women in local disaster planning.

An important inference is that vulnerability reduction is not an engineering problem. While drainage and flood protection are essential, they are no replacement for land use regulation, poverty alleviation, warning systems, and preparedness and community participation.

4. Community Resilience Factors

During the first minutes of a sudden disaster, the first and most important actors are in communities. Community organizations and informal networks, including trust, local relationships and social capital, can help to lessen the time required to respond when formal systems are not able to respond to every household in a timely fashion. Support for warning dissemination, evacuation and first aid from village committees, local volunteers, rescue organisations, religious/community leaders, teachers and health workers.

Indigenous and local knowledge can also be useful for practice. Many residents can appreciate changes in stream activity, odd rainfall timing, safe evacuation routes, and other unusual occurrences by experience. This knowledge should not be used in place of forecasting, it can be used alongside it to enhance local interpretation and action. A technical warning is made useful through community hazard maps and locally agreed evacuation routes.

Preparedness prior to the event is another important factor to resilience. Communities should designate safe buildings, establish emergency contact networks, practice drills and pre-position basic rescue and first aid supplies. They should be integrated into these activities, instead of being treated as recipients of assistance, especially women, youth and persons with disabilities.

There is already an existing policy direction in Pakistan for this. As per the National Climate Change Policy, early warning dissemination and disaster risk reduction activities should involve communities, including evacuation planning.

5. Scientific and Institutional Gaps

One of the big challenges in science is that the capacity to observe and predict rainfall on space and time scales relevant to cloud burst is still rather limited. The traditional rain gauge network might not represent the maximum rainfalls that are highly localized, especially in complex topography. Calibration, sharing of data and reliable communication methods are necessary to enhance situational awareness, as is the use of satellite precipitation estimates, weather radar, automatic weather stations, and lightning observations, among other tools.

Nowcasting, anomaly detection, rainfall–runoff modelling and risk mapping are opportunities provided by artificial intelligence and machine learning. But AI is not a substitute for meteorological knowledge and should be used as a support tool for decisions. The models that are trained on incomplete or biased data will not do well in an unprecedented situation. Explainability, validation, uncertainty information and human oversight are essential.

Central institutional challenge: Making sure a technically correct warning reaches the right people at the right time for action: the “last mile”. Technical early warning has improved in Pakistan. NDMA's Technical Early Warning system involves generating

hazard alerts and advisories, utilizing environmental data, the capabilities of AI/ML and satellite remote sensing. Local, flash-flood forecasting and warning systems are also required in vulnerable mountainous areas under the National Climate Change Policy.

6. Mitigation Strategies and Best Practices

Cloudburst risk reduction should be a combination of structural and non-structural solutions. Structural measures include, but are not limited to, improved storm-water drainage, culvert and bridge design, slope stabilization, check dams (where appropriate), debris-flow protection, retention areas and resilient critical infrastructure. Urban drainage systems should not be designed based on historical design assumptions and must be designed for changing rainfall intensities.

Engineering can be complemented by Nature based sloutions (NbS) and. Runoff and erosion reduction and environmental benefits can be achieved by implementing watershed restoration, reforestation, wetland protection, riparian buffers, and soil-conservation practices. The NCCP clearly advocates for NbS as part of DRR, which are “no-regret” and cost-effective.

Equally important would be non-structural measures. These include hazard and risk mapping, land-use zoning, enforcement of building standards, evacuation planning, public awareness, school safety, emergency drills and insurance or social-protection mechanisms (where possible).

In Pakistan, this can be done by using meteorological thresholds along with expected impacts, for instance, “low-lying houses near the stream should be evacuated”, rather than just communicating rainfall figures. This puts warnings actionable for non-specialists.

7. Risk Communication and Early Warning

Early warning is a chain: knowledge of risk, monitoring and forecasting, warning dissemination and preparedness/response capability. Failure can result from a weakness at any link. The chain needs to move quickly when cloudbursts are the warnings since the warning time is short, from minutes to hours.

Communication should be done through various means such as SMS/cell broadcast (where possible), radio, television, social media, mosque/community broadcast, local volunteers or through direct door-to-door notification in high risk settlements.

Messages should be provided in languages and formats that are understood in the local area and accessible for disabled persons. Communication should take into account that women and other groups might have unequal access to phones, transport and public information.

The last mile is the most important as seen from the Khyber Pakhtunkhwa floods in 2025. The World Bank reported that when the volume of water came through all at once, the communities had little time for action and many did not receive effective warning. Hence there is a need of pre-event community preparedness so that an alert automatically trigger rehearsed actions instead of initiating a new decision-making process in Pakistan.

8. Policy Recommendations

Risk maps of cloudbursts and flash floods need to be prepared by integrating rainfall intensity, topography, drainage, land cover characteristics, settlements, critical infrastructure and past occurrences at the district level. These maps should be used directly in land use planning and in evacuation routes.

Monitoring should expand in high-risk mountainous and urban catchments in terms of dense automatic rain gauges, radar if available, satellite products and other real-time observations. There should be interoperability among data from federal, provincial and research institutions.

Promote the operationalization of impact-based, people-centred early warning in Pakistan. Forecasts should be turned into clear triggers for the district administration, rescue service and communities. For each high-risk settlement there should be a warning focal point, evacuation route and safe location identified.

AI/ML should be used judiciously in forecasting and risk analytics, and must be backed by quality-controlled datasets, transparency in validation and expert monitoring. It is suggested that research institutions should build models which are locally calibrated instead of being imported from other sources.

The integration of climate adaptation and DRR into investments in infrastructure. Roads, bridges, schools, hospitals and drainage systems, as well as telecommunications should be evaluated for future extreme rainfall scenarios. Where technically and socially applicable, Nature based solutions should be integrated.

The community involvement should be institutionalized. Annual pre-monsoon drills should be held with all the schools, health centres, rescue services, local government, women and community organizations in the district.

The National Adaptation Plan highlights improved hydro-meteorological and early warning services, disaster risk governance and community and critical-infrastructure resilience as areas of priority adaptation. So implementation, monitoring and financing should be considered as the next step, not just a new policy document.

9. Conclusion

Pakistan is facing a compound disaster-management situation for cloudburst, which is a product of high intensity of rainfall, exposure, topography, infrastructure, and social vulnerability. Extreme precipitation is an important consideration in preparing for climate change, but risk is also influenced by land-use decisions, environmental degradation, poverty, and drainage capacity and institutional readiness. Experience of the 2025 Khyber Pakhtunkhwa flash floods has identified that having a technically correct forecast is inadequate in such short response time.

An integrated approach is thus Pakistan's best bet. There should be linkage between scientific monitoring and high-resolution forecasting, and community networks and prepared evacuation activities. Land-use planning and ecosystem based risk reduction and resilient infrastructure should be integrated with structural measures. Analysis can be supported by AI and remote sensing, provided that there is proper local data and supervision. Above all, communities should not be only recipients of warnings, but rather partners in risk reduction.

Resilience to cloudbursts is all about turning information into action on time. Even if there is no way to stop extreme rainfall, it can be managed with science-based planning, great social capital, local knowledge, accountable institutions and continued investment to minimize loss of life and protect livelihoods.

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PARTICIPANT RESEARCH PAPER

The Comparative Analysis of 2010 and 2022 Pakistan Flood Events

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Abstract

This paper compares Pakistan's two most consequential recent flood disasters in order to establish how and why their causes, magnitude, impacts and management outcomes diverged. Applying the hazard-exposure-vulnerability-risk framework, the study finds the two events were physically dissimilar. The 2010 disaster was predominantly a riverine flood concentrated along the Indus and its tributaries, propagating from Khyber Pakhtunkhwa southwards over several weeks. The 2022 disaster was rainfall-dominated, with pluvial and flash flooding overwhelming Sindh and Balochistan, provinces with negligible drainage capacity and the country's deepest poverty. Although 2022 recorded marginally fewer deaths, it affected 33 million people and produced damages of US$14.9 billion, against 20.2 million affected and US$9.7 billion in 2010. The comparison demonstrates that institutional and forecasting reforms introduced after 2010 improved hazard detection without reducing exposure or vulnerability. Catastrophic losses recurred in 2022 because risk-informed land use, provincial and district implementation capacity, and last-mile warning delivery remained weak. Pakistan's flood risk is shifting from river management towards rainfall-driven, socially differentiated risk, requiring anticipatory and locally grounded disaster risk reduction.

Keywords: Climate change adaptation; Disaster risk reduction; Early warning systems; Flood vulnerability; Indus Basin.

1. Introduction

Pakistan's settlement, agriculture and economy are organised around the Indus Basin, fed by Himalayan snowmelt and a summer monsoon originating over the Bay of Bengal and reinforced by Arabian Sea and Mediterranean systems (Ali, 2024). This makes the country structurally exposed: between 1950 and 2011 Pakistan experienced a major flood roughly every three years (Manzoor et al., 2022). Two events stand apart. The 2010 floods were the most damaging in national history until 2022 displaced them, and together they bracket twelve years of substantial institutional and technological reform.

The problem is that reform did not prevent recurrence. Despite the National Disaster Management Act 2010, the National Disaster Risk Reduction Policy 2013 and the National Flood Protection Plan-IV, Pakistan sustained heavier aggregate losses in 2022 than in 2010. A paired comparison is warranted because the two events share a national institutional context while differing in hazard type and geography, allowing hazard, exposure, vulnerability and preparedness to be separated analytically rather than conflated.

The central research question is: how and why did the causes, magnitude, impacts, vulnerabilities, preparedness, institutional response, early warning and disaster-risk-management outcomes differ between the two events, and what lessons follow for strengthening future flood resilience? The supporting objectives are to compare their hazard characteristics and their socio-economic impacts and vulnerability profiles; to assess what changed institutionally and technologically between them; and to derive evidence-based disaster risk reduction priorities. Scope is confined to these two events nationally.

2. Regional Context & Hazard Profile

Four concepts must be distinguished. Hazard is the flood-producing physical event; exposure is the people, assets, settlements and cropland in harm's way; vulnerability is the set of conditions making exposed populations susceptible to loss; and risk is the interaction of all three. Conflating them would wrongly imply that greater damage in 2022 proves a greater physical hazard.

The evidence supports a clear hazard-profile distinction. The 2010 floods were, in the official assessment, concentrated along the main rivers and caused by bank overflow and

embankment breaches, inundating over 100,000 square kilometres across 78 districts (Government of Pakistan et al., 2012). Flooding began in the northern mountains in late July and propagated down the Indus corridor over several weeks. In contrast, 2022 was driven by rainfall anomalies rather than upstream routing. National August rainfall was 243 per cent above average, the wettest since records began in 1961, with Balochistan at 590 per cent and Sindh at 726 per cent above normal (Copernicus Climate Change Service, 2022). All eight monsoon depressions of the season tracked towards the southern provinces, producing combined riverine, urban and flash flooding (UNOCHA, 2022).

The distinction holds with one refinement: 2010 also included flash flooding in Khyber Pakhtunkhwa, and 2022 included riverine peaks on the Indus, a difference of dominance, not exclusivity. On climate influence, attribution must be stated carefully. World Weather Attribution (2022) found five-day maximum rainfall over Sindh and Balochistan is now roughly 75 per cent more intense than in a climate not warmed by 1.2 degrees Celsius, but reported large uncertainties from high regional rainfall variability and could not fully quantify the anthropogenic share. Climate change plausibly intensified the 2022 hazard; it does not by itself explain the losses.

3. Risk & Vulnerability Assessment

Table 1 sets out the principal indicators.

Indicator	2010 floods	2022 floods	Comparative significance
Dominant hazard type	Riverine flooding along the Indus; bank overflow and embankment breaches	Rainfall-dominated: combined pluvial, flash and riverine flooding	Different physical processes; lead time and warning value differed fundamentally
Worst-affected areas	Khyber Pakhtunkhwa, then Punjab and Sindh along the river	Sindh and Balochistan; 84 districts declared calamity-hit	Exposure shifted to the poorest, least-drained provinces

Indicator	2010 floods	2022 floods	Comparative significance
	corridor; 78 districts		
Deaths	1,985	1,739	Slightly lower in 2022 despite far greater reach
Injured	2,946	12,867	Suggests sudden-onset impact mechanisms
Population affected	About 20.2 million	About 33 million	63% wider human reach in 2022
Housing damaged or destroyed	About 1.6 million (some sources: up to 2.1 million)	2,288,481 (897,014 destroyed; 1,391,467 partially damaged)	Comparable scale; 2022 hit mud-built rural housing
Cropland affected	About 2.4 million hectares	About 1.7 million hectares	2010 affected more farmland, yet 2022 cost the farm sector more
Livestock lost	About 450,000	1,164,270	Reflects lost asset base among the rural poor
Economic assessment	US$9.7 billion damage (DNA)	US$14.9 billion damage; US$15.2 billion losses; US$16.3 billion needs (PDNA)	Not directly comparable: inflation and wider PDNA scope

Figures for 2010 vary across authoritative sources and are reported here at the mid-range of published official estimates.

Strikingly, mortality did not scale with reach: the 2022 event affected roughly 63 per cent more people than 2010 yet killed marginally fewer. Flood type largely explains this. Slow-

rising riverine water on the flat plains of Punjab and Sindh in 2010, combined with longer advance notice from the Flood Forecasting Division, allowed populations to relocate and move most of their livestock (Shabir, 2013). In 2022 the killing mechanism differed: sudden pluvial and flash flooding, collapse of mud-built housing, and a fourfold higher injury count of 12,867 (NDMA, 2022), indicating rapid-onset impacts rather than gradual inundation.

Why, then, were aggregate losses so much greater in 2022? The answer lies in exposure and vulnerability rather than hazard magnitude alone. The 2010 hazard tracked a river corridor crossing provinces of mixed prosperity; the 2022 hazard settled over Sindh and Balochistan, which recorded around 70 per cent of total damages and losses (Government of Pakistan, 2022). These are Pakistan's poorest provinces, with unconsolidated housing, poor drainage and near-total dependence on rain-fed agriculture and livestock. Standing water persisted for months because the lower Indus flows above the surrounding plain, so overflow cannot return to the channel (Ali, 2024). The result was a livelihood shock rather than transient inundation: 8.4 to 9.1 million people at risk of poverty and 4.3 million workers affected (International Labour Organization, 2022), with over 1.16 million livestock lost (NDMA, 2022), stripping the asset base of households least able to rebuild.

Vulnerable groups bore this asymmetrically. In 2022, children accounted for 647 of 1,739 deaths and roughly a third of all deaths and injuries (UNOCHA, 2022), while some 650,000 pregnant women required maternal health services amid more than a thousand damaged health facilities in Sindh alone (UNFPA Pakistan, 2022). Comparable gendered exposure occurred in 2010; the fuller 2022 record reflects improved assessment capacity, not a new phenomenon. Monetary comparison requires caution: 2010 reports a damage-and-needs assessment, whereas 2022 separates damages, losses and reconstruction needs across a wider scope, with twelve years of inflation and asset growth intervening. The totals are not like-for-like.

4. Community Resilience Factors

Both events revealed that formal systems arrive after communities have already acted. In 2010 and again in 2022, initial rescue, sheltering and evacuation depended on kinship networks, village elders, landowners and religious institutions, with mosque loudspeakers

the de facto rural warning channel. This social capital was decisive in both, yet was never institutionalised between them.

A major difference lay in the coping capacity that survived. In 2010, riverine timing preserved much of the livestock base, so households retained productive assets. In 2022, prolonged standing water destroyed seed stock, livestock and the following planting window at once, exhausting local coping mechanisms. Indigenous knowledge also proved unevenly transferable: communities along the Indus read river-stage cues developed over generations, but populations in historically arid Balochistan and upper Sindh had no experiential template for rainfall of that magnitude.

Community integration nonetheless remained shallow in both events. Preparedness stayed top-down and season-based, awareness was concentrated in short pre-monsoon campaigns rather than year-round education, and communities were treated as recipients of relief rather than participants in warning, evacuation and recovery design (Ali, 2024).

5. Scientific & Institutional Gaps

Pakistan's capacity did improve materially between the events. The National Disaster Management Act 2010 gave statutory footing to the NDMA and to provincial and district authorities; the National Disaster Risk Reduction Policy 2013 sought to align dispersed activity under a common framework (NDMA, 2013); and the Federal Flood Commission's fourth National Flood Protection Plan extended structural and non-structural planning. Technically, the PMD's Flood Forecasting Division expanded radar, telemetry and model-based river routing, while remote sensing, GIS and hydrological modelling became routine inputs to hazard assessment, with machine learning emerging as a means of refining prediction from historical datasets (Ali, 2024).

If capability improved, why was 2022 still catastrophic? Four evidence-supported gaps stand out. First, forecasting skill is hazard-specific: the system was built around riverine prediction on the Indus, precisely the 2010 problem, and performed less well for localised convective rainfall and hill-torrent flash floods, where useful lead time is measured in hours. Second, monitoring coverage was thinnest exactly where 2022 struck, with limited radar reach and sparse gauges in Balochistan and upper Sindh. Third, implementation stayed reactive: policy was made federally while provincial and district authorities retained limited staffing, equipment and trained personnel, causing communication

delays between central and local agencies (Ali, 2024). Fourth, and most consequentially, nothing in the reform package addressed exposure, as settlement and cultivation kept expanding into floodplains and hill-torrent paths without enforceable riverine land-use law (Ali, 2024; Manzoor et al., 2022). Better forecasting cannot offset more assets placed in harm's way.

6. Mitigation Strategies & Best Practices

The comparison points to a rebalancing of structural and non-structural measures. Structurally, 2010 exposed the fragility of embankments, whose breaches often caused greater harm than their absence would have, because protection encouraged intensified land use behind them (Ali, 2024); post-2010 investment nonetheless stayed embankment-centred. In contrast, 2022 was a drainage failure as much as a river failure, since Sindh and Balochistan could not evacuate standing rainwater at all. The structural priority is therefore drainage and flood-channel capacity in the southern plains, plus flood-resilient rural housing, rather than further linear defences alone.

Non-structurally, both events make the case for risk-informed land-use planning and enforceable floodplain regulation, since exposure growth was their common factor. Anticipatory action financing, releasing resources on forecast rather than impact, addresses the specific 2022 failure of warnings arriving without the means to act.

International practice is instructive where it matches Pakistan's demonstrated deficits. Bangladesh's community-centred preparedness model speaks to the last-mile weakness evident in both events, and nature-based urban drainage addresses the pluvial problem that 2022 exposed (Ali, 2024).

7. Risk Communication & Early Warning

The two warning environments differed substantially in capability. In 2010, forecasting rested on a limited observational network, and a judicial commission later identified the absence of modern early warning arrangements, alongside unfulfilled pre-disaster obligations, as a central failing. By 2022 the PMD issued seasonal outlooks and flood advisories, the NDMA coordinated through an established emergency operations structure, and national flood-extent mapping was produced from satellite data within a day.

Yet the comparison establishes a decisive distinction: forecasting the hazard is not the same as people receiving, understanding, trusting and acting on a warning. In 2022 forecasts anticipated the season correctly, but many communities reported effectively zero usable lead time between warning and action, and digital dissemination proved least reliable when most needed, as mobile networks, electricity and internet failed (UNESCO, 2026). Warnings that did reach households were often general rather than impact-based.

Similar last-mile weaknesses recur across Pakistani flood operations, where alerts by television, radio, SMS and public address still meet non-compliance driven by mistrust of authorities, attachment to property and livestock, and unfamiliarity with the risk (Ali, 2024). Gender-sensitive delivery was largely absent in both events, with warnings channelled through male-dominated public spaces where women's mobility is constrained. Technological improvement therefore did not translate proportionately into protective action.

8. Policy Recommendations

First, the PMD should extend forecasting from riverine prediction towards nowcasting and impact-based forecasting for pluvial and flash flooding, prioritising radar and gauge density in Balochistan and upper Sindh, since the system was calibrated to 2010's hazard and under-performed against 2022's.

Second, PDMAs and DDMAs require funded, pre-positioned evacuation and stock plans, since the 2022 gap lay between an accurate forecast and local capacity to execute.

Third, the NDMA, with provincial governments, should institutionalise last-mile dissemination that survives infrastructure failure, including sirens, mosque networks, community radio and trained volunteers, with gender-sensitive channels. Both events showed digital-only delivery fails precisely at the moment of need.

Fourth, provincial land-use and irrigation departments, with the Federal Flood Commission, should enforce floodplain and hill-torrent zoning and embed flood-risk mapping in development approvals, since unregulated exposure growth is the factor common to both disasters.

Fifth, the FFC should rebalance structural investment towards drainage and flood channels in the southern plains alongside embankment maintenance, reflecting 2022's drainage failure. Finally, the NDMA and Ministry of Planning should mainstream

anticipatory action financing and climate adaptation into recovery, so reconstruction reduces the exposure that produced the loss.

9. Conclusion

The comparison reveals that the nature of Pakistan's flood risk is changing. The 2010 disaster was a river-management problem, generated upstream and propagating predictably along a known corridor. The 2022 disaster was a rainfall problem, generated locally over historically arid provinces with negligible drainage, striking populations whose poverty and asset dependence converted inundation into destitution. The hazard moved from the channel to the sky, and the risk from the corridor to the poorest districts.

Two conclusions follow. First, greater damage in 2022 does not establish that disaster management deteriorated: deaths fell marginally despite far wider reach, suggesting response capacity improved even as exposure and vulnerability grew faster. Second, reform between the events concentrated on detecting hazards and coordinating relief while largely omitting reduction of exposure and vulnerability, where the losses were actually generated.

Resilience therefore depends on integration rather than any single instrument. Climate adaptation and science-based planning must define where development is permitted; institutional capacity must reach the district level where warnings become action; technology must serve impact-based, locally intelligible communication; and social capital and local knowledge must be built into preparedness rather than relied on informally after failure. The evidence is unambiguous: Pakistan has substantially improved its ability to see floods coming, and has not correspondingly reduced what floods can destroy.

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PARTICIPANT RESEARCH PAPER

Comparative Analysis of the 2005 Kashmir Earthquake and the 2023 Türkiye-Syria Earthquakes

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Abstract

This paper compares the 8 October 2005 Kashmir earthquake in Pakistan-administered Azad Jammu and Kashmir (AJK) with the 6 February 2023 Kahramanmaraş earthquake sequence that affected Türkiye and Syria. Although the earthquakes occurred in different geological, political, and social settings, both disasters show that earthquake losses are shaped not only by the strength of shaking but also by where people live, how buildings are constructed, how institutions enforce safety rules, and how quickly assistance can reach affected communities. Kashmir illustrates the severe consequences of weak construction, mountainous isolation, limited preparedness, and damaged health and education systems, followed by important institutional improvements through ERRA and NDMA. Türkiye demonstrates that even a country with modern earthquake standards can experience enormous losses when building rules are poorly enforced and unsafe buildings remain in use. Syria adds the effects of conflict, displacement, damaged infrastructure, and restricted humanitarian access. The comparison supports policies that combine safer construction, stronger planning, community preparedness, reliable warning and communication systems, better data sharing, and accountable disaster governance. It also argues that resilience should be built before earthquakes occur rather than mainly during reconstruction.

Keywords: Climate adaptation; Disaster governance; Earthquake resilience; Seismic vulnerability; Urban planning

1. Introduction

Earthquakes are natural hazards, but disasters are largely shaped by social and human conditions. The 2005 Kashmir earthquake occurred in the Himalayan collision zone, where the Indian Plate moves beneath the Eurasian Plate. The 2023 Türkiye-Syria earthquakes occurred mainly along the East Anatolian Fault system within the broader tectonic setting of Anatolia. Both regions are highly earthquake-prone, but their levels and forms of risk differ because of settlement patterns, building quality, poverty, infrastructure, governance, and previous conflict (USGS, 2023a; UNDRR, 2015).

The central problem addressed in this paper is why two major earthquake disasters produced such extensive and uneven human and economic consequences. The rationale for comparison is that both cases offer lessons for Disaster Risk Reduction (DRR), while also showing that solutions must be adapted to local conditions. The paper therefore examines hazard characteristics, exposure and vulnerability, social impacts, community resilience, institutional weaknesses, mitigation, risk communication, and long-term policy. The analysis focuses on lessons that can be applied to earthquake-prone and climate-vulnerable regions more broadly.

2. Regional Context & Hazard Profile

The Kashmir earthquake had a moment magnitude (Mw) of 7.6 and struck on 8 October 2005. It caused severe damage in AJK and parts of Khyber Pakhtunkhwa, particularly in mountainous communities where roads and communications were easily disrupted. The 2023 Türkiye-Syria disaster began with an Mw 7.8 earthquake on 6 February, followed roughly nine hours later by another major event of Mw 7.5. The sequence affected a very large urban and rural area and produced widespread building collapse (USGS, 2023a).

In DRR, four concepts are especially important. A hazard is a potentially damaging physical event; exposure refers to people and assets located where the hazard may occur; vulnerability refers to how easily those people or assets can be harmed; and capacity refers to the resources and abilities available to prepare, respond, and recover. A useful conceptual relationship is Risk = Hazard × Exposure × Vulnerability / Capacity. The equation should not be treated as a precise mathematical prediction; rather, it emphasizes that strong earthquakes become disasters when exposure and vulnerability are high and capacity is insufficient (UNDRR, 2015).

Both regions also have long histories of seismic activity. Kashmir's mountainous terrain increases risks from landslides, road isolation, and difficult access. Türkiye's affected provinces contained dense urban populations, large numbers of older buildings, and millions of residents, including displaced Syrians. The World Bank estimated direct physical damage in Türkiye at approximately US$34.2 billion. In Syria, direct physical damage was estimated at about US$5.1 billion in areas already heavily affected by years of conflict and displacement (World Bank, 2023a, 2023b).

Earthquakes occur when tectonic forces gradually build stress within the Earth's crust until the accumulated stress exceeds the strength of rocks along a fault. The fault then ruptures suddenly, releasing stored energy as seismic waves that produce ground shaking. In Kashmir, the collision of the Indian and Eurasian plates creates strong compressional forces, contributing to reverse or thrust faulting, in which one block of crust moves upward relative to another. This mechanism can produce intense vertical as well as horizontal ground motion and, in mountainous terrain, can trigger landslides. In contrast, the 2023 Türkiye–Syria earthquakes occurred mainly along the East Anatolian Fault system, where tectonic forces produced left-lateral strike-slip movement. Here, large blocks of crust moved horizontally past one another, producing a very long rupture and intense lateral ground motion across a wide, densely populated region. Thus, the two earthquakes differed not only in magnitude but also in the way tectonic energy was released, which influenced the geographical distribution and nature of damage.

Geophysical Mechanism of the Earthquakes

3. Risk & Vulnerability Assessment

The Kashmir earthquake exposed the dangers of poorly constructed housing. Many buildings used unreinforced masonry and other forms of non-engineered construction that were not designed to withstand strong earthquake shaking. Weak connections between walls and roofs, poor materials, and limited enforcement of safety standards contributed to collapse. Damage extended beyond homes to roads, bridges, schools, hospitals, water systems, electricity, and livelihoods. The 2005 damage assessment found extensive losses in the health and education sectors, reducing access to essential services precisely when demand was highest (World Bank & ADB, 2005).

The 2023 Türkiye case shows a different but related problem. Türkiye had established earthquake standards, yet many buildings were old, poorly maintained, irregularly modified, or insufficiently inspected. Researchers identified common problems including weak ground floors, inadequate reinforcement, poor concrete quality, and structural irregularities. Buildings with weak ground floors can be especially dangerous because shops or open spaces may reduce the support available at street level, causing the lower floor to fail first during strong shaking (Pujol et al., 2024).

Regulation alone is therefore insufficient if it is not enforced. Türkiye's building amnesty policies, including the 2018 zoning amnesty, allowed some structures that did not fully meet planning or safety requirements to receive legal recognition. This illustrates a major governance lesson: disaster risk can increase when short-term political or economic incentives weaken long-term safety standards (Reuters, 2023).

Syria faced an additional layer of vulnerability. Years of conflict had already damaged housing, hospitals, schools, roads, water systems, and public institutions. The earthquake therefore struck a population with reduced physical, financial, and institutional resources. Women, children, older adults, persons with disabilities, displaced populations, and female-headed households can experience greater barriers to evacuation, healthcare, shelter, documentation, and recovery. Gender-sensitive DRR must therefore recognize that households are not internally equal and that disaster policies can affect women and men differently (UN Women, 2023).

4. Community Resilience Factors

Kashmir's response relied heavily on government and military mobilization. Pakistan's armed forces provided search and rescue, transport, helicopters, medical assistance, and access to isolated communities. At the same time, local families, religious organizations, volunteers, and community networks provided food, shelter, information, and emotional support. Strong social relationships were therefore an important form of resilience when formal infrastructure was damaged (Thompson, 2010).

Türkiye also experienced extensive volunteer participation, although the size and complexity of the disaster created major coordination challenges. In Syria, local civil society groups and volunteer rescue organizations were particularly important in northwest areas. However, the Syria case also demonstrates the limits of community

resilience when humanitarian access is restricted by conflict and political divisions. Community networks can reduce suffering, but they cannot replace functioning institutions, infrastructure, and reliable humanitarian access.

5. Scientific & Institutional Gaps

Several gaps are evident across the two cases. First, scientific knowledge does not automatically become public safety. Earthquake monitoring and hazard maps have limited value if they do not guide land-use decisions, construction permits, infrastructure investment, and emergency planning. Second, building regulations require independent and consistent enforcement. Third, disaster information is often divided among government agencies, municipalities, NGOs, utilities, and international organizations, making rapid comparison and decision-making difficult.

A further opportunity is the greater use of satellite imagery, drones, geographic information systems, and artificial intelligence for rapid damage assessment. Machine-learning tools can help identify damaged buildings and prioritize field inspections, but they should support rather than replace engineers and local knowledge. Human verification remains important where imagery is incomplete or where an incorrect classification could influence life-safety decisions.

6. Mitigation Strategies & Best Practices

The first priority should be identifying buildings and facilities most likely to cause large social losses. Schools, hospitals, bridges, water facilities, and densely occupied residential buildings should receive priority for safety assessment and strengthening. Depending on the building, measures may include reinforcing walls and columns, improving connections, strengthening foundations, or using newer technologies such as seismic isolation. New construction should be based on reliable earthquake-resistant design and independent inspection.

Non-structural measures are equally important. Risk-sensitive zoning can prevent development in highly exposed areas, while emergency routes and backup systems can improve response. Communities should receive regular earthquake drills, school safety education, first-aid training, and clear guidance on what to do during shaking. Pakistan's experience after 2005 is important because the creation of ERRA and the National Disaster Management Authority helped turn lessons from a disaster into more organized

national disaster management. Türkiye's AFAD also provides substantial national response capacity, but the 2023 earthquake showed that national strength needs to be combined with strong local coordination, reliable communication, and effective building inspection.

7. Risk Communication & Early Warning

Earthquake early warning cannot usually predict an earthquake before it begins, especially close to the epicenter. Its practical value is to provide a short period of warning before stronger shaking reaches some locations. Warning systems are most useful when connected to simple public actions, such as moving away from dangerous objects, stopping industrial processes, or automatically protecting critical systems.

The Sendai Framework emphasizes people-centered disaster information and increased access to multi-hazard early warning systems (UNDRR, 2015). Warnings should therefore be understandable, available in appropriate languages, accessible to people with disabilities, and delivered through several channels. In mountainous AJK, the major challenge is reaching isolated communities after roads and communications are damaged. In large Turkish cities, the challenge includes network congestion, large populations, misinformation, and uncertainty about damaged buildings. Syria adds the problem of humanitarian access and political fragmentation.

8. Policy Recommendations

First, governments should establish integrated risk governance linking geological agencies, municipalities, planning authorities, emergency services, universities, and civil society. Second, every high-risk city should maintain an updated building inventory and independent inspection system. Unsafe buildings should be strengthened, replaced, or managed through transparent relocation programs. Political or administrative policies should never allow unsafe construction to become effectively acceptable.

Third, humanitarian agencies should develop pre-agreed cross-border arrangements for disasters affecting conflict zones or neighboring countries. The Syria experience demonstrates how delays in humanitarian access can turn an already severe disaster into a longer humanitarian emergency. Fourth, hospitals, schools, water systems, and communication networks should have continuity plans and backup supplies. Fifth,

preparedness should deliberately include women, persons with disabilities, older adults, displaced populations, and local community leaders.

Finally, disaster planning should increasingly consider multiple risks together. Climate change can intensify heat, flooding, landslides, water stress, and other pressures on already vulnerable communities. DRR and climate adaptation should therefore be planned together rather than treated as completely separate policy areas. Governments should also develop responsible AI-supported damage assessment systems using satellite data, local reports, and engineering verification.

9. Conclusion

The comparison of Kashmir and Türkiye-Syria shows that earthquake disasters are not determined by magnitude alone. They are shaped by the interaction between hazard, exposure, vulnerability, and institutional capacity. Kashmir demonstrates the consequences of weak construction, geographic isolation, limited preparedness, and damaged essential services, while also showing how reconstruction can strengthen future disaster governance. Türkiye demonstrates that strong formal standards are insufficient when inspection and enforcement are inconsistent. Syria illustrates how conflict and displacement can greatly deepen disaster vulnerability.

The most important lesson is therefore preventive: resilience must be built before the next earthquake. Safer urban planning, enforceable construction standards, resilient critical infrastructure, community preparedness, reliable communication, shared disaster data, and transparent institutions are more effective than relying on emergency response alone. Long-term DRR should be treated as a continuous public-policy responsibility, not a temporary activity that begins after a disaster.

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PARTICIPANT RESEARCH PAPER

Drought Conditions in District Sanghar, Sindh

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Abstract

Drought in Sanghar is not only a rainfall deficit; it is a compound risk produced by heat, unreliable surface-water delivery, groundwater constraints, crops and livestock exposure, and unequal household capacity to absorb losses. This desk-based assessment synthesizes official alerts and plans, the 2023 population census, the 2024 agricultural census, food-security analyses, and peer-reviewed climate and groundwater studies. In March 2025, Sanghar was under mild drought while Sindh had accumulated a 62 percent rainfall deficit since September 2024. Exposure is substantial: the district has 2.31 million residents, 72.7 percent rural population, and 685,048 acres of cropped area. Vulnerability is intensified by dispersed settlements, a rural female literacy rate of 24.1 percent, contaminated or saline groundwater in sampled locations, and dependence on climate-sensitive wheat, cotton, and livestock. Acute food insecurity improved from the 2019 emergency analysis, yet 15 percent of the analyzed rural population was projected in IPC Phase 3 during April–September 2026. The paper recommends a union-council-scale, impact-based drought system linking climate, canal, groundwater, vegetation, crop, livestock, nutrition, and market indicators to predefined actions and financing. Water governance, inclusive communication, resilient agriculture, and accountable local coordination are central to preventing recurrent drought stress from becoming a livelihood emergency.

Keywords: Anticipatory action; climate-smart agriculture; drought early warning; Sanghar; water security

1. Introduction

Drought is a slow-onset hazard produced through meteorological, agricultural, hydrological, and socioeconomic processes. Rainfall anomaly becomes a disaster when exposure and limited coping capacity produce crop loss, livestock stress, debt, poorer diets, or displacement. Sanghar needs this systems perspective because irrigated agriculture coexists with arid, sparsely settled areas, and floods and droughts can affect the same households across seasons. The response must therefore move from hazard reporting to anticipatory risk management (UNDRR, 2021; World Meteorological Organization [WMO], 2024).

The policy problem is fragmented information. Climate, water, vegetation, agriculture, nutrition, and market data sit with different institutions and use different scales. Official products also describe Sanghar differently: PDMA's drought webpage places it in a very severe hazard class, whereas the Provincial Disaster Profile records drought as common but historically low in severity. Different methods and periods may explain the divergence, underscoring the need for transparent metadata and shared thresholds (PDMA Sindh, n.d.-a, n.d.-b).

Objectives

- Describe Sanghar's drought context and the main physical and socioeconomic drivers of risk.
- Assess exposure, vulnerability, food-security implications, and existing resilience factors.
- Identify scientific, monitoring, and institutional gaps that delay early action.
- Propose feasible mitigation, warning, and policy measures for district and provincial authorities.

Research approach and scope

This desk review covers historical evidence from 1997 onward, meteorological reporting through March 2025, and a food-security projection through September 2026. It triangulates official statistics and plans with peer-reviewed studies and IPC analyses. It includes no new household or hydrological survey and does not treat an IPC food-security phase as a drought classification. The findings should guide planning and field verification, not replace a current rapid assessment.

2. Regional Context and Hazard Profile

Sanghar covers 10,728 km² across six talukas. Its 2023 population was 2,308,465, including 1,677,683 rural residents (72.68 percent). Khipro accounts for about 55 percent of district land but has only 61.81 persons per km², creating a major last-mile monitoring and service-delivery challenge (Pakistan Bureau of Statistics [PBS], 2023a).

Table 1. Selected district indicators and drought relevance

Indicator	Evidence	Drought relevance
Population	2,308,465 people; 72.68% rural	Large rural caseload; dispersed delivery
Territory	10,728 km²; Khipro 5,933 km²	Large arid-area surveillance burden
Literacy	43.66% overall; 24.09% rural female	Voice, pictorial, and intermediary channels needed
Cropped area	685,048 acres; wheat 302,990; cotton 247,139	Income, food, and farm-employment exposure
Selected livestock	370,599 cattle; 354,986 buffalo; 107,618 sheep; 853,620 goats; 6,704 camels	Water, fodder, health, and distress-sale risks

Note. Population and literacy: PBS (2023a, 2023b). Agriculture and livestock: PBS (2026). Livestock categories are reported separately and are not household count.

Sanghar's drought profile combines climate variability and irrigation dependence. PDMA records episodes in 1997–2000 and 2013–2014. Remote-sensing research also finds recurrent severe to extreme spring and summer drought across Sindh during 2001–2023, with vegetation health declining as land-surface temperature rises (Khan et al., 2026). On 25 March 2025, PMD classified Sanghar under mild drought; Sindh rainfall since 1 September 2024 was 62 percent below normal and lower-Pakistan temperatures were 2–3°C above normal, increasing the risk of rapid intensification (PDMA Sindh, 2025b).

Table 2. Interpreting key evidence across time and measurement systems

Period	Finding	Planning interpretation
1997–2000; 2013–2014	Documented drought episodes	Recurrent hazard
Oct. 2018–Sept. 2019	Drought-affected areas assessed in IPC Phase 4	Severe livelihood and food-access stress
Sept. 2024–Mar. 2025	Sanghar mild drought; Sindh rainfall deficit 62%	Escalate monitoring before widespread impact
2004–2023 composite	Ranked 2nd of 23 districts; index 65.8	High multi-hazard agricultural vulnerability
Apr.–Sept. 2026 projection	Overall IPC Phase 2; 15% of rural population in Phase 3	Food insecurity; not a drought severity scale

Note. Sources: Ahmed et al. (2026); IPC (2019, 2026); PDMA Sindh (n.d.-b, 2025b). Percentages and categories refer to their stated analysis periods and should not be compared as a single time series.

3. Risk and Vulnerability Assessment

Agriculture, livestock, and income

Agriculture is the main pathway from drought to household welfare. Sanghar has 685,048 cropped acres, including 302,990 acres of wheat and 247,139 of cotton; 23 percent of reported wheat area was unirrigated, while irrigated farms remain sensitive to canal timing. The district also holds over 1.69 million cattle, buffalo, sheep, goats, and camels in the listed categories. Water deficits can therefore reduce yields and labour while increasing fodder scarcity, animal stress, and distress sales (PBS, 2026). A composite index ranked Sanghar second among 23 Sindh districts (65.8), indicating broad agricultural disaster vulnerability rather than drought alone (Ahmed et al., 2026).

Water security and health

Groundwater buffers have failed rainfall or canal deliveries, but quality and sustainability constrain their safe use. Among 74 samples from Sanghar, Khipro, and Jam Nawaz Ali, several contaminants exceeded World Health Organization limits, and, by some irrigation criteria, 58.33 percent were unsuitable (Landar et al., 2024). Expanding pumping alone may transfer risk to health, soil salinity, energy costs, and aquifer depletion; quality testing and abstraction monitoring must accompany access measures.

Social vulnerability and food security

Rural isolation, poverty, insecure tenancy, disability, age, and limited credit reduce households' ability to absorb a failed season. Women often manage food, water, small livestock, and care work while controlling fewer assets and information channels. Female literacy is 33.85 percent versus 53.11 percent for males, and rural female literacy is 24.09 percent (PBS, 2023b). Text-only alerts or landowner-only consultation will therefore exclude many affected people.

In 2019, drought-affected Sanghar areas entered an IPC Phase 4 Emergency analysis, showing how environmental stress can coincide with severe livelihood and food-access deficits (IPC, 2019). For April–September 2026, the district was projected overall in IPC Phase 2, with 251,633 rural residents15 percent of those analyzed in Phase 3 or worse and none in Phase 4. This improvement does not remove chronic vulnerability or prove the absence of drought because food security also reflects prices, income, assistance, crops, and prior shocks (IPC, 2026).

4. Community Resilience Factors

Sanghar has practical assets on which resilience can be built crop and livestock diversity, farmer knowledge of variable seasons, public agriculture and livestock services, and existing development platforms. The FAO-led Transforming the Indus Basin project included Sanghar in work on climate information, climate-resilient agriculture, and on-farm water management, while post-flood livelihood support has demonstrated ways to reach women sharecroppers and livestock keepers with cash, inputs, feed, and training (FAO, 2020, n.d.). These initiatives offer delivery channels, but participation and benefits should be verified by taluka, gender, disability, tenancy status, and landholding size. Resilience should be measured by the ability to maintain essential consumption and

productive assets without high-interest debt, distress migration, reduced meals, or premature livestock sales.

5. Scientific and Institutional Gaps

The main scientific gap is not routinely published district baseline linking hazard indicators to impacts. Rainfall and temperature alone cannot show canal reliability, groundwater depth and quality, soil moisture, fodder, or household access. NDVI and VHI improve coverage but require ground validation against crop calendars, irrigation, and land cover. PDMA's contingency plan notes the difficulty of estimating district caseloads for a slow-onset hazard and calls for agreed thresholds, real-time water information, and expanded monitoring (PDMA Sindh, 2025a).

Data ownership and action authority are dispersed across meteorological, disaster, water, agriculture, livestock, health, local-government, and social-protection agencies. Warnings have little value without assigned responsibility for verification, financing, and reporting. Other gaps are inconsistent hazard labels, limited union-council details, weak records of mobile livestock and informal settlements, and insufficient disaggregation. Predictive models can prioritize field checks, but opaque scores should not determine assistance without published inputs, testing, and appeal.

6. Mitigation Strategies and Best Practices

Water measures include transparent canal schedules, targeted repair where losses are demonstrated, laser land levelling, soil-moisture conservation, rainwater storage, suitable recharge structures, and conjunctive surface–groundwater planning. Solar-pumping support should include abstraction limits, monitoring, and water-quality safeguards to avoid accelerating depletion or salinity.

Agricultural measures should combine locally tested drought- and heat-tolerant seed, adjusted sowing, diversification, efficient irrigation, extension, and climate-informed decisions. Livestock protection requires fodder reserves, vaccination, mobile veterinary coverage, and water-point plans. Shock-responsive protection should pre-verify households and enable early cash, nutrition screening, service continuity, and livelihood grants before productive assets are sold. Index insurance may complement not to replace public risk reduction and must be tested for basis risk. These measures align with Pakistan's National Adaptation Plan (Government of Pakistan, 2023).

7. Risk Communication and Early Warning

An impact-based warning system should combine SPI or SPEI, heat and forecasts with canal supply, water-point status, groundwater depth and salinity, soil moisture, NDVI or VHI, crop and livestock condition, prices, nutrition, and verified community reports. Thresholds must be calibrated against local losses; the matrix below is a governance framework, not a technical standard (WMO, 2024).

Table 3. Illustrative district drought trigger–action matrix

Stage	Converging evidence	Pre-agreed action
Readiness	Seasonal risk elevated; no verified impact	Update registries, inspect water points, pre-position supplies
Watch	Climate anomaly plus declining vegetation, soil moisture, or canal supply	Verify by taluka; update dashboard; protect critical water
Warning	Multiple indicators deteriorate; impacts verified	Release funds; target feed, water, cash, health, and veterinary support
Early response	Loss, price, nutrition, or water thresholds crossed	Scale aid, protect assets, publish gaps, reassess fortnightly

Note. Indicator selection follows multi-hazard early-warning principles in WMO (2024). Numerical thresholds should be jointly calibrated by PMD, technical departments, PDMA/DDMA, and communities using local impact data.

Messages should state the hazard, people at risk, required action, available help, and update time. Dissemination should combine SMS and WhatsApp with Sindhi and Urdu voice messages, radio, village announcements, pictorial materials, and outreach through agriculture, livestock, health, and women community workers. Hotlines, focal people, and rapid feedback should reveal false alarms, exclusion, and inaccessible services.

8. Policy Recommendations The following measures translate Pakistan's 2026 shift from reactive drought relief toward proactive planning, early warning, local mitigation, and capacity building into district action (Government of Pakistan, 2026).

a. **Establish a District Drought Coordination Cell:** Place it under DDMA leadership with named focal persons from PMD, irrigation, agriculture, livestock, health, local government, social protection, and water agencies. Approve an annual pre-season plan and publish action ownership.

b. **Build a union-council drought baseline and dashboard:** Map population, poverty, disability, women-headed households, tenancy, crops, livestock, drinking-water sources, groundwater quality, canal command, health and nutrition services, and historical losses. Use shared identifiers and documented update schedules.

c. **Adopt calibrated impact triggers with anticipatory finance:** Link multi-indicator stages to ring-fenced actions and spending ceilings before the season. Review performance after each alert and revise thresholds using observed false alarms and missed events.

d. **Govern groundwater as a strategic reserve:** Expand depth, salinity, and contaminant monitoring; publish safe-use maps; license or monitor high-capacity abstraction; and condition pumping support on recharge feasibility, quality testing, and extraction controls.

e. **Scale resilient agriculture and livestock protection:** Prioritize high-risk talukas and smallholders for field-tested seed, efficient irrigation, extension, fodder reserves, animal health, and market support. Track adoption and livelihood outcomes rather than input distribution alone.

f. **Make communication and assistance inclusive:** Use Sindhi and Urdu voice and pictorial formats, involve women and persons with disabilities in message testing, include sharecroppers and mobile herders, and maintain grievance and appeal channels.

g. **Institutionalize learning and public accountability:** Publish seasonal situation reports, intervention coverage, unmet need, groundwater and canal indicators, and after-action findings. An independent review should examine timeliness, targeting, equity, and asset-loss prevention.

9. Conclusion

Sanghar's drought risk is persistent but manageable. Its scale, rural population, agricultural exposure, groundwater constraints, gendered information barriers, and food- security history make rainfall monitoring alone inadequate. evidence with water delivery, groundwater safety, crops, livestock, markets, nutrition, and community verification. Clear roles, pre-arranged finance, and inclusive communication can turn warnings into early action. Long-term risk reduction must conserve water without stimulating extraction, diversify livelihoods, protect productive assets, and measure avoided harmful coping. Union-council data and accountable coordination can shift Sanghar from episodic relief toward anticipatory, equitable, climate-resilient governance.

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PARTICIPANT RESEARCH PAPER

Smart Agriculture Technologies for Climate-Resilient Food Systems: Strengthening Disaster Risk Reduction in Pakistan's Agricultural Sector

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Abstract

Pakistan's agriculture sector, which supports roughly a third of the national workforce and underpins the country's food security, is increasingly exposed to floods, droughts, heatwaves, and erratic rainfall driven by climate change (Accountability Lab Pakistan, 2026). The catastrophic 2022 floods alone caused an estimated $30 billion in damage and losses, inundated close to 9.4 million acres of cropland, and destroyed nearly 4 million acres of farmland along with more than a million livestock (Center for Disaster Philanthropy, 2023; Islamabad Policy Research Institute [IPRI], 2022; Rizq, 2025). This paper examines how smart agriculture technologies — including precision agriculture, the Internet of Things (IoT), artificial intelligence (AI), remote sensing, and drone-based monitoring — can reduce disaster risk and build climate-resilient food systems in Pakistan. Using a desk-based review of academic, government, and institutional sources, the paper maps the country's hazard profile, assesses socio-economic vulnerability, and evaluates community resilience factors, institutional gaps, and existing mitigation strategies. It finds that although Pakistan has made policy progress through its National Climate Change Policy and National Adaptation Plan, adoption of smart agriculture technologies remains constrained by cost, weak extension services, fragmented data systems, and limited last-mile early warning reach. The paper concludes with policy recommendations for integrating smart agriculture into Pakistan's disaster risk reduction (DRR) architecture, emphasizing affordability, gender-inclusive design, and institutional coordination between the Ministry of Climate Change, provincial agriculture departments, and NDMA.

Keywords: climate resilience; disaster risk reduction; food security; Pakistan; precision agriculture; smart agriculture technologies

1. Introduction

Climate change has moved from a long-term projection to a present-day driver of disaster risk in Pakistan. Despite contributing less than one percent of global greenhouse gas emissions, Pakistan is consistently ranked among the countries most vulnerable to climate-related hazards, a paradox widely described in policy circles as a matter of climate justice (IPRI, 2022). Agriculture, which contributes close to a fifth of national GDP and employs a majority of the rural population, sits at the center of this vulnerability: it is simultaneously a victim of climate shocks and a sector whose disruption cascades into food insecurity, livelihood loss, and humanitarian need (Accountability Lab Pakistan, 2026).

The problem this paper addresses is straightforward but urgent: conventional, rain-fed and input-intensive farming systems in Pakistan are no longer able to absorb the frequency and intensity of climate shocks the country now faces. The 2022 monsoon floods, followed by renewed flooding in 2025, demonstrated how quickly a single hazard event can undermine national food stocks, rural incomes, and disaster response capacity (Rizq, 2025). At the same time, a body of international evidence shows that smart agriculture technologies — precision irrigation, IoT-based soil and weather sensors, satellite and drone-based remote sensing, and AI-driven forecasting — can materially reduce climate risk in farming systems by improving resource efficiency, early detection of hazards, and adaptive decision-making (Kabato et al., 2025).

The purpose of this research is to examine the relevance and applicability of smart agriculture technologies to climate-resilient food systems in Pakistan, framed explicitly within a disaster risk reduction lens. The specific objectives are to: (1) profile the regional hazard context and its historical impact on Pakistani agriculture; (2) assess the socio-economic vulnerability of farming communities, with attention to gender and livelihood dimensions; (3) identify existing community resilience factors and institutional or technological gaps; and (4) propose evidence-based mitigation strategies and policy recommendations suitable for NDMA and allied institutions. The scope of the paper is national, drawing primarily on evidence from flood- and drought-affected provinces (Sindh, Punjab, Balochistan, and Khyber Pakhtunkhwa), and it focuses on technologies

that are feasible for smallholder-dominated agricultural systems rather than large-scale commercial farming alone.

2. Regional Context & Hazard Profile

Pakistan's agriculture is shaped by a narrow set of interlocking hazards: riverine and flash flooding along the Indus Basin, glacial lake outburst floods (GLOFs) in the northern mountain ranges, prolonged drought in arid and semi-arid zones such as Tharparkar and parts of Balochistan, and increasingly frequent heatwaves across Sindh and southern Punjab (Ministry of Climate Change [MoCC], 2021). Rainfall patterns have become markedly more erratic, and the country has, within a single calendar year, moved from drought conditions to devastating floods — a pattern documented across the past two and a half decades and starkly visible in 2022 (PMC9708371-cited studies summarized in MoCC, 2021).

The 2022 floods remain the definitive case study of this hazard profile. Triggered by exceptionally intense monsoon rainfall combined with glacial melt, the floods affected 84 districts, submerged an estimated 9.4 million acres of cropland — 4.8 million acres in Sindh and 2.7 million acres in Punjab alone — and caused roughly $30 billion in total damage and economic losses (Center for Disaster Philanthropy, 2023; IPRI, 2022). The Congressional Research Service (2022) noted that weak enforcement of river-bank construction restrictions and unresolved lessons from the 2010 floods compounded the disaster's severity, illustrating that hazard exposure in Pakistan is not purely climatic but is amplified by governance and land-use failures.

Historically, floods of comparable or lesser scale occurred in 2010, 2011, and intermittently through the 2015-2020 period, while drought years — most notably in Tharparkar — have recurred with increasing frequency. Definitionally, it is useful to distinguish between hazard (the flood, drought, or heatwave event itself), exposure (the population, cropland, and livestock located in its path), vulnerability (the pre-existing socio-economic and physical conditions that determine the severity of impact), and risk (the resulting probability and scale of loss). Pakistan's agricultural risk profile is high precisely because exposure and vulnerability compound: a largely rain-fed, smallholder-dominated farming system sits directly within flood plains and drought-prone belts that are also home to the country's poorest rural households (MoCC, 2021).

3. Risk & Vulnerability Assessment

The socio-economic impact of climate hazards on Pakistani agriculture is severe and multidimensional. Following the 2022 floods, an estimated 10.5 million people faced high levels of acute food insecurity, a figure projected to rise toward 11.8 million in subsequent months, while UNICEF reported that over 3.5 million children were affected across the 84 flood-hit districts (Action Against Hunger, 2023). Of the $816 million required under the revised Pakistan Floods Response Plan, $269.4 million was allocated specifically to the food security and agriculture sector — underscoring how central agricultural recovery is to broader humanitarian response (Center for Disaster Philanthropy, 2023).

Livelihood disruption is most acute among Pakistan's roughly 60% of rural households that depend directly on farming and livestock (Rizq, 2025). Livestock, which accounts for nearly 60% of agricultural value addition, is particularly exposed to heat stress: rising temperatures reduce milk yields, increase disease incidence, and raise mortality among cattle and buffalo, especially in Sindh and southern Punjab (Accountability Lab Pakistan, 2026). Because livestock represents both a nutritional and financial safety net for millions of households, its loss compounds food insecurity well beyond the immediate disaster period.

Vulnerable groups bear disproportionate impact. Women, who play a significant but often unrecognized role in on-farm labor, livestock care, and post-harvest processing, face compounded vulnerability: displacement disrupts their access to markets, health services, and decision-making platforms, while gender-blind relief and agricultural-extension systems frequently fail to reach female-headed households. Smallholders and tenant farmers, who typically lack land titles, formal credit access, or crop insurance, are least able to absorb shocks or invest in recovery. Geographically, districts such as Rajanpur, Taunsa, and Dera Ghazi Khan — which sit downstream of flash-flood-prone mountain ranges and are key contributors to national food stocks — face repeated exposure that erodes their capacity to recover between events (Rizq, 2025).

Susceptibility factors that heighten this vulnerability include heavy reliance on rain-fed cultivation, limited irrigation infrastructure, degraded flood-plain drainage in rapidly urbanizing cities such as Karachi, Lahore, and Rawalpindi, and weak crop-loss data systems that delay compensation and recovery planning (Rizq, 2025). Collectively, these

factors mean that a single hazard event in Pakistan tends to produce cascading, multi-year impacts on food security rather than a short-term shock alone.

4. Community Resilience Factors

Despite high exposure, Pakistani farming communities possess meaningful resilience capacities that mitigation strategies should build upon rather than displace. Social capital — including kinship networks, biradari (clan) support systems, and community-level labor-sharing arrangements — plays a significant role in enabling rapid, informal recovery immediately after disaster events, often preceding formal government or humanitarian assistance. Indigenous knowledge, particularly around flood-recession farming, drought-tolerant local crop varieties, and traditional water-harvesting techniques in arid regions such as Balochistan and Tharparkar, continues to inform coping strategies, even as formal agricultural extension services often overlook this knowledge base (MoCC, 2021).

Local coping mechanisms observed after the 2022 floods included informal seed-sharing among neighboring farmers, temporary livestock relocation to higher ground, and diversification into kitchen gardening to offset lost staple crop production — an approach actively promoted by institutions such as Zarai Taraqiati Bank Limited (ZTBL) in flood-affected areas as an interim food-security measure. Community participation in disaster response, however, remains uneven: it is generally strongest in areas with active farmer organizations or cooperative structures and weakest in remote, sparsely serviced districts. Building genuine resilience capacity therefore requires strengthening — not replacing — these existing social structures, integrating them with formal early warning and extension systems rather than imposing purely top-down technological solutions.

5. Scientific & Institutional Gaps

A substantial body of international research demonstrates the potential of smart agriculture technologies to strengthen climate resilience. Precision agriculture tools — including IoT-based soil moisture sensors, GPS-guided machinery, and AI-driven predictive analytics — allow farmers to optimize irrigation, fertilizer use, and planting decisions in response to real-time environmental data (Kabato et al., 2025). Drones and satellite remote sensing extend this capability further, enabling continuous monitoring of crop health and early detection of flood and drought risk across large or hard-to-access areas. Globally, the smart irrigation market alone was valued at approximately $2.0 billion

in 2024 and is projected to reach $5.8 billion by 2033, reflecting rapid technological maturation (Kabato et al., 2025).

In Pakistan, however, adoption of these technologies remains at an early and uneven stage. A study examining capacity-building efforts for climate-smart agriculture in Pakistan found that the principal barrier is not awareness of the concept but the limited technical capacity of provincial agriculture extension departments, compounded by knowledge materials that are too complex for smallholder farmers and inadequately adapted to local climate realities (Khan et al., as cited in Asia-Pacific Network for Global Change Research [APN] Science Bulletin, 2022). This extension-capacity gap is a critical institutional weakness: even where smart agriculture technologies exist, farmers frequently lack the training, financing, or technical support needed to adopt them.

Data availability and quality present a second major gap. Post-disaster assessments of agricultural losses in Pakistan have historically relied on delayed field surveys rather than real-time satellite or sensor-based monitoring, slowing both emergency response and compensation processes. While internationally, AI and machine-learning models are increasingly used to generate rapid, satellite-derived crop-damage indices following flood events, integration of such tools into Pakistan's official damage-assessment workflow remains limited. Third, AI/ML adoption in Pakistani agriculture is constrained by the same structural barriers seen across other developing economies: high upfront technology costs, inadequate rural internet and electricity infrastructure, low digital literacy among smallholders, and the absence of affordable, localized (Urdu- and regional-language) advisory platforms. Finally, institutional coordination between the Ministry of Climate Change, provincial agriculture departments, NDMA, and research institutions remains fragmented, resulting in duplicated pilot projects rather than a scaled, nationally coherent smart agriculture strategy.

6. Mitigation Strategies & Best Practices

Structural Measures

Structural interventions should combine traditional flood-management infrastructure with targeted smart agriculture investment. This includes climate-resilient irrigation systems equipped with soil-moisture sensors and automated scheduling to reduce both water waste and drought vulnerability; solar-powered cold storage and post-harvest monitoring,

which international evidence suggests can substantially reduce spoilage losses in perishable value chains; and flood-tolerant, drought-resistant crop varieties supported by digital advisory platforms that recommend planting decisions based on localized weather forecasts.

Non-Structural Measures

Non-structural measures include capacity building for provincial agriculture extension officers on smart agriculture tools; farmer field schools that combine indigenous knowledge with digital advisory content; mobile-based agro-advisory services delivered in local languages; and community-based seed banks that preserve climate-resilient local varieties. Livestock-focused interventions — such as IoT-enabled herd health and heat-stress monitoring — can help protect the livestock sector that underpins rural nutrition and income (Accountability Lab Pakistan, 2026).

National and International Best Practices

Pakistan can draw on both domestic and international precedent. Domestically, ZTBL's promotion of kitchen gardening in flood-affected areas illustrates a low-cost, rapidly deployable food-security measure that could be paired with digital advisory support. Internationally, precision agriculture programs that combine drone-based monitoring with AI-driven pest and disease detection have demonstrated yield increases of 10-15% alongside reductions in water and input use, offering a template for smallholder-appropriate technology packages if costs can be subsidized or shared through cooperative models (Concave Agri, 2025). The World Bank's climate-smart agriculture lending, which supported approximately 4.7 million farmers globally in adopting improved agricultural technologies by fiscal year 2024, further demonstrates the feasibility of financing mechanisms that could be adapted to Pakistan's context (World Bank, 2024).

7. Risk Communication & Early Warning

NDMA has made notable progress in strengthening early warning systems and emergency response mechanisms for floods, heatwaves, and cyclones, including through the GLOF-II project implemented with the Ministry of Climate Change and the United Nations Development Programme (UNDP) to protect vulnerable mountain communities from glacial lake outburst floods (Accountability Lab Pakistan, 2026). Smart agriculture technologies can meaningfully extend the reach and precision of these systems: IoT-

connected weather stations and satellite-based flood-forecasting models can generate localized, field-level alerts rather than only district-wide warnings, giving farmers a narrower and more actionable window in which to protect crops, relocate livestock, or harvest early.

For such systems to be genuinely people-centred and gender-sensitive, however, dissemination must move beyond formal institutional channels. Given uneven mobile connectivity and lower digital literacy among rural women in particular, effective last-mile communication requires layering digital alerts (SMS, voice-call advisories in local languages) with community-based dissemination through local mosques, women's community groups, farmer cooperatives, and local government representatives. Community engagement in the design of warning content — ensuring messages translate technical flood or drought forecasts into concrete, actionable farming decisions — is essential to prevent alert fatigue and ensure warnings are trusted and acted upon.

8. Policy Recommendations

- Integrate smart agriculture technology adoption explicitly into the agriculture-water nexus priority area of Pakistan's National Adaptation Plan, with clear implementation targets and provincial budget lines (National Disaster Management Authority [NDMA], 2024).
- Establish a joint NDMA-Ministry of Climate Change-provincial agriculture department coordination mechanism to prevent duplication of smart agriculture pilot projects and to scale successful models nationally.
- Subsidize or provide low-interest financing for climate-smart technology packages (soil sensors, solar-powered irrigation controllers, mobile advisory subscriptions) targeted at smallholder and tenant farmers, who currently face the highest adoption barriers.
- Modernize agricultural extension services by training provincial extension officers in digital and precision agriculture tools, and by simplifying knowledge products so they are accessible to farmers with limited formal education (APN Science Bulletin, 2022).

- Invest in real-time, satellite- and sensor-based crop-loss and damage assessment systems to accelerate post-disaster compensation and reduce reliance on slow manual field surveys.
- Mandate gender-inclusive design in all agricultural early warning and advisory programs, including women-specific outreach channels and involvement of women's community groups in warning dissemination.
- Strengthen community-based seed banks and indigenous knowledge documentation as a complement — not a substitute — to digital advisory systems, preserving climate-resilient local crop varieties.
- Pursue international and multilateral climate finance (building on precedents such as World Bank climate-smart agriculture lending) specifically earmarked for smallholder-appropriate smart agriculture technology in flood- and drought-prone districts (World Bank, 2024).

9. Conclusion

Pakistan's experience with the 2022 floods and recurrent drought and heatwave events demonstrates that conventional agricultural practices are increasingly insufficient to withstand the country's climate risk profile. Smart agriculture technologies — precision irrigation, IoT-based monitoring, AI-driven forecasting, and satellite and drone-based remote sensing — offer a scientifically grounded pathway to building more climate-resilient food systems, provided they are deployed in ways that are affordable, gender-inclusive, and grounded in local knowledge rather than imposed as purely external technical fixes.

The evidence reviewed in this paper underscores that technology alone cannot resolve Pakistan's agricultural vulnerability; it must be paired with strengthened institutional coordination, modernized extension services, accessible financing, and early warning systems that genuinely reach the last mile. Social capital and indigenous knowledge remain vital resilience assets that should be integrated with, rather than displaced by, digital tools. For NDMA and its partner institutions, the central lesson is that science-based planning and technology integration must proceed hand-in-hand with community participation and equity considerations if Pakistan's food systems are to withstand an increasingly volatile climate future.

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PARTICIPANT RESEARCH PAPER

Flash Flood Hazards in Mountainous Regions: Risk Assessment and Mitigation

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Abstract

Flash floods are among the most rapid and destructive natural hazards affecting mountainous regions. Steep topography, intense rainfall, narrow valleys, complex drainage networks, unstable slopes, snow and glacier melt, and vulnerable settlements can combine to generate floods with very high peak discharge within a short period. The resulting impacts can include loss of life, damage to houses and public infrastructure, disruption of roads and bridges, agricultural losses, and cascading hazards such as landslides and debris flows.

This paper examines the nature of flash-flood hazards in mountainous regions, with particular attention to Pakistan's mountain areas. It applies the conceptual framework of Risk = Hazard × Exposure × Vulnerability and discusses how modern risk assessment can combine Geographic Information Systems (GIS), remote sensing, Digital Elevation Models (DEMs), historical rainfall and flood records, land-use and population data, river and channel characteristics, and hydrological and hydraulic modelling. Evidence from mountainous communities in Pakistan, particularly the Swat Valley and Hindu Kush region, demonstrates that flash-flood risk is not solely a physical phenomenon but is also shaped by social, economic, infrastructural, and institutional vulnerabilities.

The paper further examines mitigation approaches ranging from risk-informed land-use planning and early-warning systems to resilient infrastructure and community preparedness. It argues that effective flash-flood risk reduction requires an integrated approach linking risk mapping, monitoring, early warning, early action, resilient infrastructure, and community preparedness. In the context of climate change and changing cryospheric conditions, strengthening these systems is increasingly important. The paper concludes that flash floods cannot be eliminated, but their impacts can be substantially reduced by lowering exposure and vulnerability and improving the speed and effectiveness of preparedness and response.

Keywords: Flash floods, mountainous regions, disaster risk reduction, climate change, GIS, early warning, resilient infrastructure, community preparedness, Pakistan, Swat Valley.

Introduction

Mountainous regions are particularly susceptible to flash floods because their physical characteristics can rapidly transform intense rainfall into high-energy flood events. Steep slopes accelerate surface runoff, while narrow valleys and confined drainage channels concentrate water over short distances. As a result, communities located in valleys and along rivers and streams may have very limited time to respond when a flash flood develops.

A flash flood is characterized by its short duration and very high peak discharge. Such events can develop within hours and, in some circumstances, in less than three hours following intense rainfall. In mountainous environments, flash floods may also be triggered or intensified by snow and glacier melt, landslides, debris flows, and glacial lake outburst floods (GLOFs).

The danger therefore cannot be understood simply by considering the amount of rainfall received. Rather, it results from the interaction between rainfall intensity, terrain, drainage characteristics, exposed populations and infrastructure, and underlying vulnerability. Settlements, roads, bridges, agricultural land, schools, and other infrastructure located in highrisk areas may experience significant losses when an extreme event occurs.

Climate change adds further complexity to this risk. Changes in precipitation patterns, glacier loss, permafrost thaw, and changes in snow accumulation and melt can alter hydrological processes in mountain environments. The IPCC has identified increasing risks from floods and landslides in mountain regions, particularly as extreme precipitation and cryospheric changes intensify.

Pakistan provides an important context for understanding these challenges. Its northern mountainous regions, including the Hindu Kush and valleys of Khyber Pakhtunkhwa, are exposed to multiple interacting hazards. Evidence from Swat and other mountainous areas demonstrates the need to move from hazard-specific approaches toward integrated, multi-hazard disaster risk reduction.

Objectives of the Study

This paper aims to:

1. Examine the characteristics and drivers of flash-flood hazards in mountainous regions.

2. Explain the relationship between hazard, exposure, and vulnerability in determining disaster risk.
3. Review approaches for assessing flash-flood risk using spatial, hydrological, environmental, and socioeconomic information.
4. Examine evidence from mountainous regions of Pakistan, particularly Swat and the Hindu Kush.
5. Identify major structural and non-structural measures for reducing flash-flood impacts.
6. Examine the implications of climate and cryospheric changes for future mountain flood risk.
7. Propose an integrated framework for flash-flood risk reduction based on risk mapping, monitoring, early warning, early action, resilient infrastructure, and community preparedness.

Conceptual Framework: From Hazard to Disaster

A useful framework for understanding disaster risk is:

Risk = Hazard × Exposure × Vulnerability

This framework demonstrates that the occurrence of a hazard does not automatically result in a disaster. Disaster impacts depend on what is located in the hazard area and how vulnerable exposed people and assets are.

Hazard

Flash-flood hazard assessment should consider factors such as:

- Rainfall intensity and duration
- Flood depth
- Flood velocity
- Historical flood frequency
- River and channel characteristics
- Slope and elevation
- Drainage patterns
- Snow and glacier melt
- Landslide and debris-flow potential

In mountainous areas, topography is particularly important because steep slopes can rapidly concentrate runoff into narrow valleys and channels.

Exposure

Exposure refers to the people, infrastructure, livelihoods, and assets located in areas that may be affected by flooding. Important exposure variables include:

- Population and settlements
- Houses and buildings
- Roads and bridges
- Schools and other public facilities
- Agricultural land
- Livestock and livelihood assets
- Critical infrastructure

Vulnerability

Vulnerability determines how severely exposed people and assets may be affected. It can be influenced by:

- Poverty and socioeconomic conditions
- Weak or poorly located infrastructure
- Limited preparedness
- Lack of early-warning access
- Poor accessibility
- Institutional capacity
- Limited community awareness
- Inadequate evacuation arrangements

The presentation emphasizes that research from mountainous communities in Pakistan demonstrates that flood vulnerability is not purely a physical issue; social, economic, physical, and institutional factors also influence risk.

Flash-Flood Risk Assessment in Mountainous Regions

Effective risk assessment requires an understanding of both physical hazards and the characteristics of exposed communities.

Modern flash-flood assessment can integrate several sources of information, including GIS and remote sensing, Digital Elevation Models, historical rainfall and flood records,

river and channel characteristics, land-use and population data, and hydrological and hydraulic modelling.

GIS and Remote Sensing

GIS provides an important platform for combining spatial information on elevation, drainage networks, settlements, roads, agricultural areas, and hazard zones. Remote sensing can complement ground-based information by providing observations over large and difficult-toaccess mountainous areas.

Spatial analysis can help identify:

- Flood-prone valleys
- Drainage channels
- Areas of high population exposure
- Critical infrastructure at risk
- Potential evacuation routes
- Areas requiring structural mitigation

Digital Elevation Models

Digital Elevation Models are particularly useful in mountainous areas because elevation and slope strongly influence the movement and concentration of floodwater. DEM-based analysis can help identify drainage patterns, low-lying areas, steep slopes, and potential flow pathways.

Historical Data

Historical rainfall and flood records provide important evidence for understanding the frequency and characteristics of previous events. Combining historical records with spatial information can help identify recurring high-risk locations.

Hydrological and Hydraulic Modelling

Hydrological and hydraulic modelling can support assessment of rainfall-runoff relationships, flood depths, flow paths, and flood velocities. These approaches can strengthen hazard mapping and inform decisions concerning infrastructure, land-use planning, and evacuation.

Evidence from Mountainous Pakistan

Pakistan provides an important real-world setting for studying flash-flood risk because of its diverse mountainous terrain and exposure to multiple hydro-meteorological hazards.

Swat Valley

Research from the Daral and Chail valleys of Swat demonstrates the complexity of flood processes in mountainous environments. Summer stream discharge in these areas can increase due to the combined effects of snow, ice and glacier melting and monsoon rainfall. Mountain communities are consequently exposed to recurring socioeconomic and infrastructure damage associated with flash floods.

This illustrates why flood assessment in mountain environments cannot focus solely on rainfall. Multiple water sources and seasonal processes can interact to increase stream discharge and flood risk.

Hindu Kush

The Hindu Kush region presents another example of multi-hazard interaction. Steep terrain, dense drainage networks, glacier-fed valleys, and unstable slopes can contribute to complex hazard processes. Flash floods may trigger or occur alongside debris flows and slope failures, while landslides can further increase the scale of damage.

This suggests that mountainous flash-flood risk should be approached as part of a multi-hazard system rather than as an isolated flood problem.

Flash Floods as Cascading Hazards

One of the most important characteristics of mountain flash floods is their potential to generate cascading hazards.

A single intense rainfall event may result in:

Intense rainfall → rapid runoff → flash flood → debris flow → slope failure → landslide

Each process can increase the severity of the next. Floodwater may destabilize slopes, while landslides and debris flows can block or redirect channels, increase sediment loads, damage infrastructure, and create additional hazards downstream.

This cascading nature of risk has significant implications for disaster preparedness. Risk assessments should therefore consider the interaction between floods, landslides, debris flows, and other hazards rather than assessing each hazard independently.

Climate Change and Emerging Mountain Flood Risks

Climate change is increasing the complexity of disaster risk in mountain regions. Changes in temperature, precipitation, snow patterns, glacier conditions, and permafrost can influence the timing and magnitude of runoff.

Mountain regions are experiencing changes associated with glacier loss, permafrost thaw, and changing snow and precipitation patterns. The IPCC projects that damages from water-related hazards, including floods and landslides, will increase considerably with greater warming.

In Pakistan, research has also identified relationships between short-duration monsoon precipitation events and flash-flood occurrence, with northern regions showing particularly high flood vulnerability.

These changes create an important challenge for conventional disaster management systems. Historical patterns may no longer provide sufficient guidance for future risk, making continuous monitoring, updated hazard mapping, and climate-informed planning increasingly important.

Mitigation and Disaster Risk Reduction Strategies

Effective mitigation requires a combination of structural, technological, institutional, and community-based approaches.

Risk-Informed Planning

Risk-informed planning should begin with the identification of high-risk valleys, flood channels, and exposed settlements. Hazard maps should be incorporated into land-use and infrastructure planning, while unsafe construction in high-risk flood zones should be restricted wherever feasible.

Infrastructure investment should therefore be guided by risk information rather than solely by existing settlement patterns.

Early-Warning Systems

Because flash floods can develop very rapidly, early warning is a critical component of risk reduction.

Early-warning systems can incorporate:

- Rainfall monitoring
- River-level monitoring

- Weather forecasting
- Satellite observations
- Community-based warning mechanisms
- SMS and mobile communication
- Local communication networks

However, technical detection alone is insufficient. Warnings must reach exposed communities quickly and be understandable and actionable.

The experience of Nepal demonstrates the importance of linking hydro-meteorological monitoring with community warning systems. At the same time, flash floods in hills and small rivers present particular challenges because of their unpredictable and rapid nature.

Structural Measures for Flash-Flood Mitigation

Structural measures can reduce the intensity and destructive potential of floodwater and protect critical infrastructure.

Potential measures include:

Check Dams and Retention Structures

Check dams and retention structures can help slow runoff and reduce the movement of water and sediment through vulnerable channels.

Resilient Bridges and Culverts

Bridges and culverts should be appropriately designed according to local flood characteristics and drainage requirements. Inadequately designed crossings can become bottlenecks during high-flow events.

Riverbank Protection

Riverbank protection can reduce erosion and protect settlements, roads, agricultural land, and other infrastructure located near channels.

Slope Stabilization

Because landslides and slope failures can interact with flash floods, slope stabilization is an important component of integrated mountain risk management.

Improved Drainage

Improved drainage can reduce localized accumulation of runoff and support the safe movement of stormwater away from vulnerable settlements and infrastructure.

The presentation identifies these measures as key components of structural flash-flood mitigation.

Community Preparedness

Infrastructure and technology must be complemented by community preparedness. Communities living in mountain valleys are often the first to experience the impacts of flash floods and therefore need the knowledge and capacity to act quickly.

Key community preparedness measures include:

- Clearly marked evacuation routes
- Designated emergency shelters
- Community disaster-management teams
- Regular evacuation drills
- Community awareness on flood risks
- Local warning and communication mechanisms
- Clearly defined responsibilities during emergencies

Prepared communities can respond more quickly to warnings and reduce the time between receiving information and taking protective action.

Community preparedness is particularly important in flash-flood environments because the available response window may be extremely short.

Integrated Approach to Flash-Flood Risk Reduction

The evidence presented in this paper indicates that no single intervention can adequately address flash-flood risk in mountainous regions.

An effective approach should connect scientific risk assessment with practical preparedness and community action:

Risk Mapping → Monitoring → Early Warning → Early Action → Resilient Infrastructure → Community Preparedness

This sequence represents a continuous risk-management process rather than a one-time intervention.

Risk Mapping

Identify where hazards are likely to occur and who or what is exposed.

Monitoring

Continuously monitor rainfall, river conditions, weather patterns, and relevant environmental changes.

Early Warning

Translate monitoring information into timely and understandable warnings.

Early Action

Ensure communities and institutions have predefined actions that can be taken when warnings are received.

Resilient Infrastructure

Design and strengthen infrastructure based on identified hazards and future risk.

Community Preparedness

Build local capacity through awareness, planning, evacuation routes, emergency shelters, disaster teams, and regular drills.

Discussion

The central finding of this paper is that flash-flood disasters are produced through the interaction of natural hazards and human vulnerability. High rainfall intensity alone does not explain disaster severity. The physical characteristics of mountain environments determine how quickly water is concentrated, while settlement patterns, infrastructure quality, poverty, preparedness, accessibility, and institutional capacity influence the consequences.

The evidence from Pakistan further demonstrates that flash floods should be viewed as part of a broader multi-hazard environment. In Swat, snow and glacier melt can interact with monsoon rainfall, while in the Hindu Kush, steep terrain and unstable slopes can contribute to cascading events involving floods, debris flows, and landslides.

This has important implications for disaster-risk governance. Risk assessments should move beyond static flood maps and incorporate changing climate conditions, land-use patterns, population exposure, infrastructure vulnerability, and community preparedness.

Similarly, early-warning systems should not be treated only as technical systems. Their effectiveness depends on communication, institutional coordination, public understanding, and the capacity of communities to act quickly.

Conclusion

Flash floods in mountainous regions represent a complex disaster-risk challenge arising from the interaction of intense rainfall, steep topography, concentrated drainage, exposed populations, vulnerable infrastructure, and limited preparedness. The risk is further complicated by snow and glacier melt, landslides, debris flows, and changing climatic and cryospheric conditions.

Evidence from Pakistan, particularly the Swat Valley and Hindu Kush, demonstrates that mountain flash floods cannot be understood or managed as isolated flood events. They are part of interconnected hazard systems in which one event can trigger or intensify another.

Risk reduction therefore requires an integrated approach combining scientific assessment, spatial technologies, monitoring, early warning, early action, resilient infrastructure, and community preparedness.

The objective is not to eliminate flash floods—which is impossible—but to reduce exposure, vulnerability, and response time.

Ultimately, the most effective approach is one that connects science with community action: Identifying risk before disasters occur, monitoring changing conditions, communicating warnings quickly, preparing communities to act, and ensuring that infrastructure and development decisions are informed by current and future risk.

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PARTICIPANT RESEARCH PAPER

Flood Vulnerability Assessment in Lahore: A Case Study of Urban Flood Risk and Community Resilience

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Abstract

Urban flooding has emerged as one of the most significant disaster risks facing rapidly developing cities in South Asia. Lahore, the second most populous city of Pakistan and capital of Punjab province, has experienced recurrent and increasingly severe urban flooding events over the past decade, with devastating impacts on infrastructure, livelihoods, and public health. This research paper assesses flood vulnerability in Lahore through a multi-dimensional framework that examines physical, socio-economic, institutional, and community-level factors contributing to disaster risk.

The study draws upon GIS-based Analytical Hierarchy Process (AHP) methodologies, institutional analysis, and community-level assessments to evaluate Lahore's flood risk profile. Findings indicate that land use change—particularly rapid urbanization and expansion of impervious surfaces—is the most significant factor contributing to flood vulnerability. The city's colonial-era drainage infrastructure is inadequate for current monsoon intensity, while encroachments on natural waterways further reduce drainage capacity. Institutional fragmentation between disaster management authorities, municipal agencies, and water management bodies constrains effective flood risk governance.

The paper identifies community-based adaptation strategies, including revival of indigenous knowledge and participatory early warning systems, as critical resilience factors. It recommends strengthening multi-hazard early warning systems, enforcing floodplain zoning regulations, investing in nature-based solutions, and establishing anticipatory financing mechanisms to shift from reactive disaster response to proactive risk management. These recommendations align with Pakistan's National Adaptation Plan and the Sendai Framework for Disaster Risk Reduction 2015–2030.

1. Introduction

Urban flooding has become a critical challenge for rapidly growing cities in the developing world, particularly in South Asia where climate change, unplanned urbanization, and inadequate infrastructure converge to create heightened disaster risk. Lahore, the capital of Punjab province and Pakistan's second most populous city, exemplifies this challenge. The city has experienced recurrent and increasingly severe urban flooding events over the past decade, with devastating impacts on infrastructure, livelihoods, and public health.

The importance of understanding flood vulnerability in Lahore is underscored by the city's rapid urbanization and its location within the Ravi River basin. Between 2018 and 2022, built-up land in Lahore increased from 34.9 km^2 to 37.4 km^2, significantly intensifying flood risk through the expansion of impervious surfaces . The central areas of Lahore—including Anarkali, Lakshmi Chowk, Ghari Shahu, Waris Road, Barkat Market, The Mall, and Johar Town—have been repeatedly paralyzed by knee-deep floodwaters during monsoon seasons .

The problem is compounded by systemic institutional and infrastructural challenges. Much of Lahore's drainage system was constructed during the colonial era and was not designed to handle current monsoon intensity . Encroachments on natural waterways and drainage corridors reduce the capacity of the city's hydraulic infrastructure, while institutional fragmentation between the Water and Sanitation Agency (WASA), the Provincial Disaster Management Authority (PDMA), and municipal governments constrains coordinated action

Purpose and Objectives

The purpose of this research is to assess flood vulnerability in Lahore and recommend evidence-based interventions for disaster risk reduction. The specific objectives are:

1. To assess the spatial extent and physical factors contributing to urban flood vulnerability in Lahore
2. To evaluate the socio-economic and institutional dimensions of flood risk
3. To identify community-level resilience factors and adaptation practices
4. To recommend community-based and policy interventions for flood risk reduction.

2. Regional Context & Hazard Profile

Lahore is located in the alluvial plains of the Ravi River, with an average elevation of approximately 217 meters above sea level. The city's topography is characterized by gentle slopes, which limits natural drainage capacity. The region experiences a semi-arid climate with distinct monsoon seasons, receiving the majority of its annual rainfall between July and September.

Hazard Definitions

A hazard is a potentially damaging physical event or process. In Lahore's context, the primary hazard is pluvial (rainfall-induced) urban flooding, which occurs when intense rainfall overwhelms drainage systems, leading to surface water accumulation . Exposure refers to people, infrastructure, and assets located in flood-prone areas. Vulnerability describes the physical, social, economic, and institutional conditions that make exposed populations susceptible to harm. Risk emerges from the interaction of hazard, exposure, and vulnerability.

Historical Flood Events

Lahore has experienced recurrent urban flooding events over the past decade. In 2011, the UN reported that heavy rainfall triggered flash flooding in Sialkot and Kasur districts and urban flooding in central Lahore . The same year, officials claimed urban flooding was a chief cause for the outbreak of dengue fever in central Punjab . Subsequent events in 2012, 2013, and 2016 caused widespread disruption, with streets transformed into rivulets and low-lying areas paralyzed by floodwaters .

Vulnerability Profile

The Pakistan Meteorological Department and the National Emergency Operations Centre (NEOC) have identified Lahore as one of the cities most vulnerable to urban flooding . Key vulnerability factors include:

- **Rapid Urbanization:** The expansion of impervious surfaces reduces natural water absorption
- **Inadequate Drainage:** Colonial-era infrastructure is insufficient for current precipitation intensity
- **Encroachments:** Illegal occupation of drainage corridors reduces waterway capacity

- **Climate Change:** Increased monsoon variability and intensity exacerbate flood risk.

3. Risk & Vulnerability Assessment

Physical Factors Contributing to Flood Vulnerability

Research using GIS-based Analytical Hierarchy Process (AHP) has identified land use as the most significant factor in detecting vulnerable areas in Lahore. This method demonstrated 88% accuracy for roads, 80% for commercial areas, and 70% for residential areas. Other significant physical factors include elevation, slope, rainfall distribution, drainage network density, and soil type.

The study by Zia et al. (2021) found that land use change—particularly the expansion of impervious surfaces—most significantly influences flood risk. The 2022 floods affected approximately 33 million people across Pakistan and caused economic losses of approximately USD 15.2 billion. Flash and urban flooding damaged about 40% of railway tracks and over 8,330 km of roads, with poor urban planning and water resource management being partly responsible.

Socio-Economic Impacts

Flooding in Lahore has severe socio-economic consequences. Commuting difficulties affect both private and public transport, disrupting economic activity and causing hidden economic losses . A single public holiday due to flooding is estimated to cost approximately 1% of the country's GDP . The financial burden on governments and citizens increases drastically after rainwater flooding, with crucial funds redirected from other development projects.

Vulnerable Groups

Vulnerability is not evenly distributed. Poor households have fewer financial resources to prepare for or recover from disasters. Women, children, the elderly, and persons with disabilities face additional barriers in evacuation, access to information, and recovery . Research indicates that local communities in Lahore are highly vulnerable to climate-related challenges, with significant impacts on livelihoods, infrastructure, and socio-economic well-being.

4. Community Resilience Factors

Social Capital and Community Networks

Community resilience is a critical component of disaster risk reduction. A successful example of community-based adaptation in low-lying areas of Lahore demonstrates the effectiveness of participatory approaches. Local residents involved in identifying risks, planning drainage solutions, sharing early warnings, and deciding collective actions have strengthened community ownership and coordination, reducing damage during extreme events.

Indigenous Knowledge and Coping Mechanisms

Traditional practices in the Lahore region, including rainwater storage, shaded courtyards, thick brick walls, and cross-ventilated housing, have long helped communities adapt to heat and water stress. These practices are closely linked to local culture and values and remain effective in managing climate risks. However, they are increasingly being replaced by modern construction methods.

Community Participation in Disaster Planning

Research emphasizes that communities should participate in hazard mapping, evacuation planning, and identification of vulnerable households. The National Adaptation Plan has been criticized for its limited emphasis on community engagement and local knowledge integration, suggesting that more inclusive approaches are needed.

5. Scientific & Institutional Gaps

Institutional Fragmentation

Pakistan's disaster management system operates across multiple tiers—federal, provincial, and district—but coordination gaps significantly constrain effectiveness. The separation between Disaster Management Authorities (focused on relief) and Ministries of Water/Agriculture (focused on development) creates budget delays and uncoordinated action. Despite the functioning of an established multi-tiered disaster management framework for more than a decade, flood impact mitigation remains lacking.

Infrastructure Deficits

Lahore's drainage system, largely built during the colonial era, is inadequate for current monsoon intensity . Encroachments block or narrow drainage access, reducing the capacity of waterways to accommodate excess water during flooding . While Pakistan has allocated PKR 1.4 trillion (approximately USD 5 billion) for infrastructure development

in fiscal year 2024-2025, water management remains an overlooked aspect of urban planning.

Data and Technology Gaps

While Pakistan has made progress in strengthening technical early warning capabilities, significant gaps remain in data availability and quality. The Punjab government's Phase II Floodplain Mapping Survey, launched in 2026, aims to collect comprehensive data on populations residing along rivers and nullahs using mobile applications and satellite imagery. This initiative will support AI-based early warning systems, relief camp planning, and evacuation decisions.

6. Mitigation Strategies & Best Practices

Structural Measures

Structural measures for flood mitigation in Lahore include upgrading drainage systems, constructing retention basins, and implementing flood protection infrastructure. The "Recharge Pakistan" initiative, which began implementation in 2025, aims to create recharge basins and retention areas across multiple watersheds. These nature-based solutions offer the possibility of bolstering flood resilience without requiring extensive capital investment.

Nature-Based Solutions

Nature-based solutions have been increasingly recognized as effective flood mitigation strategies. The concept of "sponge cities"—integrating green infrastructure such as parks, wetlands, permeable pavements, and green roofs—has been piloted in Karachi and holds potential for Lahore. Lahore has already established some underground rainwater storage tanks, and housing societies could be required to invest in such measures.

Floodplain Management

The Punjab government's Floodplain Mapping Survey, launched in two phases, will provide evidence-based zoning to prevent encroachments and unplanned settlements in flood-prone areas. The survey will also support timely decisions regarding construction and strengthening of protective embankments and assess river erosion to enable preventive measures.

7. Risk Communication & Early Warning

Multi-Hazard Early Warning Systems

The NDMA has been strengthening technical early warning capabilities using multi-hazard monitoring, environmental and hazard data, satellite observations, and advanced analytical tools. The Punjab government's floodplain mapping initiative will further strengthen the AI-based early warning system by collecting real-time data on vulnerable populations.

Last-Mile Communication

Effective early warning requires forecasts to reach people in ways they understand and trust. Communication should use multiple channels, including SMS, mobile applications, television, radio, and community networks. The floodplain mapping survey is collecting contact details of local stakeholders such as mosque imams and lambardars to facilitate communication at the rural level.

People-Centered Approaches

Gender-sensitive communication is essential, as women and marginalized groups may have different access to information and decision-making authority. The floodplain mapping survey explicitly aims to identify vulnerable populations, including children, the elderly, and persons with disabilities.

8. Policy Recommendations

Based on the analysis of flood vulnerability in Lahore, the following policy measures are recommended:

a. Enforce Strict Floodplain Zoning and Land-Use Regulations

Unplanned development on floodplains and constriction of the Ravi River channel amplify flood risk. Legally binding floodplain zoning ordinances should be enforced, and development in highly exposed areas should be prohibited. The Punjab government's floodplain mapping initiative provides the evidence base for such zoning decisions.

b. Upgrade Drainage Infrastructure and Separate Rainwater/Wastewater Systems

Much of Lahore's drainage system was built during the colonial era. Authorities must upgrade drainage systems, install new pipelines to separate wastewater and rainwater, and ensure treatment facilities are not overloaded by contaminated runoff.

c. Mandate Water-Sensitive Urban Design for New Housing Developments

Housing societies should be required to have proper water management systems in place before approvals are granted. This should include integrated stormwater management, rainwater harvesting, and retention ponds.

d. Invest in Nature-Based Solutions

Nature-based solutions such as recharge basins, rainwater harvesting systems, urban greening, and sponge city principles should be prioritized as low-cost, effective flood mitigation measures. The "Recharge Pakistan" initiative provides a model that can be scaled up.

e. Establish Anticipatory Financing and Forecast-Based Action

Pre-arranged forecast-based financing should be established to trigger relief actions before severe flooding occurs, shifting from reactive relief to proactive risk management.

f. Strengthen Community-Based Early Warning Systems

Community-based early warning systems, involving residents in identifying risks and sharing warnings, have proven effective. These should be expanded across vulnerable neighborhoods.

g. Institutionalize Climate Preparedness in Local Governance

Climate preparedness should be institutionalized through early-warning systems and contingency planning at the municipal level. Regular drills and simulation exercises with community involvement should be standard practice.

h. Regulate Encroachments and Restore Waterway Capacity

Encroachments block drainage access and reduce the capacity of waterways. Systematic removal of encroachments from drainage corridors should be implemented.

i. Integrate Technology with Community Knowledge

AI-based early warning systems should be connected to community-level communication networks. The floodplain mapping survey's collection of local stakeholder contact details provides a foundation for this integration.

j. Mainstream Gender and Social Inclusion

Disaster plans should explicitly address the needs of women, children, older people, persons with disabilities, and economically vulnerable households.

9. Conclusion

Urban flooding in Lahore represents a complex and interconnected challenge shaped by rapid urbanization, inadequate infrastructure, institutional fragmentation, and climate change. This research has demonstrated that flood vulnerability is determined not by any single factor but by the interaction of physical exposure, socio-economic conditions, institutional capacity, and community resilience.

The key findings of this study are:

- Land use change—particularly the expansion of impervious surfaces—is the most significant factor contributing to flood vulnerability in Lahore
- The city's colonial-era drainage infrastructure is inadequate for current monsoon intensity, while encroachments on natural waterways further reduce drainage capacity
- Institutional fragmentation between disaster management authorities, municipal agencies, and water management bodies constrains effective flood risk governance
- Community-based adaptation strategies, including revival of indigenous knowledge and participatory early warning systems, are critical resilience factors
- Recent initiatives such as the Floodplain Mapping Survey and Recharge Pakistan provide foundations for evidence-based risk reduction

The path toward flood resilience in Lahore requires moving from reactive disaster response toward anticipatory, science-based, and community-centred risk management. Stronger infrastructure is necessary, but it must be accompanied by effective early warning systems, reliable data, community participation, institutional coordination, and inclusive policies.

Ultimately, disaster risk is shaped by the interaction of hazards, exposure, vulnerability, and preparedness. A resilient Lahore requires an integrated approach in which science, technology, institutions, communities, and policy work together to transform climate information into practical risk reduction.

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PARTICIPANT RESEARCH PAPER

FOG AND DENSE FOG HAZARDS IN PAKISTAN: IMPACTS ON TRANSPORTATION, AVIATION, AND PUBLIC SAFETY

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Abstract

Fog is a recurring winter hazard in the Indus Plains of Pakistan, particularly from November to February. Reduced visibility caused by fog creates serious challenges for road, rail, and air transportation and poses risks to public safety. This paper examines the key meteorological factors that contribute to hazardous fog, its geographical distribution, and its socio-economic impacts. It draws on research from the Bahawalpur region, Lahore's smog episodes, the wider Indo-Gangetic plain, and international research on transportation safety and fog- related accidents.

The findings suggest that fog severity can be assessed more effectively using indices that consider both the duration of fog and visibility, such as the Hazardous Fog Index. Dense fog has repeatedly caused closures and disruptions on major transportation routes, including the Islamabad-Lahore Motorway. In urban areas, low wind speed, high humidity, and air pollution can intensify smog and reduce visibility. Road and rail users, aviation, and low-income communities are particularly vulnerable.

Despite the recurring nature of fog, research on community resilience, real-time monitoring, forecasting, and coordination among relevant institutions. The paper recommends strengthening visibility- monitoring networks, using satellite technology, improving mitigation measures, and developing people centered early warning systems. And enhancing coordination among meteorological, transport, and disaster management institutions.

Keyword: Aviation Safety; Early Warning Systems; Hazardous Fog Index; Public Safety; Transportation Disruption, Pakistan.

1. Introduction

Fog is a type of stratus cloud that forms close to the ground when the air becomes nearly saturated with moisture. As water vapor condenses, visibility can fall to one kilometer or less (Ahrens, 2007).In Pakistan, fog is particularly common across the Great Plains of Punjab and Sindh during winter. Radiation and frontal fog can cover large areas and persist for several days (khan et al.,2014). Although fog can benefit to agriculture by adding moisture and protecting crops from frost, dense fog can create serious problems. It increases the risk of traffic accidents, cause motorway closures, delays or cancel flights, and may result in livestock losses (khan et al., 2014; Aslam,2012).

In major cities such as Lahore, fog can mix with industrial and vehicle emissions, forming smog that reduces visibility and worsens air quality (Bilal et al., 2022).Internationally, fog-related poor visibility is also considered an important factor in highway crashes and transportation disruptions (National Research Council, 1996).

Despite being a recurring winter hazard, fog in Pakistan has not yet been studied through a fully integrated approach linking climatic patterns with transportation risks and public-safety planning (Khan et al., 2014; Singh and Gautam, 2022). Therefore, this paper examines the causes, distribution, and impacts of hazardous fog and suggests mitigation, communication, and policy measures for disaster risk reduction.

2. Regional Context and Hazard Profile

Pakistan has five broad meteorological regions: the coastal belt, the Baluchistan Plateau, the north-western and western mountains areas, Himalayan region, and Great Plains, or Indus Plains. Fog intensity varies across these regions. With Punjab and Sindh's Great plains most affected areas, while upper Punjab and western mountains experience moderate fog. Coastal and higher mountainous areas generally face lower risk.

Fog mainly occurs from November to February. Bahawalpur, in southern Punjab, is particularly vulnerable due to frequent and intense fog. Radiation and frontal fog are the most common types while advection, upslope, mixing, barometric, steam, and industrial smog may also occur.

Pakistan forms part of the wider Indo-Gangetic Plain, a densely populated and fog-prone regions. During December and January, Low temperature, high moisture, and a shallow

atmospheric boundary layer can produce widespread, long- lasting fog, with visibility sometimes below 100 meters.

In Lahore, temperature inversions, light winds, high humidity, and industrial emissions can intensify winter smog, with crops burning further worsening visibility and air quality.

3. Risk and Vulnerability Assessment

Researchers studying the Bahawalpur region developed a Hazardous Fog Index (HFI) to assess the severity of fog. The index considers the factors such as the number of foggy days, duration of fog, and visibility level. These factors help identify how often fog occurs and how dangerous it can be. The following visibility classifications were adapted to suit local conditions.

Visibility Range	Classification
< 40 m	Dense fog
40–200 m	Thick fog
200–1,000 m	Thin / low fog
1–2 km	Mist / haze
2–4 km	Poor visibility
4–10 km	Moderate visibility
10–40 km	Good visibility
> 40 km	Excellent visibility

For Bahawalpur, fog categories were adjusted to local conditions. Visibility below 50 meters indicates dense fog,50-80 meters of medium or thick fog, and above 80 meters low or thin fog. Fog poses risks to several sectors, especially road transportation where poor visibility causes traffic disruptions, accidents, and motorway closures. The Islamabad- Lahore Motorway has reportedly been completely closed during very thick fog. Rail transportation may experience delays and interruptions, while aviation can face flight delays, cancellations, and schedule changes, particularly when fog occurs with severe smog around Lahore.

Maritime transportation is also affected in coastal areas due to reduced visibility and navigation difficulties. Livestock, especially newborn calves, lambs, and kids, face

increased health risks and mortality during cold, foggy weather. Fog also causes socio-economic impacts by reducing productivity, delaying perishable goods, disrupting commuting, and limited food access. Reduced visibility gives drivers less reaction time, increasing accident severity, particularly for trucks requiring greater stopping distances.

4. Community Resilience Factors

Research on community resilience to fog hazards in Pakistan remains limited. Available literature provides little information on how communities cope with fog, use traditional or local knowledge, or participate in managing related risks. However, indirect evidence exists fog affected areas of the wider Indo-Gangetic plain. In these regions, people may adjust travel plans and agricultural activities according to weather conditions and available advisories, especially during winter when fog is common.

Drivers also use informal measures during poor visibility, including slowing down, using hazard lights, and following vehicle lights ahead. Although these behaviors are commonly observed, limited research assesses their consistency or effectiveness. International Studies have also show that technical monitoring and warning systems alone may not ensure safer driving, as many drivers continue at speeds that provide insufficient stopping distance.

These findings highlight gaps in Pakistan's fog resilience. Alongside forecasting and monitoring, greater attention is needed to public awareness, community involvement, reliable reporting, and locally appropriate coping strategies.

5. Scientific and Institutional Gaps

Research on fog in Pakistan has traditionally relied on manual observations, with visibility often estimated using fixed objects such as trees and power poles instead of continuous measurements. This limits the development of detailed and consistent fog records needed for effective planning and risk management.

Fog and smog severity is influenced by wind, atmospheric stability, humidity, and crop burning timing, which vary annually and require continuous weather and air-pollution monitoring.

Satellite-based methods, including dynamic brightness-temperature-difference thresholding, can produce long-term fog records when supported by ground-station data

across the Indo-Gangetic Plain, but these methods remain insufficiently integrated into Pakistan's monitoring and forecasting systems.

Institutional gaps also exist, including weak integration of weather information with traffic management, limited real-time visibility sensors on high-risk routes, and underuse of artificial intelligence and machine learning for prediction. Addressing these challenges requires long-term investment, standardized coordination, and stronger data sharing among the Pakistan Meteorological Department, transport authorities, airports, and NDMA to improve forecasting, transportation management, and preparedness.

6. Mitigation Strategies and Best Practices

Literature identifies several fog-dispersal techniques, each with limitations. Dry ice can freeze supercooled water droplets but is ineffective for warmer fog. Hygroscopic particles, such as salt, and temporarily improve visibility, but the method is costly and short-lived. Heating air can evaporate fog droplets but requires substantial energy making it expensive and inefficient. Helicopter-induced turbulence can mix drier air into shallow radiation fog but is less effective for thick or differently formed fog.

Selected dispersal techniques could be considered along high-risk transportation routes in the Indus Plains, but dispersal alone is insufficient. Better forecasting can combine reanalysis of weather data, satellite observations, and atmospheric trajectory modeling to identify conditions preceding severe fog.

International measures include visibility sensors, radar-based vehicle detection, dynamic message signs and variable speed limits. Public awareness and staff training are equally important. Drivers should reduce their speed and maintain safe distances, while traffic and emergency teams should respond to visibility information and operate near frequently affected areas to reduce accidents and improve transportation safety

7. Risk Communication and Early Warning

Although the studies reviewed do not describe a fully developed and operational early-warning system for fog in Pakistan, they provide useful scientific evidence that could support the development of one. Factors such as fog duration, visibility, and composite measures such as the Hazardous Fog Index (HFI) can help determine how severe and dangerous a fog event may be. At the same time, weather conditions that often occur before severe fog, including high pressure, weak winds, temperature inversions, and high

relative humidity, can be monitored to provide earlier warnings to motorists, railway operators, airports, and the public.

Satellite based fog data can also help identify areas where fog occurs frequently. This information could be used by forecasting agencies to establish suitable warning levels for different regions and to direct public-safety messages toward areas at greater risk. In other countries real-time warnings are communicated through dynamic roadside message signs, radio and smartphone alerts, traveler-information system, and navigation application that can provide alternative routes when roads are affected by severe fog.

For Pakistan, an effective early-warning system should be designed around the needs of the people who will use it. It should consider differences in driver's experience, age, literacy in language so that warnings are clear and accessible to everyone. There is also a need to improve the connection between roadside warning signs and individual travelers, as many people currently have limited access to direct, real-time information before entering fog-affected area.

Community involvement could make such a system more effective. residents and roads users could contribute by reporting fog conditions and visibility in their areas. However, community participation and local reporting have received little attention in the existing research on fog in Pakistan, making this an important area for future research and development.

8. Policy Recommendations

Develop a coordinated fog-response system: Establish A framework that brings together the Pakistan Meteorological Department, National Highway Authority, Motorway police, Civil Aviation Authority, Pakistan Railway, and NDMA. This would improve coordination in monitoring fog conditions, sharing information, and responding to emergencies.

Improve real-time monitoring: Install visibility sensors and radar-based vehicle detection systems along high-risk routes, particularly the Islamabad- Lahore Motorway and other roads across the Indus Plains that frequently experience fog- related closures.

Strengthen forecasting and early warnings: Make greater use of satellite-based fog detection and reanalysis weather data in national forecasting systems. This could help identify severe fog conditions earlier and provide timely warnings to people at risk.

Introduce practical mitigation measures: Use measures such as dynamic message signs, variables speed limits, and where technically and economically feasible, appropriate fog-dispersal techniques on major transportation routes.

Improve public communication: Develop people-centered warning systems that provide a clear and timely information through radio, mobile applications, and navigation platforms. Alerts should be available in relevant local languages and designed to be easily understood by people with different level of literacy and driving experience.

Control urban pollution: Strengthen monitoring and management of pollution from vehicles, industries and seasonal crop burning, particularly in cities such as Lahore where these sources can worsen winter smog and visibility problems.

Encourage community involvement: Give local communities and road users opportunities to report fog conditions through simple citizen-reporting systems. Public awareness campaigns should also promote safe driving practices, including reducing speed and maintaining a safe distance during dense fog.

Strengthen institutional capacity: Provides specialized training in fog forecasting, emergency response, and traffic management. Agencies should also explore the use of artificial intelligence and machine-learning tools for fog prediction and establish standardized procedures for sharing data between relevant institutions.

9. Conclusion

Fog and dense fog are recurring hazards across Pakistan's Indus Plains, with the Great Plains of Punjab and Sindh, particularly Bahawalpur among the areas most seriously affected. Every winter, poor visibility creates major challenges for Road, rail and air transportation, while also putting public safety at risk and causing economic and livelihood losses. The situation can become even more serious in polluted urban areas such as Lahore, where weather conditions and air pollution interact to produce a severe episode of smog.

The available evidence shows that fog duration and visibility are important factors in determining how dangerous a fog event can be. Tools such as the Hazardous fog index can help assess the severity of these events. Research from other countries also shows that reduced visibility significantly increases the risk of Road crashes, particularly for heavy vehicles and traffic travelling in inner lanes.

Despite the recurring nature of the problem, research on community resilience to fog in Pakistan is still limited. Important gaps also remain in continuous monitoring, accurate forecasting and coordination among the institutions responsible for transportation, weather services, and disaster management. Reducing the impact of fog will therefore require a coordinated approach that combines scientific knowledge, satellite and sensor technology, stronger institutional cooperation, and people-centered early-warning systems. Greater involvement of local communities is also needed to ensure that warnings reach people in time and lead to safer decisions. In this way fog and dense fog can be addressed more effectively as part of Pakistan's wider Disaster Risk- Reduction in climate adaptation efforts.

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PARTICIPANT RESEARCH PAPER

GENDER-RESPONSIVE DISASTER RISK REDUCTION AND CLIMATE ADAPTATION

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Abstract

Disasters and climate change do not affect all people in the same way. Existing gender inequalities shape exposure to hazards, access to information and resources, mobility, livelihood security, health services, decision-making and the ability to recover. Gender-responsive disaster risk reduction (DRR) and climate adaptation therefore require more than identifying women as a vulnerable group; they require risk governance that recognizes different needs, capacities and forms of knowledge and gives women meaningful roles in preparedness, response, recovery and adaptation. This paper examines the relationship between gender, disaster risk and climate adaptation, with particular reference to Pakistan. The 2022 floods demonstrate how climate-related disasters can intensify reproductive-health risks, protection concerns, displacement and livelihood disruption for women and girls. At the same time, women contribute important local knowledge and resilience capacities that are frequently underused in formal disaster governance. Pakistan has recently strengthened its policy focus through the National Disaster Risk Reduction Strategy 2025–2030, the National Adaptation Plan and initiatives of the National Disaster Management Authority (NDMA) Gender and Child Cell. The paper argues that effective resilience requires sex-, age- and disability-disaggregated data, gender-responsive financing, inclusive early warning, women's leadership, accessible services, community participation and stronger coordination between DRR and climate adaptation institutions.

Keywords: Climate Adaptation; Disaster Risk Reduction; Gender Equality; Resilience; Women

1. Introduction

Climate change is increasing the importance of disaster risk reduction and adaptation in countries exposed to floods, droughts, heatwaves, storms and other hazards. However, risk is not created by the physical hazard alone. Disaster risk is also shaped by exposure, vulnerability, capacity and the social and institutional conditions in which people live. Gender is therefore a critical dimension of risk. Social norms, unequal access to land and finance, unpaid care responsibilities, restrictions on mobility, limited participation in decision-making and unequal access to information can affect how different groups prepare for and recover from disasters. UNDRR emphasizes that gender-responsive DRR should address the systems that create and sustain inequality rather than treating women only as passive recipients of assistance (UNDRR, 2025).

Pakistan provides a particularly important context for examining this relationship. The country faces floods, droughts, heatwaves, glacial lake outburst floods, shifting rainfall patterns and other climate-related hazards. The 2022 floods affected more than 33 million people and exposed major gaps in health, protection, shelter and livelihoods. UNFPA reported that approximately 650,000 pregnant women in flood-affected areas required maternal health services, while women and girls faced increased risks of gender-based violence and disruption of reproductive health care (UNFPA, 2022). These impacts demonstrate that gender-responsive DRR is not a separate social issue but an essential part of effective disaster management.

The purpose of this paper is to examine how gender can be systematically integrated into DRR and climate adaptation. It focuses on four objectives: to explain the gender dimensions of disaster risk; to assess key vulnerabilities and resilience capacities; to identify institutional and scientific gaps; and to propose practical strategies for gender-responsive DRR and adaptation in Pakistan. The scope covers preparedness, risk assessment, early warning, response, recovery, livelihoods, community resilience and policy governance.

2. Regional Context & Hazard Profile

South Asia is highly exposed to climate-related hazards, while social and economic inequalities influence the capacity of households and communities to cope. Pakistan's geographical diversity creates multiple and overlapping risks: riverine and flash floods,

drought, extreme heat, coastal hazards, landslides, glacier-related hazards and changing monsoon patterns. The National Disaster Risk Reduction Strategy 2025–2030 identifies floods, droughts, earthquakes, GLOFs, heatwaves, forest fires and shifting monsoon patterns among the country's significant risks and places inclusive governance and technological innovation within its resilience approach (NDMA, 2025).

For DRR purposes, a hazard refers to a potentially damaging physical, climatic or environmental event; exposure refers to people, infrastructure, livelihoods and assets located in hazard-prone areas; vulnerability refers to the conditions that increase susceptibility to harm; and risk emerges from the interaction of hazards, exposure and vulnerability with available capacities. Gender influences each of these dimensions. For example, women may have less access to land, financial assets, transport or formal employment, while social expectations can increase unpaid care work during emergencies. At the same time, men may face higher exposure to occupational or rescue-related risks. A gender-responsive approach therefore examines differences rather than assuming that one gender is uniformly vulnerable (UNDRR, 2025).

The 2022 Pakistan floods provide a strong case study. UNFPA reported that around 8.2 million women of reproductive age were among the affected population and that nearly 650,000 pregnant women required maternal health services. Damage to roads and health facilities further constrained access to essential care (UNFPA, 2022). The experience shows how a climate-related hazard can interact with health, mobility, poverty, displacement and protection risks, producing differentiated impacts across communities.

3. Risk & Vulnerability Assessment

Gender-responsive risk assessment begins with data that can reveal who is exposed, who has access to resources, who makes decisions and who is likely to be excluded. Sex-, age- and disability-disaggregated data should be complemented by qualitative information on household roles, mobility, livelihoods, access to services and local decision-making. UNDRR identifies the availability and use of disaggregated data as a core requirement for understanding the gendered nature of disaster risk (UNDRR, 2023). Pakistan's NDMA Gender and Child Cell has similarly recommended a comprehensive repository of gender-disaggregated data and stronger gender analysis in DRR decision-making (NDMA, 2025).

Socio-economic vulnerability is particularly important. Women engaged in agriculture, informal work or home-based production may lose income and productive assets during floods and droughts while simultaneously taking on additional care responsibilities. Loss of livestock, crops, household equipment and access to markets can reduce household resilience. The Asian Development Bank notes that gender-responsive policies need to address underlying inequalities, including access to decent work, participation in decision-making and protection from violence (ADB, 2023).

Health and protection are additional dimensions. Displacement can make sanitation, privacy, menstrual hygiene and maternal health services difficult to access. During the 2022 floods, UNFPA reported heightened risks of gender-based violence and severe disruption to reproductive health services. More than 1,000 health facilities were reported damaged in Sindh and 198 in affected districts of Balochistan at an early stage of the emergency (UNFPA, 2022). Such impacts illustrate why evacuation centres, camps and emergency health systems must be designed with gender-specific needs in mind.

Vulnerability should not, however, be equated with helplessness. Women possess knowledge of household water management, food security, caregiving, agriculture and community networks that can strengthen preparedness and recovery. A risk assessment that records only vulnerability can therefore produce incomplete policy. It should also identify capacities, leadership and coping mechanisms. Women-focused investments in skills, financial literacy, institutional participation and livelihood resilience can strengthen both household and community adaptive capacity (ADB, 2020).

4. Community Resilience Factors

Community resilience depends heavily on social capital, trust, local networks and meaningful participation. Women often operate through informal networks that can support information sharing, caregiving, food distribution and assistance to vulnerable households. These networks can become important assets during evacuation and recovery if authorities recognize and engage them. Community-based DRR should therefore include women-led groups, local organizations, health workers, teachers and community representatives in risk mapping, preparedness planning and drills.

Indigenous and local knowledge is another resilience factor. Communities often understand seasonal changes, water routes, agricultural practices and locally appropriate

coping strategies. Combining this knowledge with scientific forecasting can improve preparedness. Participation should be meaningful rather than symbolic: women should have opportunities to influence priorities, budgets, evacuation arrangements and recovery programmes. This is consistent with the Sendai Gender Action Plan, which promotes women's empowerment and leadership in DRR (UNDRR, 2024).

5. Scientific & Institutional Gaps

Despite growing recognition of gender in DRR, important gaps remain. The first is data. Many disaster databases do not consistently capture sex, age, disability, livelihood, location and other relevant characteristics at sufficient geographic resolution. Without reliable data, institutions cannot accurately identify differentiated risks or measure whether programmes are reaching those most affected. Pakistan's recent NDMA roadmap explicitly calls for better gender-disaggregated data, gender audits and stronger participation of women and girls in DRR decision-making (NDMA, 2025).

The second gap is institutional implementation. A policy may mention gender without providing budgets, indicators, responsibilities and accountability mechanisms. Gender-responsive DRR should therefore move from general commitments to operational requirements, including gender analysis in project design, dedicated resources, monitoring indicators and representation in decision-making bodies. The National Disaster Risk Reduction Strategy 2025–2030 includes gender equity and social inclusion as cross-cutting themes and recommends gender analysis, gender audits, equal representation and gender-sensitive indicators (NDMA, 2025).

Technology can also strengthen inclusion, but only when access barriers are considered. Digital early warnings, GIS, remote sensing, mobile communication and AI-supported risk analysis can improve decision-making. However, unequal access to phones, internet, electricity, literacy and digital platforms may exclude some women and marginalized groups. Technology should therefore complement, rather than replace, local communication channels and community outreach.

6. Mitigation Strategies & Best Practices

Gender-responsive DRR and climate adaptation require structural and non-structural measures. Structural measures include resilient health facilities, safe shelters, water and sanitation infrastructure, flood protection and climate-resilient community facilities. These

investments should incorporate safety, privacy, accessibility and the needs of pregnant women, children, older persons and persons with disabilities. Non-structural measures include preparedness training, livelihood diversification, public awareness, community drills, social protection and inclusive planning.

A practical approach for Pakistan is to integrate gender analysis into the full disaster-management cycle. Before disasters, authorities should map gender-specific risks, establish women-inclusive preparedness committees and ensure that early-warning messages reach women through channels they can access. During emergencies, shelters and assistance should provide privacy, sanitation, reproductive health services, protection mechanisms and safe complaint systems. During recovery, women should have equal access to cash assistance, livelihood restoration, land and housing support, training and reconstruction employment.

International experience also supports investment in women's agency rather than only protection. ADB recommends women-focused investments in human resource development, institutional strengthening, financial literacy, representation and skills development as pathways to climate and disaster resilience (ADB, 2020). Such measures can reduce vulnerability while strengthening local capacities.

7. Risk Communication & Early Warning

An early warning system is effective only when people receive, understand and can act on the warning. Gender-responsive early warning therefore requires attention to access, language, literacy, mobility, disability and household decision-making. Messages should use multiple channels, including SMS, radio, mosque/community announcements, local leaders, health workers and face-to-face outreach. Women-led community organizations can help identify households that may otherwise be missed.

The warning itself should be people-centred and action-oriented. Communities need to know what hazard is expected, when it may occur, what action is recommended, where to evacuate and how assistance can be obtained. Two-way communication is equally important. NDMA's gender roadmap recommends communication channels linking communities, women and girls, women-led organizations, DRR practitioners and policymakers (NDMA, 2025). Feedback mechanisms can reveal whether warnings are reaching women and whether evacuation sites are safe and accessible.

8. Policy Recommendations

First, Pakistan should institutionalize gender-responsive risk assessment through mandatory sex-, age- and disability-disaggregated data and gender analysis in national, provincial and district DRR plans. Second, gender-responsive budgeting should be strengthened so that inclusion is supported by identifiable resources rather than policy statements alone. Third, women should have meaningful representation in disaster-management committees, local government planning, climate adaptation programmes and recovery decision-making. Fourth, emergency plans should guarantee access to maternal and reproductive health services, dignity supplies, safe sanitation and protection from gender-based violence.

Fifth, climate adaptation and DRR planning should be better integrated. Pakistan's National Adaptation Plan provides a framework for reducing climate risks and strengthening resilience across sectors, while the NDRRS 2025–2030 provides a national DRR framework. Their implementation should use common gender-sensitive indicators and coordinated financing (MoCC&EC, 2023; NDMA, 2025). Sixth, investments should support women's livelihoods, financial inclusion, skills and access to productive resources. Finally, institutions should expand partnerships with women-led organizations, academia, civil society and local communities so that policies are informed by lived experience and local knowledge.

These recommendations are consistent with recent institutional developments in Pakistan. NDMA's Gender and Child Cell has developed a roadmap aligned with the Sendai Gender Action Plan, while the Authority has also advanced inclusive disaster-management initiatives and guidance for vulnerable groups. The challenge is to ensure that these frameworks are implemented consistently at provincial and district levels and translated into measurable outcomes.

9. Conclusion

Gender-responsive DRR and climate adaptation are essential to building resilient communities in a changing climate. Disaster risk is not gender neutral because social roles, access to resources, power relations, livelihoods and institutional structures shape exposure and capacity. The experience of Pakistan's 2022 floods demonstrates the consequences of failing to account for differentiated needs, particularly in health,

protection, mobility and livelihoods. At the same time, women are not simply victims; they are knowledge holders, caregivers, livelihood actors, community organizers and potential leaders in risk reduction.

A resilient approach therefore requires a shift from viewing gender as an additional consideration to treating it as a core element of risk governance. Better disaggregated data, inclusive early warning, women's leadership, gender-responsive financing, accessible services, community participation and integrated climate adaptation can improve both equity and disaster outcomes. Pakistan's recent policy initiatives provide an institutional foundation, but sustained implementation, local ownership, accountability and evidence-based monitoring are necessary. Gender-responsive DRR is ultimately not only about protecting women and girls; it is about making disaster management and climate adaptation more effective, inclusive and sustainable for society as a whole.

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PARTICIPANT RESEARCH PAPER

Impact of El Niño and La Niña on Global Disaster Risk: A Comparative Analysis with a Focus on Pakistan

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Abstract

The El Niño–Southern Oscillation (ENSO) is one of the most important sources of year-to-year climate variability and can substantially alter temperature and precipitation patterns across different regions of the world. El Niño represents the warm phase of ENSO, while La Niña represents its cooler phase. Although these phenomena originate in the tropical Pacific Ocean, their atmospheric teleconnections can influence droughts, floods, heatwaves, storms, agricultural production and other hazards far beyond the Pacific region.

This paper examines the relationship between ENSO and global disaster risk, with particular attention to Pakistan. It argues that ENSO should not be viewed as an isolated cause of disasters. Rather, ENSO interacts with global warming, changing precipitation patterns, glacier and snow dynamics, rapid urbanization, environmental degradation, poverty and inadequate infrastructure to create cascading and interconnected risks. The uploaded NDMA presentation similarly identifies Pakistan's hazards as interconnected rather than isolated, linking floods, GLOFs, landslides, drought, heatwaves, forest fires, food insecurity and infrastructure damage.

The paper recommends strengthening multi-hazard early warning systems, climate information services, resilient infrastructure, community participation, anticipatory action, food and water security, and the integration of technology and scientific forecasting into disaster risk governance.

1. Introduction

The global climate system is influenced by both long-term anthropogenic climate change and natural climate variability. Among the most significant natural climate phenomena is the El Niño–Southern Oscillation (ENSO), a recurring interaction between the tropical Pacific Ocean and atmosphere. ENSO alternates irregularly between El Niño, La Niña and neutral conditions. El Niño is associated with unusually warm sea-surface temperatures in the central and eastern equatorial Pacific, while La Niña is associated with unusually cold conditions. These oceanic changes modify atmospheric circulation and can influence weather patterns across the globe.

The importance of ENSO for disaster risk management lies in its ability to change the probability of hazards rather than producing a single predictable disaster everywhere. The World Meteorological Organization notes that ENSO can significantly influence global temperature and rainfall patterns, with different regions experiencing increased risks of drought, flooding or extreme heat depending on the phase and season.

Pakistan provides an important case for examining these interactions. Its geography encompasses high mountains, glaciers, river systems, agricultural plains, urban centres, deserts and a long coastline. Consequently, the country is exposed to multiple hazards, including riverine and flash floods, droughts, heatwaves, GLOFs, landslides, cyclones, forest fires and coastal hazards.

The purpose of this paper is therefore to comparatively examine El Niño and La Niña in relation to disaster risk and assess how Pakistan's exposure and vulnerability can transform climate variability into severe humanitarian and socioeconomic consequences.

2. Regional Context & Hazard Profile

ENSO operates on a global scale, but its consequences are geographically uneven. El Niño generally increases global temperatures and changes rainfall distributions, while La Niña often produces broadly opposite effects. However, the precise impact varies by region, season, event strength and interaction with other climate drivers.

The IPCC cautions that the relationship between climate change and future ENSO characteristics contains uncertainties. There is no clear evidence that climate change has already produced a fundamental shift in ENSO frequency or teleconnections, but enhanced ENSO-related precipitation variability is projected under higher warming

scenarios. This distinction is important: disaster planning should not assume that every flood or drought in Pakistan is directly caused by ENSO.

The disaster risk context becomes clearer when four concepts are distinguished. A **hazard** is a potentially damaging physical event or process. **Exposure** refers to people, infrastructure, assets and ecosystems located in hazard-prone areas. **Vulnerability** describes the physical, social, economic and environmental conditions that make exposed populations susceptible to harm. **Risk** emerges from the interaction of hazard, exposure and vulnerability.

Pakistan's vulnerability is intensified by its dependence on climate-sensitive agriculture and water resources, rapidly growing urban populations and extensive settlements in flood-prone areas. The World Bank identifies Pakistan as highly vulnerable to climate-related disasters, while its climate-risk assessments highlight floods, drought, heat and changing water availability as major concerns.

Historical disasters illustrate this vulnerability. The 2010 floods affected approximately 21 million people, while the 2022 floods affected approximately 33 million people and caused billions of dollars in damages and economic losses. These events demonstrate that disaster impacts depend not only on meteorological intensity but also on settlement patterns, infrastructure quality, preparedness and socioeconomic conditions.

3. Risk & Vulnerability Assessment

ENSO-related climate variability can affect Pakistan through changes in temperature, rainfall, drought probability and broader regional circulation. However, these effects should be understood probabilistically rather than as simple one-to-one relationships. An ENSO phase may increase or decrease the likelihood of particular conditions, while other atmospheric and oceanic factors determine the actual outcome.

The NDMA presentation identifies an extensive range of hazards affecting Pakistan: flash floods, urban floods, riverine floods, GLOFs, avalanches, landslides, droughts, cyclones, smog, earthquakes, mudslides, rockfalls, seawater intrusion, cloudbursts, soil salinity, forest fires and heatwaves. The breadth of this hazard profile demonstrates why Pakistan requires a multi-hazard rather than single-hazard risk-management approach.

Socioeconomic impacts are particularly significant. Flooding can destroy houses, roads, bridges, schools, health facilities, agricultural land and livestock. Drought can reduce crop

production and livestock productivity, increase water stress and undermine rural incomes. Extreme heat can reduce labour productivity and place pressure on health systems and electricity supplies. The World Bank notes that climate hazards can affect health, livelihoods, food security and safety while deepening existing inequalities.

Food security is a major concern because agricultural production depends heavily on water availability and suitable temperatures. Climate variability can disrupt planting and harvesting cycles, while floods may destroy standing crops and stored food. The World Bank also projects substantial climate-related risks to agricultural yields and food security in Pakistan.

Vulnerability is not evenly distributed. Poor households often have fewer financial resources to prepare for disasters, relocate temporarily or rebuild damaged homes. Rural communities may depend directly on agriculture, livestock and natural resources, increasing their exposure to drought and floods. Women, children, older people and persons with disabilities can face additional barriers in evacuation, access to information and recovery. Therefore, gender-sensitive and socially inclusive disaster planning is essential.

The key lesson is that a climate hazard becomes a disaster when it interacts with existing vulnerabilities. Building resilience therefore requires reducing exposure and susceptibility while increasing the capacity of households, communities and institutions to anticipate, absorb and recover from shocks.

4. Community Resilience Factors

Community resilience is a critical component of disaster risk reduction because national warning systems and infrastructure cannot eliminate all risks. Communities are often the first to experience a hazard and the first to respond.

Social capital, including family networks, community organizations, local leadership and mutual assistance, can support evacuation, shelter, food distribution and recovery. Local knowledge can also contribute to understanding seasonal environmental changes, flood pathways, water availability and warning signs.

The NDMA presentation's emphasis on moving **“From Risk to Resilience”** is particularly relevant. It identifies improved early warning systems, stronger infrastructure, protection of food and water security and disaster risk reduction as core resilience priorities.

Community participation should therefore be integrated into disaster planning rather than treating communities merely as recipients of warnings. Local residents should participate in hazard mapping, evacuation planning, simulation exercises and identification of vulnerable households.

Indigenous and locally developed coping mechanisms can complement scientific forecasting. However, local knowledge should not replace scientific information. The strongest approach combines community experience with meteorological, hydrological, satellite and climate information.

5. Scientific & Institutional Gaps

Effective ENSO-related disaster management requires reliable climate data, forecasting capability and institutions capable of translating forecasts into early action. Important gaps remain in many developing countries, including limitations in observation networks, localized risk information, data sharing and technical capacity.

Artificial intelligence and machine learning can potentially improve hazard forecasting, pattern recognition and risk assessment. Satellite remote sensing can support flood mapping, glacier monitoring, drought assessment and land-use analysis. Pakistan's NDMA Technical Early Warning system currently highlights AI/ML, satellite remote sensing and real-time multi-hazard monitoring as components of its disaster preparedness capabilities.

Nevertheless, technology alone cannot solve institutional weaknesses. Forecast information must reach decision-makers and communities in a timely, understandable and actionable form. Coordination between federal and provincial authorities, meteorological agencies, local governments and communities remains essential.

Data quality is another challenge. Climate-risk planning requires long-term, high-resolution datasets that connect weather information with population, infrastructure, agriculture and socioeconomic vulnerability. Investment in interoperable databases and open information-sharing mechanisms can improve risk assessment.

6. Mitigation Strategies & Best Practices

Disaster risk reduction should combine structural and non-structural measures. Structural measures include flood protection, drainage systems, resilient roads and bridges, safe

shelters, slope stabilization and climate-resilient water infrastructure. These investments should be guided by updated hazard maps and climate projections.

Non-structural measures include land-use planning, building codes, public awareness, insurance and risk financing, emergency preparedness, evacuation planning and climate-informed agricultural practices.

For Pakistan, special attention should be given to floodplain management, GLOF risk in mountainous areas, urban drainage, heatwave preparedness and coastal resilience. The World Bank identifies investment in climate resilience as essential for protecting Pakistan's economy and reducing poverty.

Agricultural adaptation should include improved water management, climate-resilient crops, diversified livelihoods and better climate information for farmers. Ecosystem-based approaches, such as watershed protection, reforestation and wetland conservation, can complement engineered infrastructure.

International best practice increasingly emphasizes anticipatory action: using forecasts to release resources and undertake preparedness measures before a disaster occurs. This approach is particularly valuable for hazards where warnings can provide several days or weeks of lead time.

7. Risk Communication & Early Warning

Early warning systems are among the most cost-effective tools for reducing disaster losses. An effective system requires four connected elements: risk knowledge, monitoring and forecasting, warning communication, and preparedness to respond.

Pakistan has been strengthening its technical early warning capabilities. NDMA reports that its technical early warning functions use multi-hazard monitoring, environmental and hazard data, satellite observations and advanced analytical tools to support timely alerts and risk-informed decisions.

However, producing a forecast is only the first step. The warning must reach people in ways they understand and trust. Communication should use multiple channels, including SMS, mobile applications, television, radio, social media, mosque/community networks and local authorities. Messages should explain not only **what** is expected but also **what people should do**.

Gender-sensitive communication is also important. Women and marginalized groups may have different access to phones, transport, information and decision-making authority. Warning systems should therefore identify communication barriers and ensure that messages reach vulnerable groups.

The current NDMA approach includes disaster early warnings and hazard outlooks covering risks such as extreme rainfall, flooding, GLOFs, avalanches, forest fires and heatwaves, demonstrating the value of multi-hazard preparedness.

8. Policy Recommendations

Based on the analysis, the following policy measures are recommended:

a. **Develop an integrated ENSO–disaster risk framework.** ENSO forecasts should be incorporated into seasonal and multi-hazard risk assessments rather than considered separately from other climate drivers.
b. **Strengthen people-centred early warning systems.** Forecasts should be translated into localized, actionable warnings that reach vulnerable populations through multiple communication channels.
c. **Expand climate-resilient infrastructure.** Flood drainage, river protection, roads, bridges, water systems and public buildings should be designed using current and projected climate risks.
d. **Improve climate and disaster data integration.** Meteorological, hydrological, satellite, demographic and socioeconomic datasets should be integrated to produce localized risk maps.
e. **Increase community participation.** Local communities should participate in risk mapping, preparedness planning, drills and recovery decisions.
f. **Integrate AI and remote sensing responsibly.** Artificial intelligence, machine learning and satellite technology should supplement—not replace—expert judgment and community knowledge.
g. **Protect food and water security.** Climate-smart agriculture, water conservation, diversified livelihoods and improved irrigation management should be prioritized.
h. **Strengthen institutional coordination.** Federal, provincial and local disaster-management institutions should use common protocols for forecasting, warning, evacuation and response.

i. **Mainstream gender and social inclusion.** Disaster plans should explicitly address the needs of women, children, older people, persons with disabilities and economically vulnerable households.

j. **Shift from response to anticipatory risk management.** Resources should be mobilized before forecast hazards occur whenever credible warnings provide sufficient lead time.

These recommendations align closely with the uploaded presentation's central message: disaster hazards are interconnected and resilience requires simultaneous investment in early warning, infrastructure, food and water security and disaster risk reduction.

9. Conclusion

El Niño and La Niña are natural components of the climate system, but their effects can substantially alter disaster risk around the world. Their significance is particularly important in a warming climate because natural variability interacts with long-term temperature increases, changing rainfall patterns, glacier dynamics and socioeconomic vulnerability.

For Pakistan, ENSO should not be treated as a standalone explanation for floods, droughts or heatwaves. Instead, it should be incorporated into a broader risk framework that considers multiple climate drivers and the country's extensive exposure and vulnerability. Pakistan's experience with major floods, heatwaves, droughts and mountain hazards demonstrates the consequences of interconnected risk.

The central finding of this paper is that resilience depends on moving from reactive disaster response toward anticipatory, science-based and community-centred risk management. Stronger infrastructure is necessary, but it must be accompanied by effective early warning, reliable data, community participation, food and water security, institutional coordination and inclusive policies.

Pakistan already possesses important institutional foundations for this transition, including NDMA's expanding technical early warning and multi-hazard monitoring capabilities. The next step is to connect scientific forecasting with local decision-making and ensure that warnings lead to timely action.

Ultimately, disaster risk is not determined by hazards alone. It is shaped by the interaction of climate variability, exposure, vulnerability and preparedness. A resilient

Pakistan therefore requires an integrated approach in which science, technology, institutions, communities and policy work together to transform climate information into practical risk reduction.

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PARTICIPANT RESEARCH PAPER

The Role of International Organizations in Disaster Risk Reduction and Response: A Pakistan Case Study

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Abstract

Pakistan ranks among the world's most climate-vulnerable countries despite contributing only a fraction of global historic carbon emissions, and its history of recurrent earthquakes, floods, and cyclones has repeatedly overwhelmed national response capacity. This paper examines the role of international organizations in disaster risk reduction (DRR) and response in Pakistan, drawing on the country's five most significant disasters between 1935 and 2022, including the 1935 Quetta earthquake, the 2005 Kashmir earthquake, 2007's Cyclone Yemyin, the 2010 Indus super-floods, and the 2022 monsoon mega-floods. It reviews the humanitarian, financial, and technical roles played by United Nations agencies, international financial institutions, and the Red Crescent/Red Cross network, and it weighs their documented benefits against persistent limitations such as slow and conditional disbursement, coordination gaps, and aid dependency. The analysis finds that international engagement remains indispensable for financing, technical expertise, and coordination immediately after large-scale disasters, but that its long-term value depends on how firmly it is anchored in national ownership. The paper concludes with policy recommendations centred on strengthening NDMA-led coordination, expanding pre-disaster financing, localizing early warning systems, and negotiating faster and less-conditional disbursement of pledged international support.

Keywords: Disaster risk reduction, early warning systems, humanitarian financing, international organizations, Pakistan.

1. Introduction

Pakistan sits at the confluence of the Indus River basin, an active tectonic boundary, and an intensifying South Asian monsoon system, exposing it to floods, earthquakes, cyclones, and droughts in near-continuous succession. It ranks eighth on the Global Climate Risk Index despite contributing less than half of one percent of global historic carbon emissions (UN/Government of Pakistan, 2022), a mismatch that has made it a focal point in debates on climate justice and loss-and-damage financing.

The scale of loss is difficult to overstate: the 2022 monsoon floods alone affected an estimated 33 million people and caused over $40 billion in damage (OCHA, 2022), while the 2005 Kashmir earthquake remains the deadliest disaster in the country's modern history. Each major disaster follows a similar pattern — a surge of humanitarian assistance, pledges at donor conferences, and an uneven translation of those pledges into disbursed funds and rebuilt capacity.

This paper's problem statement is that while international organizations play a significant role in Pakistan's disaster response, the terms, speed, and sustainability of that engagement remain contested. Its purpose is to critically assess both the contributions and limitations of international involvement, using Pakistan's five most consequential disasters as an evidentiary base. The objectives are threefold: to profile Pakistan's disaster risk and historical disaster pattern; to evaluate the financial, technical, and coordination roles of key international actors; and to derive policy recommendations that strengthen national ownership while preserving the benefits of international partnership. The scope is limited to disaster response and recovery financing and coordination, not Pakistan's broader climate adaptation architecture.

2. Regional Context & Hazard Profile

Disaster risk is conventionally understood as a function of hazard, exposure, and vulnerability, moderated by capacity to cope. A hazard is a potentially damaging physical event; exposure refers to people and assets situated in hazard-prone areas; vulnerability describes characteristics that make them susceptible to harm; and risk is the resulting probability of harmful consequences (UNDRR, 2022). Pakistan's hazard profile is unusually dense: the Indus basin, where monsoon rainfall and Himalayan glacial melt combine, drives recurring flood risk; active seismic boundaries in the north and west

generate earthquake risk from Quetta to Kashmir; and the southern coastline is periodically struck by Arabian Sea cyclones.

The table below reviews the country's five most significant disasters, illustrating both the diversity of hazards and a worsening trend in scale, from the 1935 Quetta earthquake through the 2022 monsoon mega-floods, whose intensity scientific attribution studies link directly to climate change (NDMA; EM-DAT; OCHA; UNICEF; ReliefWeb).

Year	Event	Scale	Human & Economic Toll	Significance
1935	Quetta Earthquake	M7.7	~30,000–60,000 deaths	One of South Asia's deadliest quakes; levelled Quetta city
2005	Kashmir Earthquake	M7.6	~73,000 deaths; 3.3M homeless	Deadliest disaster in Pakistan's modern history
2007	Cyclone Yemyin	Cat. 2	~730 deaths; 2.3M affected	Flash floods across Balochistan & Sindh coastlines
2010	Indus Super-Floods	—	~2,000 deaths; 20M affected	One-fifth of the country submerged; worst floods on record until 2022
2022	Monsoon Mega-Floods	—	~1,700 deaths; 33M affected	$40B+ in losses; 7.9M displaced; climate-change amplified

A comparative reading shows a clear pattern by hazard type. Earthquakes dominate the death toll: the 1935 Quetta and 2005 Kashmir events together account for over 130,000 deaths, reflecting the sudden-onset nature of seismic events and limited warning time. Floods dominate displacement and cost: the 2010 and 2022 floods affected 20 million and 33 million people respectively — lower death tolls but far larger humanitarian and economic footprints. This divergence shapes the assistance required: earthquake

response prioritizes urban search-and-rescue, while flood response depends on sustained logistics, shelter, and food security support over months.

3. Risk & Vulnerability Assessment

The socio-economic impact of Pakistan's major disasters extends well beyond the death toll. The 2022 floods left 84 districts declared 'calamity-hit' and generated an estimated $16.3 billion requirement for resilient rehabilitation and reconstruction (OCHA, 2022–2023). Livelihoods dependent on agriculture, the backbone of the rural economy, were disproportionately disrupted, with crops, irrigation infrastructure, and livestock destroyed across Sindh and southern Punjab, while cross-agency assessments found more than 3.5 million children at risk of a worsening nutrition crisis.

Vulnerability is not evenly distributed. Women, children, the elderly, and persons with disabilities consistently bear a disproportionate share of disaster impact, through loss of access to health services, disrupted schooling, or heightened protection risks in displacement. Women in flood-affected areas often face constrained mobility, reduced access to relief distribution points, and elevated protection risks in crowded relief camps, while shouldering the bulk of caregiving during recovery. Informal settlements along riverbanks, weak building codes in seismic zones, and limited livelihood diversification compound the susceptibility of already-marginalized populations to recurring shocks.

4. Community Resilience Factors

Despite weak formal safety nets, Pakistani communities have repeatedly shown resilience rooted in social capital and local knowledge. Kinship networks, mosque committees, and informal community organizations routinely mobilize first-response support — sheltering neighbours, sharing food stocks, organizing evacuation — well before formal humanitarian actors arrive. Indigenous knowledge of seasonal flood patterns and locally adapted housing techniques continues to inform coping mechanisms, even where it is not systematically documented or integrated into formal DRR planning.

Community participation in early warning dissemination has proven valuable where deliberately fostered, for instance through Red Crescent-supported community-based DRR programmes and NDMA/PDMA outreach. Yet these capacities remain under-leveraged at scale: response planning still tends to treat affected communities primarily as aid recipients rather than partners with locally validated knowledge — a persistent gap

between community-level coping strength and its integration into institutional DRR strategy.

5. Scientific & Institutional Gaps

Significant gaps remain in the scientific, technological, and institutional foundations of Pakistan's DRR system. Flood forecasting and glacial lake outburst flood (GLOF) monitoring, while improved with UN agency support, still lag the scale and speed of monsoon variability observed under climate change. Adoption of AI and machine-learning tools for hazard prediction and resource allocation remains at an early, largely donor-funded stage rather than embedded in routine NDMA and PMD operations, and historical disaster-loss data, exposure datasets, and vulnerability indices remain incomplete and fragmented across agencies.

Institutional weaknesses compound these technical gaps. Coordination between the federal NDMA and provincial disaster management authorities (PDMAs) is not always seamless, and capacity varies considerably between provinces, with Balochistan and interior Sindh typically weakest. Post-Disaster Needs Assessments, such as the one conducted after the 2022 floods, have improved the evidence base for recovery planning, but institutional capacity to translate findings into financed, sequenced, monitored reconstruction remains a persistent constraint.

6. International Organizations, Mitigation Strategies & Best Practices

A layered ecosystem of UN agencies, international financial institutions, and humanitarian networks shapes Pakistan's disaster response. UN OCHA coordinates the humanitarian response and issues Flash Appeals; UNICEF and the World Food Programme lead on child protection, nutrition, and food security; the World Bank and Asian Development Bank provide post-disaster financing and reconstruction loans; WHO supports health emergency response; the IFRC/Red Crescent network is a first-responder and community-based DRR actor; and UNDP focuses on recovery planning and institutional capacity building.

These contributions are well documented. In emergency financing, the World Bank and ADB mobilized billions in post-2022-flood recovery loans and grants. In rapid relief, the OCHA-coordinated Flash Appeal delivered food, shelter, and medicine to over 7.7 million people by mid-2023. In technical capacity, UN agencies support NDMA's flood

forecasting, GLOF monitoring, and hazard-mapping systems. And in global visibility, sustained international reporting has kept Pakistan's climate vulnerability on the global agenda, contributing to the COP27 'loss and damage' fund.

Associated mitigation strategies span structural measures — embankments, drainage, and retrofitted health facilities financed through World Bank and ADB resilience projects — and non-structural measures such as NDMA/PDMA capacity building, Red Crescent-delivered preparedness training, and simulation exercises. International best practice increasingly emphasizes parametric insurance, anticipatory action financing that releases funds ahead of a forecast hazard, and multi-hazard early warning systems integrating seismic, hydrological, and meteorological data — approaches Bangladesh and the Philippines have begun institutionalizing and that offer transferable lessons for Pakistan.

Institution	Pledged	Status
Islamic Development Bank	$4.20B pledged	Largest single pledge
World Bank	$2.00B pledged	$969M disbursed by early 2024
Asian Development Bank	$1.56B pledged	Only ~$109M disbursed by early 2024
AIIB	$1.00B pledged	$250M disbursed
IMF (EFF tranche)	$1.10B pledged	Repeatedly delayed pending reforms
Bilateral (US, Saudi, China, EU, Japan)	Multiple	Mixed grant / loan / oil-facility support

At the January 2023 Geneva Donors' Conference, international partners pledged over $9 billion against Pakistan's $16.3 billion reconstruction needs; of roughly $11 billion pledged across all international donors, only about $1.4 billion — some 13 percent — had been disbursed within the first year, illustrating the disbursement gap discussed above (Geneva Donors' Conference, 2023; ADB; World Bank).

7. Risk Communication & Early Warning

Effective risk communication and early warning depend on reaching the last mile with actionable, comprehensible information in time to act. International partners have supported NDMA and the Pakistan Meteorological Department in strengthening forecasting capacity, but translating forecasts into people-centred, gender-sensitive warnings remains uneven. Women, who often have less access to mobile technology in rural areas, and persons with disabilities, who may face physical barriers to evacuation, require deliberately tailored communication rather than generic broadcast alerts.

Community engagement in dissemination — through mosque announcements, community volunteers, and local government functionaries — has proven more effective at reaching remote, low-literacy populations than technology-dependent channels alone. The 2022 floods response showed both the value and limits of current arrangements: Post-Disaster Needs Assessment-guided planning improved the evidence base, yet aid distribution was still slowed by weak last-mile coordination with local authorities.

8. Policy Recommendations

The findings above point toward a policy agenda centred on converting international support into durable, nationally owned capacity rather than recurring dependency. Four recommendations follow directly from the evidence reviewed.

S. No	Recommendation	Rationale
1	Strengthen NDMA-Led Coordination	Position national institutions as the lead coordinator of all international assistance rather than a recipient of parallel, uncoordinated efforts.
2	Invest in Pre-Disaster Financing	Expand contingency funds and parametric insurance mechanisms to reduce reliance on post-disaster appeals and shorten the gap between hazard and relief.
3	Localize Early Warning Systems	Scale up NDMA/PMD forecasting capacity so that international technical support builds local systems rather than substituting for them.
4	Negotiate Faster, Untied Disbursement	Push for streamlined, less-conditional release of pledged international financing to close the gap

S. No	Recommendation	Rationale
		between commitments and delivery.

These recommendations respond directly to the limitations identified in this paper: aid dependency, slow and conditional disbursement, coordination and duplication gaps, and sovereignty concerns over donor-driven agenda-setting. Repeated reliance on external appeals can weaken incentives for domestic investment in resilience; pledged funds often arrive late, partially, or tied to conditions that limit Pakistan's flexibility in recovery planning; multiple agencies with overlapping mandates can fragment response efforts and strain local government capacity; and donor priorities sometimes shape national DRR policy more than locally identified needs. Addressing these limitations through stronger national coordination, pre-arranged financing, localized technical systems, and faster disbursement would allow Pakistan to retain the benefits of international partnership — resource mobilization, technical expertise, and global accountability — while reducing exposure to its structural weaknesses.

9. Conclusion

Pakistan's disaster history, from the 1935 Quetta earthquake to the 2022 mega-floods, shows a rising human and economic toll despite decades of institutional learning, underscoring the urgency of science-based planning that integrates social capital, indigenous knowledge, and modern technology within a genuinely integrated national approach to resilience. International organizations remain indispensable partners for financing, technical expertise, and coordination in the immediate aftermath of large-scale disasters, as demonstrated by the billions mobilized in post-2022-flood recovery financing and the millions reached through coordinated humanitarian appeals.

At the same time, the evidence reviewed in this paper shows that international engagement delivers its greatest value when paired with strong national ownership, and its least value where dependency, disbursement delay, or institutional fragmentation are allowed to persist. The path forward for Pakistan's disaster risk reduction system is therefore not a reduction in international engagement, but a recalibration of it: better coordinated, faster disbursed, and more firmly anchored in locally led institutions such as NDMA and the provincial disaster management authorities. Achieving this recalibration

will determine whether the next major disaster is met with the same recurring cycle of appeal, delay, and partial recovery, or with a more resilient and self-directed national response system.

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PARTICIPANT RESEARCH PAPER

IoT-Based Flood Monitoring and Early Warning Systems: A Survey of Technologies, Gaps, and Policy Pathways for Disaster Risk Reduction

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Government of Pakistan

Abstract

Floods are among the most damaging weather-related hazards in climate-vulnerable countries, and Pakistan's 2022 monsoon disaster demonstrated how exposure, weak infrastructure, and delayed communication can combine into a national crisis. This review examines how Internet of Things (IoT) technologies can strengthen flood monitoring and people-centred early warning systems (EWS) in Pakistan and comparable South Asian settings. It synthesizes evidence on low-cost water-level and rainfall sensors, connectivity, cloud analytics, machine learning, community-based warning, and institutional coordination. The analysis finds that IoT can expand observation coverage and shorten the time between detection and action, but sensors alone do not create safety. Data gaps, power and connectivity failures, poor maintenance, limited local capacity, false alarms, and weak last-mile dissemination can all break the warning chain. The paper therefore proposes an integrated model linking community sensors with NDMA/PDMA procedures, multilingual alerts, volunteer networks, and routine drills. Policy priorities are standardized data, targeted deployment in high-risk districts, sustainable maintenance finance, AI/ML capacity, and inclusive governance aligned with the Early Warnings for All initiative.

Keywords: Climate change adaptation; disaster risk reduction (DRR); early warning systems (EWS); flood monitoring; Internet of Things (IoT).

Introduction

Flood risk is produced by the interaction of a physical hazard with exposure and vulnerability. Climate change is increasing the likelihood of intense rainfall and compound events, while settlement growth, degraded drainage, unsafe housing, and livelihood dependence on agriculture increase the consequences of flooding. Pakistan illustrates this interaction. The 2022 floods affected approximately 33 million people and caused 1,739 deaths; the post-disaster needs assessment estimated US$14.9 billion in damage, US$15.2 billion in economic losses, and US$16.3 billion in recovery and reconstruction needs (Government of Pakistan et al., 2022; NDMA, 2024).

Traditional gauges, manual observation, and periodic bulletins remain important, but they can be sparse, difficult to maintain, or too slow for flash-flood settings. IoT systems add distributed sensors that measure water level, rainfall, flow, soil moisture, or structural vibration and transmit observations to a gateway or cloud platform. Alerts can then be triggered by thresholds, forecast models, or a combination of sensor and weather data (Danang et al., 2019; Wang & Abdelrahman, 2023).

This paper asks how IoT-based monitoring can complement, rather than replace, national and community EWS. It focuses on Pakistan and the wider South Asian region, with three objectives: to describe the technical and institutional requirements of an effective system; to assess risks, gaps, and inclusion challenges; and to recommend a practical pathway for linking technology to early action.

Regional Context and Hazard Profile

Pakistan faces multiple flood types. Glacial lake outburst floods (GLOFs) and flash floods threaten high-altitude and mountainous communities, often with limited lead time. Riverine floods affect densely populated and agriculturally important areas along the Indus system. Urban and pluvial flooding, including drainage overload and waterlogging, increasingly affects cities. A single national sensor design is therefore unlikely to fit every location.

Table 1. Hazard-specific design requirements for IoT-enabled flood monitoring.

Hazard type	Primary monitoring signals	Operational requirement	Priority communication

GLOF / mountain flood	Lake level, temperature, rainfall, debris or flow	Redundant sensors, local observers, rapid escalation	Sirens, radio, satellite/GSM backup, trained village teams
Flash flood	Short-duration rainfall, upstream level, flow velocity	Very low latency and local thresholds	SMS/IVR, mosque or community announcements, evacuation routes
Hazard type	**Primary monitoring signals**	**Operational requirement**	**Priority communication**
Riverine flood	River gauge, rainfall, upstream discharge, forecast models	Trend monitoring and forecast lead time	NDMA/PDMA bulletins, SMS, media, district control rooms
Urban / pluvial flood	Rainfall intensity, drain level, pump status, road cameras	Dense sensing and traffic/public service coordination	Mobile alerts, variable-message signs, local government channels

The 2022 disaster also showed that vulnerability is uneven. A warning that arrives only in a technical dashboard is not a completed warning. It must be understandable, trusted, accessible, and linked to a feasible action (IFRC, 2009; UN DESA, 2023).

Risk and Vulnerability Assessment

IoT can reduce observational vulnerability by extending monitoring into places that lack expensive gauge infrastructure. Low-cost ultrasonic or pressure sensors, rain gauges, microcontrollers, and GSM or LoRa gateways can be deployed in distributed networks. Solar power and edge processing can reduce dependence on continuous grid electricity or a permanent broadband connection. However, low cost does not mean low risk. Sensors can drift, be damaged by debris, lose power, or transmit incomplete data.

Manual activation, weak calibration, and unplanned replacement cycles can turn a promising pilot into an unreliable service.

Data and model risk are equally important. Machine-learning forecasts require long, consistent, and representative time series. A model trained on one basin may not generalize to another with different terrain, rainfall patterns, or sensor quality. Black-box predictions can also make it difficult for officials and communities to understand why an alert was issued. For operational use, model outputs should be combined with transparent thresholds, expert review, uncertainty indicators, and documented escalation procedures (Nik Mohd Kamal et al., 2025; Wang & Abdelrahman, 2023).

Social vulnerability can amplify technical gaps. Women may receive alerts later where they have less access to phones or public information. People with hearing, visual, or mobility limitations may need alternative formats and assistance plans. Lowincome families may understand a warning but lack transport, cash, or a safe destination. These conditions make community participation a core design requirement, not an optional outreach activity.

Community Resilience Factors

Community networks often provide the last mile of an EWS. Local volunteers, mosque committees, schools, health workers, farmers' groups, media, and rescue organizations can interpret warnings and support evacuation, shelter, and accountability. Bangladesh's cyclone preparedness model demonstrates the value of trained volunteers who connect official forecasts to household action. Comparable arrangements can complement IoT deployments in Pakistan, especially where connectivity is intermittent.

Local knowledge also improves sensor placement and warning credibility. Residents know which roads become impassable, which bridges fail first, where water accumulates, and which messengers are trusted. The strongest design is therefore hybrid: community observation and knowledge inform the system, IoT improves continuous measurement, agencies validate the signal, and local networks deliver action-oriented messages.

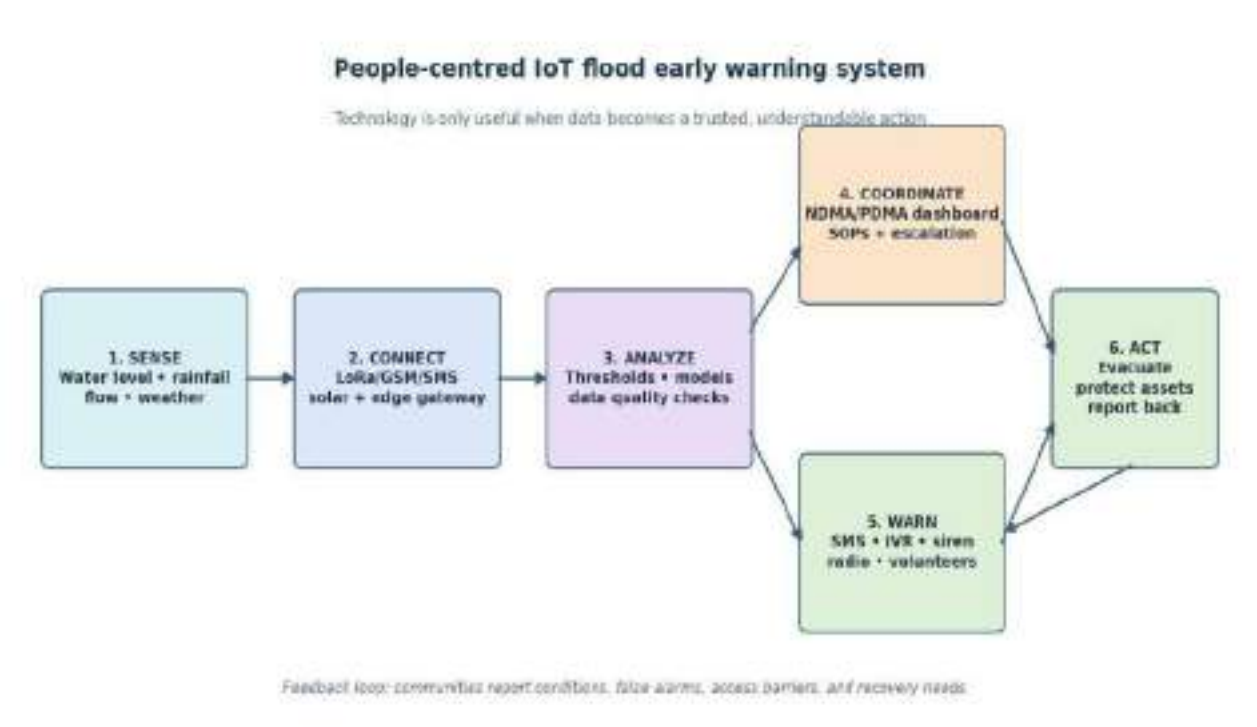

Figure 1. Conceptual architecture for a people-centred IoT flood early warning system.

Scientific and Institutional Gaps

The global picture reinforces the need to strengthen the full warning chain. UNDRR and WMO reported that 101 countries, or 52 percent, reported having a multi-hazard early warning system in 2023; the indicator measures reported existence, not equal quality or effectiveness (UNDRR & WMO, 2023). The remaining gap is not solved by devices alone. Four weaknesses are especially important in Pakistan and similar contexts:

- Observation and data continuity: sensor coverage, calibration, metadata, and long-term maintenance are often weaker than the initial deployment plan.
- Connectivity and energy: mountainous and rural areas may face unreliable electricity, mobile coverage, backhaul, and physical access for repairs.
- Institutional interoperability: agencies may use different standards, dashboards, thresholds, and reporting procedures, delaying escalation.
- Capacity and accountability: local operators need training, budgets, ownership, and drills; communities need to know what an alert means and who is responsible for action.

Research prototypes using time-series methods, long short-term memory networks, or hybrid sensor-weather models are promising, but operational deployment requires validation across seasons, basins, and missing-data conditions. A minimum national data standard and shared evaluation protocol would make evidence more comparable and reduce duplication.

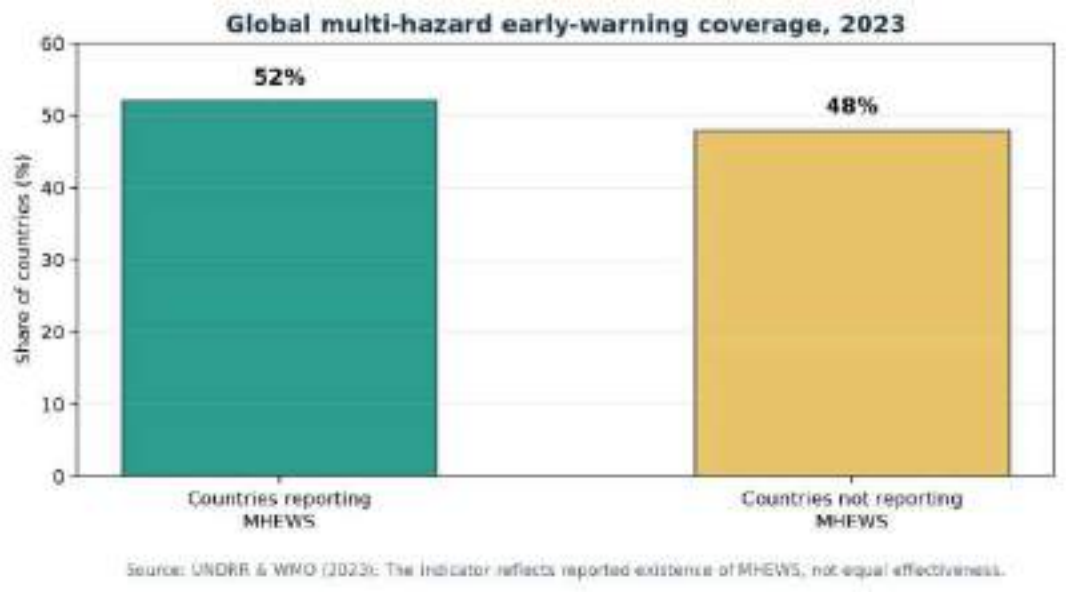

Figure 2. Global reported MHEWS coverage in 2023. The figure is a benchmark for the scale of the implementation gap, not a Pakistan-specific performance measure.

Mitigation Strategies and Best Practices

A practical mitigation strategy combines structural and non-structural measures. Structural measures include drainage improvement, safe bridges, flood shelters, river protection, and resilient power and communications. Non-structural measures include land-use planning, risk maps, building guidance, preparedness training, drills, insurance or social protection, and early warning. IoT is most valuable when it supports this wider package.

Deployment should begin with risk-based pilots rather than scattered technology demonstrations. A pilot should define the hazard, target population, warning threshold, responsible agency, maintenance budget, backup communications, and success measures before sensors are purchased. Useful success measures include data

availability, alert lead time, false-alarm rate, message reach, comprehension, evacuation completion, and restoration time after failure. Systems should be tested during drills and ordinary conditions, not only during a crisis.

Risk Communication and Early Warning

An effective EWS has four linked elements: risk knowledge; detection and forecasting; warning dissemination; and preparedness to respond. IoT mainly strengthens the second element, but failure in any other element can negate the investment. Messages should state the hazard, location, expected timing, severity, recommended action, safe destination, and source of assistance. They should use local languages and multiple channels, including SMS, IVR, sirens, radio, social media, mosque announcements, and trained volunteers.

Last-mile design should be tested with the people most likely to be missed. Women's groups, disability organizations, older people, schools, and remote settlements should participate in message design and drills. Agencies should publish clear escalation rules, including when a sensor alert is confirmed, who authorizes a public warning, and how false alarms are corrected without undermining trust. Community feedback should be recorded as system data, not treated as anecdotal.

Policy Recommendations

The following recommendations translate the review into an implementation pathway:

Table 2. Recommended policy pathway for an integrated IoT flood EWS.

Priority	Recommended action	Lead / partners	Suggested horizon
1. Standardize	Adopt national specifications for sensor metadata, calibration, thresholds, APIs, data sharing, cyber security, and maintenance logs.	NDMA, PMD, PDMAs, universities, telecom operators	0–12 months
2. Target risk	Prioritize districts and basins using hazard, exposure,	NDMA/PDMA, local government,	0–18 months

	vulnerability, and access-to-warning criteria; avoid technology-first placement.	communities	
3. Close the last mile	Require multilingual, gender-sensitive dissemination plans using SMS/IVR, sirens, radio	PDMAs, Rescue 1122, local committees, media	0–18 months
Priority	**Recommended action**	**Lead / partners**	**Suggested horizon**
4. Build capability	Create training and maintenance programmes for technicians, district control rooms, volunteers, and data analysts.	NDMA, universities, technical institutes	12–36 months
5. Govern AI/ML	Use transparent validation, uncertainty reporting, human review, and cross-basin testing before operational decisions.	PMD, universities, NDMA/PDMA	12–36 months
6. Finance continuity	Protect recurring budgets for calibration, replacement, connectivity, drills, and post-event evaluation, not only capital purchase.	Finance and climate institutions, donors	12–36 months

Conclusion

IoT-based flood monitoring can improve the spatial coverage, speed, and granularity of flood observation in Pakistan and South Asia. Low-cost sensors, cloud platforms, edge processing, and machine-learning tools can complement established hydrometeorological services and help communities receive earlier, more localized warnings. Yet the central finding of this review is straightforward: a sensor network is not

an early warning system unless it is connected to trusted institutions, clear procedures, inclusive communication, and the capacity to act.

The strongest pathway is a hybrid one. National and provincial agencies should provide standards, forecasting, coordination, and accountability. Universities and technology partners should improve data quality and model validation. Local governments and community organizations should shape warning thresholds, message formats, evacuation plans, and feedback loops. With stable adaptation finance and alignment with Early Warnings for All, Pakistan can use IoT not as a fashionable pilot, but as part of a durable, people-centred disaster risk reduction system.

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PARTICIPANT RESEARCH PAPER

Impact of Climate Change on Food Security and the Agriculture System

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Abstract

Climate change is emerging as a systemic threat to Pakistan's food security and agriculture, disrupting crop productivity, water availability, livestock, soils, infrastructure, food supply chains, rural livelihoods and nutrition through rising temperatures, erratic rainfall, droughts and floods. Rise in 1°C temperature can reduce yields of maize by 7.4%, wheat by 6.0% and rice by 3.2%, while anthropogenic climate change has already significantly slowed global agricultural productivity growth. Pakistan's vulnerability is particularly high because agriculture contributes 23.44% of GDP and consumes approximately 95% of freshwater withdrawals; in 2025–26, surface-water availability was only 92.0 MAF against 103.5 MAF average system usage. Recent floods demonstrate the scale of risk: the 2025 floods inundated 17,304 km², including 14,498 km² of agricultural land, exposing approximately 11.3 million people, while 7.5 million people were in IPC Phase 3 or worse during December 2025–March 2026. Climate shocks therefore threaten all four pillars of food security (availability, access, utilization and stability) by reducing production, increasing prices, eroding incomes, disrupting markets and worsening nutritional vulnerability. The paper recommends shifting from reactive disaster response to anticipatory, climate-resilient food-system management through climate-triggered early warning, shock-responsive social protection, climate-smart agriculture, resilient seeds, water-productivity reforms, agricultural insurance, AI and satellite-based monitoring, resilient infrastructure, diversified food systems and integrated climate-risk planning, making food security a core pillar of disaster risk reduction and climate adaptation.

1. Introduction

Climate change is a shift in weather parameters over a long period of time usually a decade or more due to natural or anthropogenic activities (UN, 2026). Climate change is one of the primary threats to the global food security, and agriculture systems that is disrupting the socio-economic well-being of the general populace and posing a severe threat to food availability, access, utilization and stability of food and agriculture system (Anshida et al, 2026). Changing climate leads to rising temperature, shifting weather patterns, erratic rainfall, flash floods, drought, pest and diseases outbreak and other unfavorable climate shocks that directly and indirectly affect the arable land, reducing crop productivity, yield, affecting assets, food price inflation, and food supply chain (Sharma, 2023; Arneth, 2019; Lobell, 2008; Zhao et al., 2017).

World Food Program (2025) defined food security as *"The state in which all people, at all times, have physical, social, and economic access to sufficient, safe, and nutritious food that meets their dietary needs and food preferences for an active and healthy life."*. furthermore, there are 4 key dimensions of food security

Dimensions	Description
Food availability	Sufficient supply of food through domestic production, domestic stock or trade
Food accessibility	Physical and economic access to acquire food. It reflects accessibility to market and purchasing power.
Food utilization	How the body uses the nutrients in food, which relies on clean water, proper sanitation, and good food preparation.
Stability	Maintaining the other three pillars over time, without disruption from weather shocks, economic crises, or conflict.

Given the global fragile food security baseline, 645 million people faced hunger in 2025 and about 2.1 billion experienced moderate or severe food insecurity. Similarly, roughly 2.7 billion could not afford a healthy diet (FAO, 2026). Natural disasters loss of US$3.8 trillion in crop and livestock during 1991–2021 which is equivalent to about US$123 billion annually or 5% of global agricultural GDP (FAO, 2023).

2. Regional Context & Hazard Profile

Being an Agrarian economy, Agriculture accounts for 23.44% of GDP in 2025–26 and remains a bedrock to food supply, rural livelihoods and exports (Government of Pakistan, 2026). Pakistan is the top 10 most vulnerable countries to the negative impacts of climate change despite emitting less than 1% of the GHGs. It is affected by riverine and flash floods, drought, extreme heat, erratic monsoon rainfall, waterlogging, salinity, changing growing seasons and climate-sensitive pests and diseases. Similarly, IPCC (2019) reported that a shift in Pakistan's crop calendar i.e. spring maize growing periods advanced by approximately 4.6 days per decade during 1980–2014, while autumn maize sowing was delayed by about 3.0 days per decade.

In 2025 monsoon floods, 17,304 km² inundated across Punjab, Sindh and Khyber Pakhtunkhwa, including 14,498 km² of agricultural land which accounts for 7.3% of agricultural area in the three provinces. In staple crops, rice was the most affected mapped crop at 2,959 km², followed by cotton at 1,307 km² and sugarcane at 403 km². the disaster exposed 11.3 million people, including roughly 6 million rural residents (FAO, 2026).

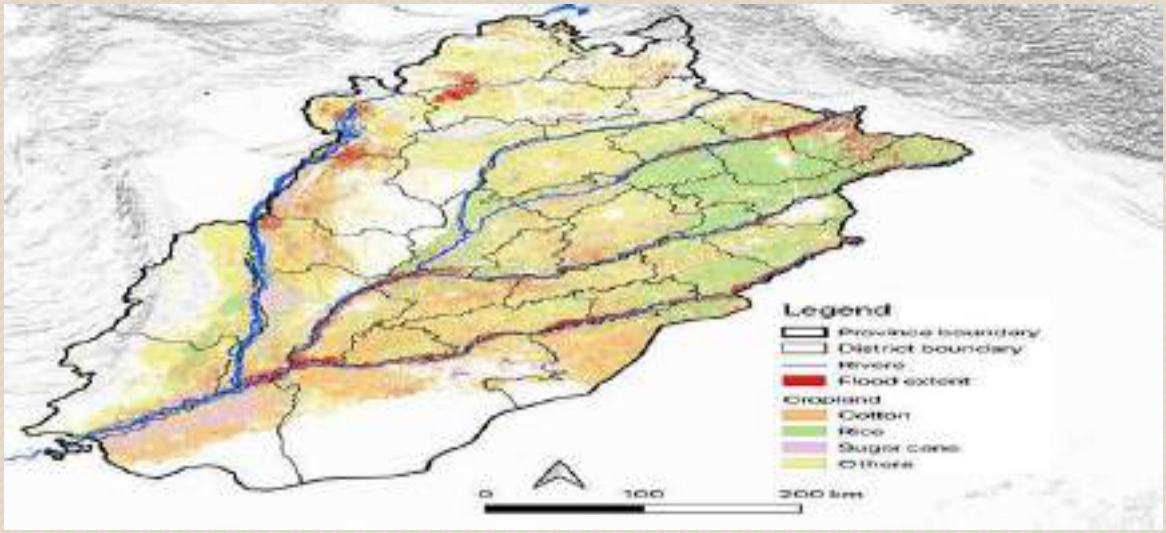

Figure 1. Flood extent over major cropland zones, reproduced from the supplied research file and cross-checked against FAO's 2025 geospatial assessment (FAO, 2026).

3. Risk & Vulnerability Assessment

Climate change and its allied disasters affect all four dimensions of food security.

a) Availability

First, availability is affected as heat shortens crop life cycle; drought reduces soil moisture and irrigation; floods destroy crops, and pests and diseases expand. According to Rana et al (2024) that climate change could potentially reduce Pakistan's wheat yield by 14.7% and rice yield by 20.5% by 2050.

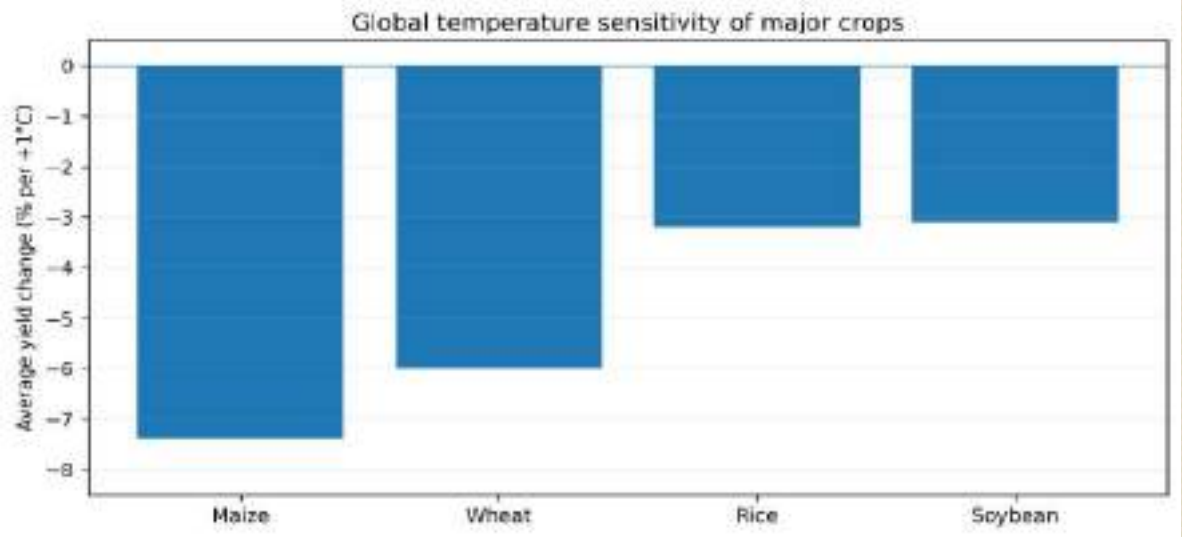

Figure 2. Average global yield response to +1°C warming, without CO_2 fertilization, effective adaptation and genetic improvement (Zhao et al., 2017).

b) Access to food

Physical and economic access is vulnerable due to climate shocks which disrupts agriculture infrastructure, reducing food supply and increasing food price inflation. FAO (2026) reported that wheat-flour prices inflation by about 50–90% during July 2025-January 2026 (FAO, 2026). Furthermore, a study was conducted by IPC estimated 7.5 million people (21% of the analyzed population in 45 vulnerable rural districts of Pakistan), were affected including about 1.25 million in Emergency (IPC, 2026). Climate change makes markets inaccessible and food unaffordable.

c) Utilization of food

Utilization represents nutrition, food safety and WASH pathways. World Food Program (2026) reported 40% of under-five children as stunted in Pakistan while UNICEF (2024) reported that 38% of young children live in severe food poverty and 47% in moderate food poverty (UNICEF, 2024). Climate shocks can reduce dietary diversity and impair nutrient absorption.

d) Stability dimension

Fourth, stability of the first three dimensions is affected by repeated shocks, floods, droughts and heatwaves that prevent households from rebuilding productive assets between events, producing vicious cycle of low productivity.

4. Impact on the Agriculture System

Agriculture system is composed of inputs, processes and outputs. Climate change disrupts agriculture system through heat-induced crop stress, drought-driven soil and fodder losses, soil erosion, waterlogging, and infrastructure damage (Rahman et al., 2025).

4.1 Water–Food Security Nexus

Pakistan agriculture system accounts for 95% of freshwater withdrawal, costing 4% of GDP and making it among the lowest 10% of countries in agricultural water productivity (World Bank, 2021). Furthermore, Pakistan's water productivity is around 130 grams of crop output per cubic metre, compared with 1,560 g/m³ in the United States, 800 g/m³ in China, 390 g/m³ in India, and (World Bank, 2024).

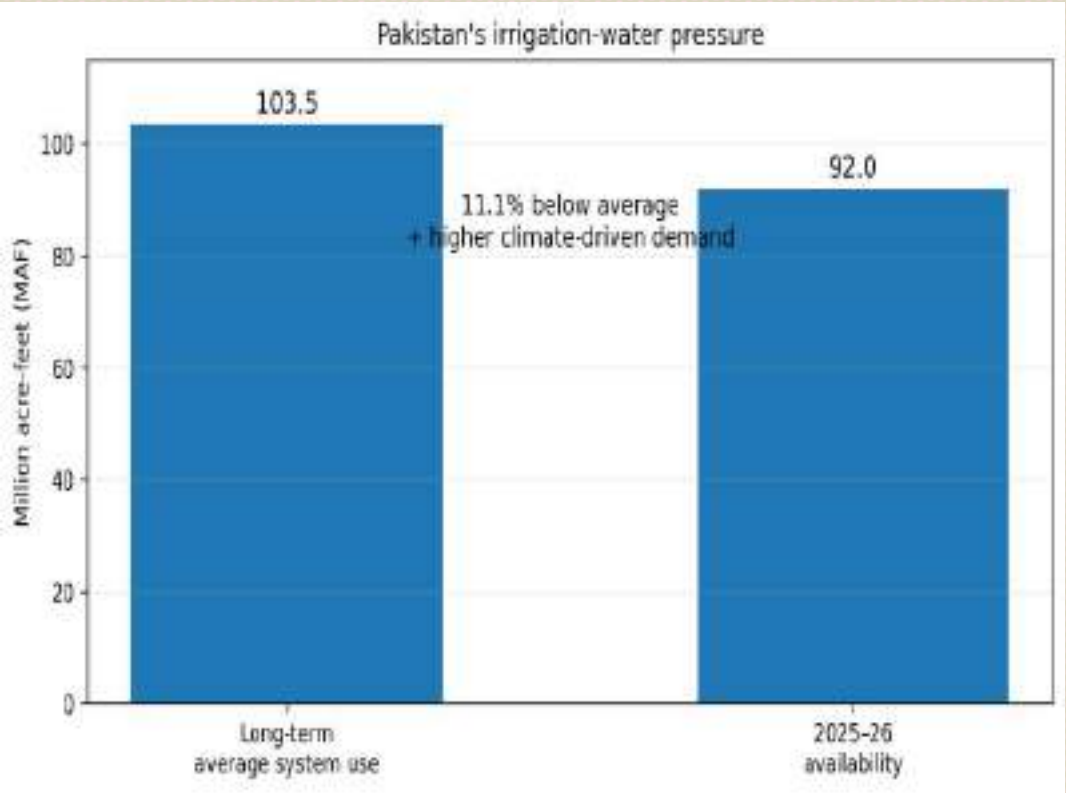

Figure 3. Pakistan's 2025–26 surface-water availability was 92.0 MAF against average system usage of 103.5 MAF, an 11.1% shortfall (Government of Pakistan, 2026).

4.2 Crops, Livestock and Agricultural Value Chains

A 2026 Scientific Reports study provides especially strong evidence for wheat. Across 41 years of data at Islamabad and Chakwal, warming was associated with shorter phenological stages and yield declines from 2.0 to 1.5 t/ha at Chakwal and 2.3 to 1.4 t/ha at Islamabad. Simulated delayed sowing caused losses of up to 27% at Islamabad and 25% at Chakwal, while earlier sowing reduced heat exposure (Ahmed et al., 2026).

Livestock is also vulnerable through heat stress, feed and water shortages, disease and extreme events. The 2022 flood assessment recorded more than 800,000 animals lost (Government of Pakistan, 2022). Climate risk therefore extends beyond the farm gate into storage, processing, transport and markets. The 2025 floods show the cascade clearly.

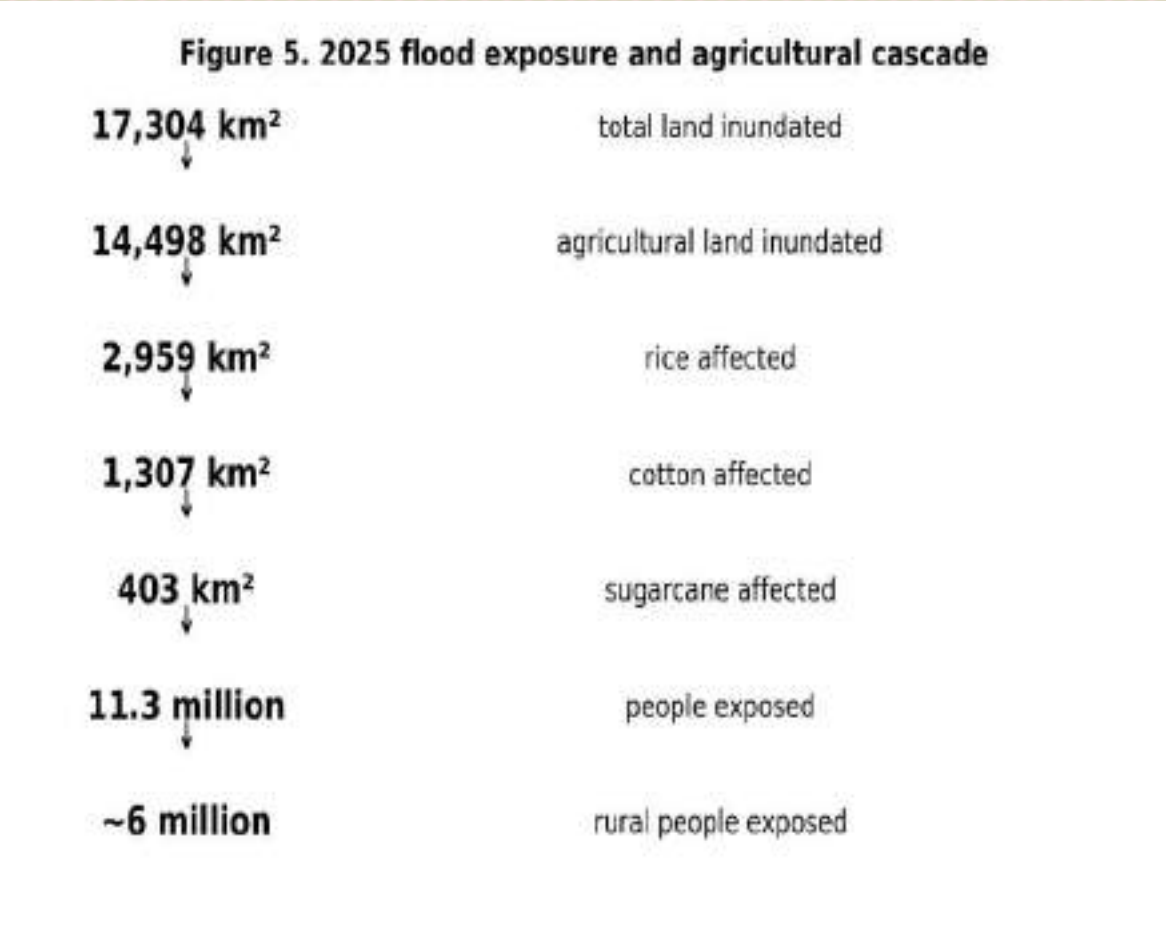

Figure 5. Verified 2025 flood exposure and agricultural cascade (FAO, 2026).

5. Community Resilience Factors

Resilience is not only a technology problem; it is also a social-capital problem. Producer groups, extension networks, savings mechanisms, trusted leadership and timely weather information can help farmers adjust sowing, diversify crops, share machinery and recover faster. Indigenous knowledge remains valuable for crop calendars, water management and livestock coping, especially when combined with scientific forecasts and finance.

A practical resilience model is building local capacity coupled with credible science, finances and resilient institutions. At household level, this means diversified income, seed and fodder reserves, savings or insurance and nutrition-sensitive social protection. At community level, it means water-user associations, farmer field schools, local grain/fodder banks and participatory hazard mapping. At district level, it means integrated crop, water, hazard, price and food-security dashboards. At national level, it means an integrated climate resilient DRM mechanism for sustainable agricultural practices.

6. Scientific & Institutional Gaps

Four gaps stand out with respect to food security and agriculture systems:

i. First is data fragmentation: climate observations, crop yields, irrigation data, satellite imagery, market prices, nutrition indicators and social-protection registries are often managed separately.

ii. Second is weak translation of forecasts into decisions; a forecast has little value if it does not trigger a predefined action.

iii. Third is limited hazard-specific evidence. A 2026 study in Sindh found that climate-smart agriculture practices explained 57% of resilience variation in drought-vulnerable Tharparkar, but the relationship was negligible in flood-prone districts, showing why one uniform adaptation package is inappropriate (Chaiboontha et al., 2026).

iv. Fourth is limited institutional and financial capacity for anticipatory action. Satellite remote sensing can monitor crop stress, evapotranspiration, flood extent and drought; machine learning can improve prediction; and mobile platforms can deliver advisories. FAO's 2025 flood assessment combined Sentinel-1 radar, machine-learning-derived crop maps and population data for rapid impact estimation (FAO, 2026). The challenge is institutionalising these tools into planning, budgeting, extension and emergency triggers.

7. Mitigation Strategies & Best Practices

Adaptation should be layered.

a. At farm level: heat-, drought-, flood- and salinity-tolerant varieties; timely sowing; conservation agriculture; integrated pest management; soil-health restoration; diversified cropping; efficient irrigation; and climate-smart livestock management.
b. At system level: modern irrigation governance, groundwater monitoring, drainage, resilient storage and roads, cold chains, crop insurance and diversified markets.
c. At policy level: repurpose incentives that encourage water-intensive low-value production, finance climate-resilient public goods, and integrate adaptation into agricultural development budgets.

Disaster-risk reduction should use anticipatory action. Thresholds based on rainfall, soil moisture, river levels, crop stress, staple-food prices and IPC indicators can trigger pre-agreed actions such as cash top-ups, seed distribution, livestock feed, emergency water, market logistics and temporary food reserves. This operationalises the core DRR logic of understanding risk, strengthening governance, investing in resilience and preparing before impact.

8. Risk Communication & Early Warning

Pakistan needs a people-centred, last-mile early-warning architecture.

hazard monitoring → forecast → impact model → district risk level → predefined trigger → targeted assistance → feedback → post-event learning.

Pakistan Meteorological Department, SUPARCO, NDMA, provincial disaster-management authorities, agriculture departments, Pakistan Bureau of Statistics, food-price systems and IPC analysis should be interoperable rather than parallel information streams.

Communication must be actionable rather than descriptive. A farmer does not need only a “heatwave probability”; the message should state what to do, by when, and what support is available. SMS, voice calls, radio, extension workers, local leaders and women’s community networks should be combined so digital exclusion does not become climate exclusion.

9. Integrated Climate–Food Security–DRR Operating Model

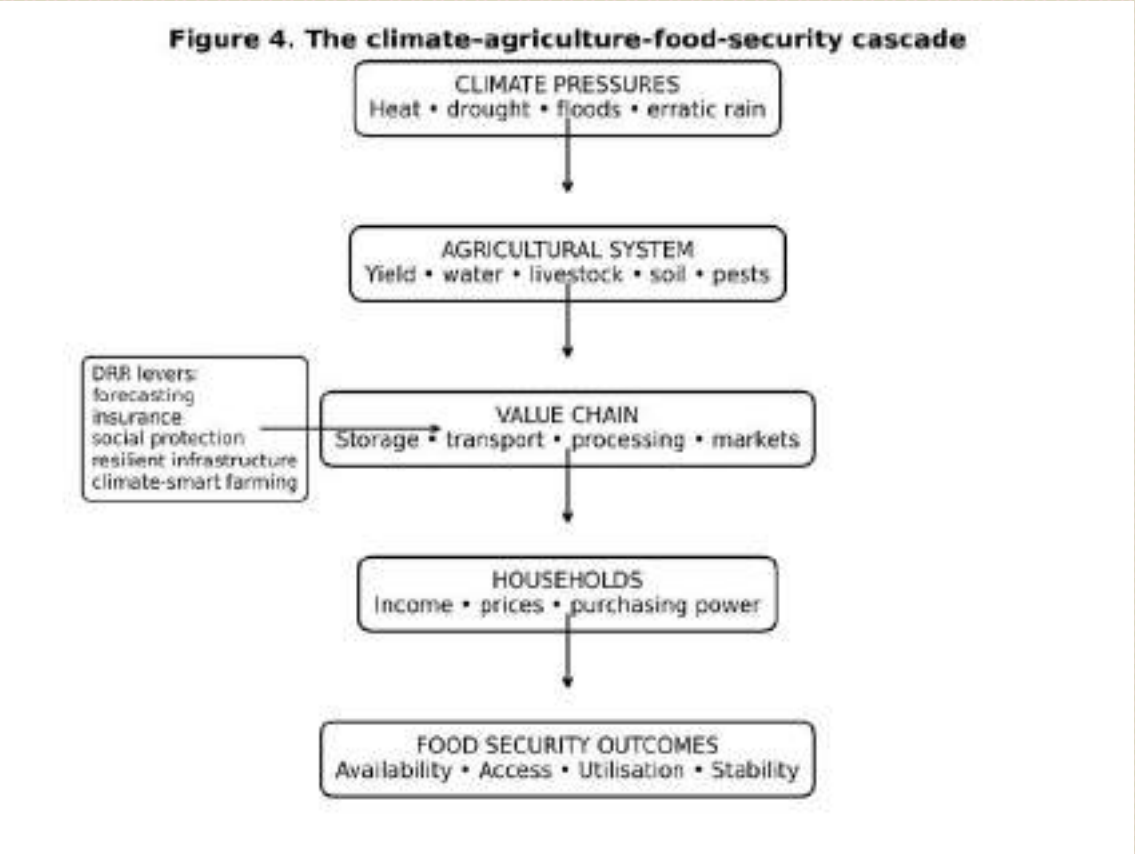

Figure 4. A systems model for connecting climate intelligence to food-security outcomes and DRR action.

10. Policy Recommendations

i. Establish a Climate-Triggered Food Security Early Warning System linking climate, crop, water, prices, nutrition and IPC data to predefined actions.

ii. Institutionalize shock-responsive social protection so BISP/cash assistance can scale automatically after verified flood, drought or food-price thresholds.

iii. Create district food, seed and fodder reserves in high-risk areas, with transparent release rules and nutrition-sensitive targeting.

iv. Adopt district-level climate–crop–water zoning to align crop choice with future water availability, heat and hazard exposure.

v. Launch a “more crop per drop” programme centred on irrigation scheduling, laser leveling, watercourse improvement, telemetry and water accounting.

vi. Build a national climate-resilient seed pipeline for heat, drought, flood, salinity and pest tolerance, supported by public agricultural R&D.

vii. Scale satellite- and AI-enabled agricultural intelligence for crop stress, evapotranspiration, flood/drought mapping and yield forecasting, with human validation.

viii. Expand weather-index and area-yield insurance with targeted premium support for smallholders and rapid digital claims after verified events.

ix. Climate-proof agricultural value chains—roads, bridges, drainage, storage, cold chains, processing and market links—so adaptation protects production, access and affordability.

x. Integrate gender into climate-agriculture programmes through female extension agents, land documentation, credit, digital access and producer organisations.

xi. Mainstream climate and disaster-risk screening into agricultural investment and provincial development budgets, using measurable resilience indicators rather than expenditure alone.

10.1 Implementation Road Map

Horizon	Priority	Lead instruments	Outcome indicator
0–2 years	Anticipate shocks	Early warning, cash triggers, reserves, advisories	Lead time; households protected before impact
3–5 years	Transform systems	Water productivity, zoning, insurance, resilient markets	Yield per m^3; insured area; post-shock recovery time
6–10 years	Structural resilience	Seed R&D, groundwater governance, resilient infrastructure	Climate-adjusted productivity; reduced loss per event

11. Conclusion

The evidence shows that climate change is transforming Pakistan's food-security challenge from a problem of production alone into a system-wide risk involving water, incomes, nutrition, infrastructure, markets and disaster exposure. Global research identifies material yield penalties from warming, while Pakistan-specific studies document substantial projected losses for wheat, rice and maize and recent disasters show how quickly climate shocks propagate through the food chain.

The strategic response should rest on three shifts: from response to anticipation; from production volume to water-, nutrition- and climate-adjusted productivity; and from fragmented projects to integrated resilience. Pakistan can reduce avoidable losses by connecting science with finance, local institutions, social protection and resilient infrastructure. The central DRR principle is simple: predict risk, act before impact, protect productive assets, and recover in ways that reduce the next shock's consequences.

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PARTICIPANT RESEARCH PAPER

Disaster Risk Assessment of Earthquake and Landslide Hazards in Battagram District, Preparedness and Resilience Strategies

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Abstract

District Battagram, located in the mountainous region of Khyber Pakhtunkhwa, Pakistan, is highly exposed to multiple natural hazards, particularly earthquakes, landslides, flash floods, and snowfall. This study assesses the disaster risks associated with earthquake and landslide hazards and examines existing vulnerabilities, preparedness, and resilience capacities in the district. The assessment considers the district's mountainous terrain, steep slopes, climatic conditions, fragile infrastructure, and dependence on agriculture and livestock, which increase the exposure of local communities to disasters. The 2005 earthquake and recurrent floods and landslides demonstrate the significant impacts of disasters on lives, livelihoods, infrastructure, transportation, and essential services. Key vulnerabilities include poverty, low literacy, limited disaster risk management knowledge, vulnerable mud and wood houses, social inequalities, and gaps in disaster risk management implementation. The study also reviews the roles of NDMA, PDMA, district administration, Rescue 1122, health departments, communities, volunteers, and NGOs in disaster preparedness and response. It recommends strengthening early warning systems, improving district-level disaster risk management implementation, adopting structural and non-structural measures, and enhancing coordination among stakeholders to improve disaster preparedness, resilience, and community safety.

Keywords: Disaster Risk Assessment; Earthquake; Landslides; Disaster Preparedness; Resilience

Introduction

The loss of lives and property due to natural disasters are rising at global level. The important concern is that the poorest of poor communities are highly vulnerable to these disasters. Consequently, the loss and damages in world are much higher in vulnerable groups i.e. children, women, old age people, disables, migrants etc. of these communities. The October 08, 2005 earthquake and floods 2010 and 2022 and 2025 were some of the worst disaster events in the history of Pakistan. Pandemic of corona virus affected Million of human beings in term of life threats and losses of livelihoods pushing them under the line of poverty with miserable conditions. Thousands of people were died and injured and damages of property caused millions of dollars losses. The public building collapse particularly the schools and the school going children loss was much higher than any other sector.

These disasters are not only threatened the lives of human being but also affecting the Livelihood of the community members. Damages in livelihood activities are indirectly affecting children, females and old age dependents of affected families. The importance of need for effective disaster management and climate change adaptation is highly demand driven assignment in the situation.

About District Battagram

District Battagram is green, scenic and beautiful tourist area located between 34°33′ and 34°47′N and 72°54′ and 73°15′ E in the western Himalayan province North of Khyber Pakhtunkhwa Pakistan. District Battagram is bounded by the Kohistan valley in the north, Siran valley in the east, the Konsh and Agror valleys in the south and the Black mountain and river Indus in the west. The entire population of the tract is Muslim with the exception of only a few Sikh families in Shamlai and Battagram. District Battagram is mountainous region ranging in altitude from 525 m at Thakot to 4690 m above mean sea level at Sukaisar. The area is generally rough and mountainous having variable slopes from gentle to precipitous.

The climate varies from sub-tropical at the base of the hills to “alpine” conditions on the higher reaches. District Battagram can be categorized into agricultural land, wasteland, forest and alpine meadows. All small streams coming from the sub valleys join two main streams Nandiar Khuwar and Allai Khuwar in District Battagram to join River Indus.

The surface soil is formed by the weathering of the parent rocks. The top soil is constantly being washed away by run off from higher slopes. The soil under fir and spruce is deep and quite rich in humus, whereas it is shallow and poor under pines and scrub zones including Waste Land. The vegetation zones of District Battagram fall under moist temperate category of the internationally known Western Himalayan Moist temperate ecology. District Battagram forests can further be classified into six categories on the basis of available indicator plant species. These includes tropical sub humid forests, sub-tropical Chir-pine forests, moist temperate blue pine forests, mixed coniferous forest, pure fir and spruce forests and alpine pastures. Nature of soil and fertility of the Battgram make it prone to multiple disasters like Earthquake, flash floods, land sliding and thunderstorms.

Battgram Altitude from sea level: 600 M above the sea level

Area of Battgram: 1,301 Square kilo meters

Physical features and topography: Battgram is the major city of North Khyber Pakhtunkhwa. It is sited 205 km north of Islamabad and 260 km from Peshawar. The city is situated in the north part of the Hazara Division which is known for its pleasant weather and for the tourism. It serves as a gate for Kohistan the northern part of the Pakistan

Population: Battgram district has 51,366 households and a population of 335,984. The district has a sex ratio of 101.26 males to 100 females and a literacy rate of 39.09%: 54.69% for males and 23.34% for females. 103,719 (30.89% of the surveyed population) are under 10 years of age. The entire population lives in rural areas. 799 (0.24%) people in the district are from religious minorities, mainly Christians. (Census report 2023)

Livelihoods source: Majority of the people are dependent on agriculture as a first source of livelihood, followed by pasture animal husbandry. They grow rice, maize, wheat, red beans and vegetables.

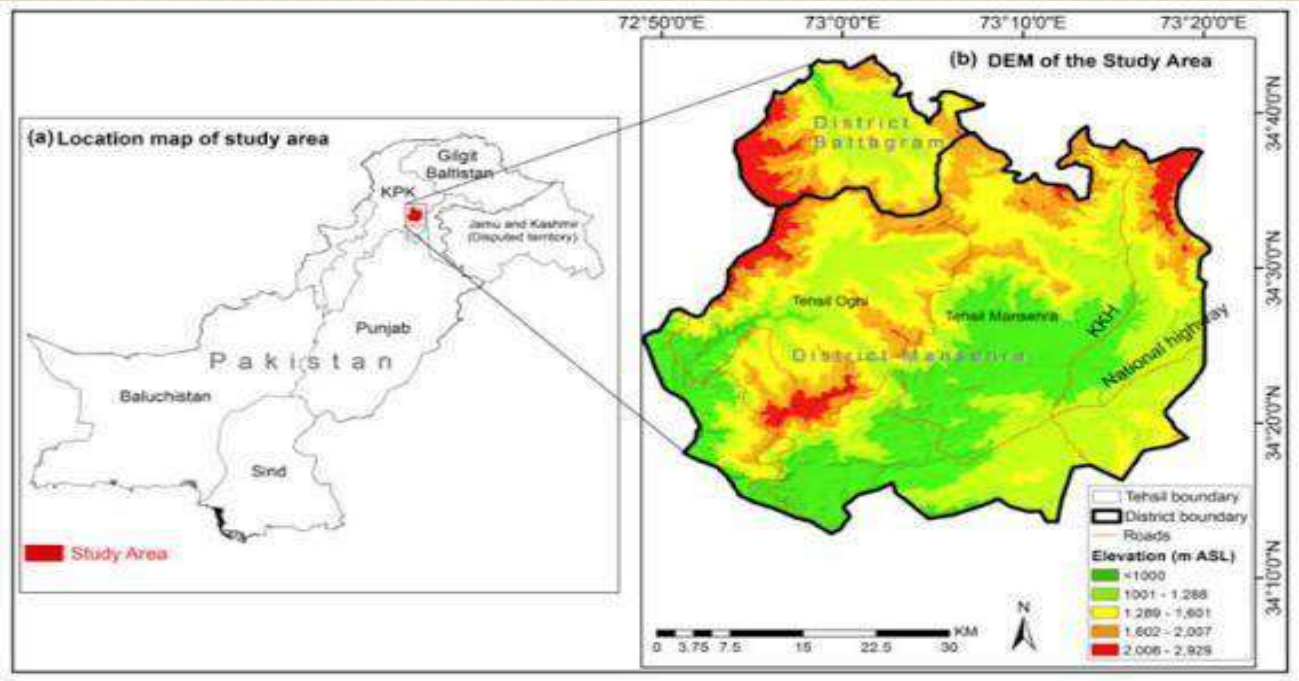

Fig 1. Map of District Battagram

History and social status of Battgram:

Social groups:

Major ethnic groups in the districts are Swatis, Khankhel, Akhunkhel, Syeds and Gujars inhabit District Battagram with a small population of Kashmiries and Kohistanies.

- Gujjar
- Swati Pukhtoons
- Akhunkhel
- Mada khel/Yousafzai

Language spoken in Battgram

a. Pushto 80%
b. Gujri: 18%
c. Hindko & kohistani: 2%

Climate of Battgram

The summer season in district Battagram is hot which usually starts from May and ended in September. In the month of June, the temperature reaches up to 41.5 ºC. The temperature drops rapidly from October onward. December and January are the coldest months in which temperature fall below freezing point in the hilly areas. Owing to thorough cultivation and artificial irrigation, the area is

humid. July, August, December and January are the rainy months for the area. The unprecedented Heavy Rain falls recorded during the wet spell of July 2010. A little rain falls in the remaining months of the year. The comparative dampness is fairly high all over the year, yet the month of December has the maximum humidity of 63.35%.

Geography of District Battgram

The district of Battagram is located at altitude of 34.41 and longitude of 73.1. It is surrounded

by Kohistan District to the north, Mansehra District to the east, Torghar District to the south, and Shangla District to the west. It has a land area of 1,301 square kilometres (502 sq mi). Battagram obtained the status of a district in July 1993, when it was upgraded from a Tehsil and separated from Mansehra District. Recently tehsil Alla has been promoted as separate district in 2026.

Location and level of Altitude from sea level

- Battagram is situated at 34°41'N 73°1'E and has an altitude of approximately 1,038 meters (3,408 feet) above sea level.
- It is nestled amidst the picturesque mountains of northern Pakistan.

Population of district Battgram:

List of Hazards:

S. No	Hazard	Frequency
1	Earthquake	High
2	SLand slides	High
3	Snowfall & clod	High
4	Pandemics	Medium
5	Thunder storm	Low

History of disasters in District Battgram:

Types of Disasters in Khyber Pakhtunkhwa

The province of Khyber Pakhtunkhwa faces a number of natural and man induced hazards including floods, earthquakes, avalanches / landslides, droughts, militancy and terrorism. Khyber Pakhtunkhwa location in a zone of tectonic weakness makes the likelihood of earthquakes in the region particularly high.

Although earthquakes occur relatively rarely in relation to other natural hazards, they usually have the potential to cause major damage. A much more frequent occurrence is flooding. These floods leave a substantial material damage in their wake, and claim human lives time and time again. In the mountainous regions, flooding and thawing very often cause landslides and torrents, and in rare cases also glacier run and glacial lake outburst floods. In the north of the province a threat of avalanche holds sway during the winter, while in the south droughts may occur in the summer. Major disasters in recent years include the 2005 earthquake, the 2010 monsoon floods, and the IDP crisis as a result of the GOP led operations against militant outfits (ongoing since 2008).

History of damages by frequent disasters

Earthquake

A major devastating earthquake of Magnitude 7.8 on the rector scale jolted the district of Battgram as some other part of Hazara and Kashmir valley.

Battagram was one of the areas affected by the Pakistan earthquake of October 8, 2005 when more than 4,500 people were killed and approximately 35,000 were injured. Many residents of the area were rendered homeless and without shelter. Since October 8, 2005, the NGOs and the governmental organization ERRA (Earthquake Reconstruction and Rehabilitation Authority) have been engaged in reconstruction work but as of 2009, the reconstruction work is not completed. In some cases, residents have rebuilt houses themselves.

Landslides in Battgram

Battagram District in Khyber Pakhtunkhwa (KPK) remains under critical threat of sudden landslides, flash floods, and debris flows due to heavy monsoon downpours. The National Emergency Operations Centre (NEOC) and the Pakistan Meteorological Department (PMD) have issued immediate hazard warnings for the mountainous terrain of upper KP, noting that continuous intense rainfall has significantly compromised slope stability

Current Vulnerabilities & Road Closures

- **Karakoram Highway (KKH) Impact**

The main highway axis extending through adjacent Kohistan and lower Hazara divisions has experienced recurrent blockages from sliding debris. The National Disaster Management Authority (NDMA) has designated high-risk arterial zones,

warning that connecting links through Battagram, Shangla, and Torghar face severe transport disruptions.

Localized Soil Saturation

Steep terrain across tehsils like Allai is prone to structural mountain cracks during high-moisture spells, prompting local authorities to occasionally order preemptive village evacuations to safeguard populations.

Landslide Susceptibility

The district features highly steep terrain, fragile lithology, and an intense monsoonal climate. Earthquakes act as primary triggers for massive slope failures. Active risk points like the Sohbat Charra slide zone in Allai have historically blocked vital roads and entirely cut off emergency rescue operations

Snowfall hazards in Battagram, Khyber Pakhtunkhwa (KPK)

Battgram is exposed to significant seasonal challenges, primarily due to the district's mountainous geography and vulnerable infrastructure. During heavy winter spells, such as intense systems and winter temperature drop to a minus degree in hilly areas, that can drop up to nearly 4 feet of snow in high altitude zones, the region experiences critical logistical and safety threats

Flash floods in Battgram

Geography of Battgram is making the district prone to flash floods, riverine floods and landslides due the nature of rocks and vegetation soil on the mountains. Flash floods in Battagram cut off communities by destroying bridges, link roads, and communication networks, making relief and rescue operations extremely challenging. Agricultural lands were observed as eroded, livestock drowned, and local markets destroyed, depriving families of their primary sources of food and income. Public service delivery systems including schools, health centers, and water supply schemes collapsed under the pressure of the floods, creating a multi-dimensional crisis. The periodic onset of flood disasters in Battgram observed in the year of 1992, 2010, 2022, 2024 and year 2025.

Hazard vulnerabilities in district Battgram

Poverty	Persons with disabilities
Low literacy rate	Strict traditions

Children	Old age people
Women	Men dominated society
Low income generation groups	DRM implementation gaps
Mud and wood houses	Lack of DRM knowledge

Disaster Preparedness and resilience strategies in district Battgram

Though there is huge gap in the management of disaster response and rehabilitation process in the area, yet there are some important bodies and actors for disaster management to cope up the disaster emergencies in Khyber Pakhtunkhwa and particular in district of Battgram.

Coping capacities: Battgram at a glance

S. No	Agency	Strategy	When
1	ERRA	Reconstruction	2005 onward
2	NDMA	Emergency	Regular
3	PDMA	Early warning	Seasonal
4	Deputy commissioner	Regular	Regular
5	Rescue 112	Emergency	Day night
6	Health department	Emergency/Rehab	Regular
7	Union Council	Community level	Data & information
8	Volunteers	Trained individual	Acute emergency
9	NGOS	Capacity building	Project base work
10	Skilled professional	Deployment	emergency

Scope of the Study

This study is based on the research assigned by the NDMA Pakistan under the training of Disaster management and climate change strategies. Students, teachers and researchers can read and take advantage from the findings, recommendations and results of the study for the improvement of disaster affected communities in the country.

Justification of the Study

This study is needed for the better life and need for improvement after the devastating flood, 1992 2010, 2022 and earthquake 2005, which affected District Battgram and other parts of the country. This study will not only increase the awareness and hazard knowledge including earthquake, landslide and flood management but also recommends the remedies and solution for the improved livelihood of Study area as well as other parts of the country where consecutive disasters are being observed.

Findings & Recommendations

- Advance and improved Early warning system is required
- District level DRM policy implementation should be ensured
- Structural and non-structural measure for disaster rehabilitation
- Coordination and cooperation among stake holders.

PARTICIPANT RESEARCH PAPER

The Paris Agreement and its Linkages with Disaster Risk Reduction

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List of Abbreviations

Abbreviation	Meaning
AA	Anticipatory Action
BTR	Biennial Transparency Report
CBDRM	Community-Based Disaster Risk Management
CCA	Climate Change Adaptation
COP	Conference of the Parties
DRR	Disaster Risk Reduction
DDMA	District Disaster Management Authority
EWS	Early-Warning System
FRLD	Fund for Responding to Loss and Damage
GCF	Green Climate Fund
GGA	Global Goal on Adaptation
GST	Global Stocktake
M&E	Monitoring and Evaluation
MHVRA	Multi-Hazard Vulnerability and Risk Assessment
MoCC&EC	Ministry of Climate Change and Environmental Coordination
NAP	National Adaptation Plan
NCQG	New Collective Quantified Goal on Climate Finance
NDC	Nationally Determined Contribution
NDMA	National Disaster Management Authority
NEOC	National Emergency Operations Centre
NIDM	National Institute of Disaster Management
CoE C2DM	Centre of Excellence in Climate Change & Disaster Management
NDRMF	National Disaster Risk Management Fund
PDMA	Provincial Disaster Management Authority
PMD	Pakistan Meteorological Department
SFDRR	Sendai Framework for Disaster Risk Reduction
UNDRR	United Nations Office for Disaster Risk Reduction
UNFCCC	United Nations Framework Convention on Climate Change

Abstract

For Pakistan, climate change is no longer a distant environmental concern. It is already visible in harsher heat, uncertain rainfall, destructive floods, prolonged dry spells, pressure on the Indus Basin and growing risks in mountain, coastal and urban areas. These impacts are felt most sharply by households that have limited savings, weak housing, climate-sensitive livelihoods or poor access to public services. This is why the Paris Agreement matters to disaster managers. It provides the global framework for limiting warming, strengthening adaptation, mobilizing finance, improving technology and capacity, and addressing loss and damage. The Sendai Framework provides the practical method for understanding risk, strengthening governance, investing in resilience and preparing for emergencies. Put simply, Paris gives direction and support; DRR turns that direction into safer people, services and settlements.

This assignment explains how the Paris Agreement can support the everyday work of Pakistan's disaster-management institutions. Article 7 focuses on adaptation: building capacity, strengthening resilience and reducing vulnerability. Article 8 deals with loss and damage and highlights areas familiar to NDMA, PDMAs and district administrations, including early warning, emergency preparedness, slow-onset events and comprehensive risk management. The Agreement's provisions on finance, technology, capacity-building and transparency are equally important because plans cannot be implemented without resources, trained people, reliable information and accountability.

The assessment finds that Paris has produced important governance gains: near-universal participation; a recurring Nationally Determined Contribution cycle; stronger recognition of adaptation; dedicated institutional arrangements for loss and damage; and a growing expectation that climate risk should influence planning and investment. However, delivery remains far below the scale of need. The world is not yet on a pathway consistent with the Agreement's temperature goals, adaptation finance is insufficient and difficult to access, local technical capacity remains uneven, and fragmented data and mandates weaken implementation. In disaster-risk terms, the global system has improved direction and accountability faster than it has reduced exposure and vulnerability.

Pakistan already has a useful policy opening. NDC 3.0 calls for multi-hazard vulnerability and risk assessment across the entire country and in every district by

2030, expansion of flood, drought and extreme-weather warning to all communities, and community-based disaster risk management in at least 100 districts. These are not abstract international promises. They can guide monsoon planning, heatwave preparedness, district risk maps, safer public infrastructure and community training. To achieve this, NDMA, PDMAs, DDMAs, PMD, line departments, district administrations, local governments and communities will need common standards for risk information, warning, anticipatory action, recovery and loss accounting.

Three NDMA wings and directorates are especially important for making this policy practical. The National Emergency Operations Centre (NEOC) provides the operational link between climate and hazard monitoring, seasonal outlooks, impact-based projections, warning and coordinated action. The National Institute of Disaster Management (NIDM) can turn lessons from emergencies into awareness, standardized training and a dependable cadre of officials, responders and trained volunteers. NDMA's Centre of Excellence in Climate Change & Disaster Management (CoE C2DM) can connect climate science, disaster operations, applied research and professional learning. Together, they form a useful cycle of evidence, decision, action and learning rather than three isolated facilities.

Key finding: For a district officer or field responder, the Paris Agreement is useful only when it improves decisions on the ground: knowing who is at risk, warning people in time, releasing funds before impact, keeping essential services functional and learning honestly after every emergency.

The final chapter proposes a national resilience pathway and a focused pitch package for COP31 in Antalya, Türkiye, scheduled for 9-20 November 2026. Pakistan should take an evidence-led position that combines a fair demand for accessible, predictable and grant-oriented support with demonstrable domestic readiness. Priority pitches include a Pakistan Climate and Disaster Resilience Compact; a last-mile early-warning and anticipatory-action initiative; a dedicated projectpreparation facility; a South Asia/Hindu Kush-Himalaya risk-information partnership; practical access to loss-and-damage finance; debt-sensitive resilience finance; locally led adaptation; and an operational contribution to the second Global Stocktake. The recommended diplomatic message is straightforward: international climate finance should reward measurable protection, while national institutions must demonstrate credible pipelines, fiduciary discipline, inclusive delivery and transparent results.

1. Introduction

1.1 Background and rationale

Climate change and disaster risk are connected but are not identical. Climate change modifies the probability and severity of climate-related hazards, while disaster risk is produced by the interaction of hazards with exposure, vulnerability and capacity. A heavy-rainfall event becomes a disaster when settlements, infrastructure, livelihoods and institutions are exposed and insufficiently protected. This distinction matters because emission reduction alone cannot remove existing vulnerability, and emergency response alone cannot prevent escalating future hazards. Effective policy must therefore combine mitigation, adaptation and disaster risk reduction.

The Paris Agreement was adopted in 2015 under the UNFCCC to strengthen the global response to climate change. Its long-term temperature goal is accompanied by commitments on adaptation, finance, technology, capacity-building and transparency. In the same year, states adopted the Sendai Framework for Disaster Risk Reduction 2015-2030. Sendai focuses on preventing new risk, reducing existing risk and managing residual risk. Together, these frameworks establish a policy chain from global climate ambition to practical protection of people and assets (UNFCCC, 2015; UNDRR, 2015).

Pakistan makes this relationship easy to understand. A spell of extreme heat is not only a weather issue; it becomes a health, electricity, water and labour-safety issue. Heavy monsoon rainfall can quickly become riverine flooding, urban flooding, road disruption, school closure, crop loss and disease. In Gilgit-Baltistan and Khyber Pakhtunkhwa, glacial and flash-flood risks affect remote settlements and critical roads. In Balochistan, Sindh and parts of southern Punjab, drought and water stress can undermine livelihoods long before an emergency is officially declared. The 2022 floods showed how one climate-related event can become a humanitarian, development, fiscal and governance crisis. Climate diplomacy and disaster management therefore cannot be handled as separate files.

1.2 Problem statement, aim and objectives

Pakistan's main challenge is not the absence of policies. The harder issue is converting policies into funded, coordinated and sustained action at provincial, district and community levels. A plan may promise early warning, but the last village may not receive or understand the message. A risk map may exist, but it may not be used when a road, school or housing scheme is approved. Equipment may be

procured, but maintenance and trained staff may be missing. This assignment therefore asks a practical question: how can the Paris Agreement help Pakistan reduce risk and protect people before the next emergency?

The aim is to assess the policy and operational relationship between the Paris Agreement and DRR, with particular attention to Pakistan's institutions and priorities before COP31. The specific objectives are to:

- Explain the evolution, legal design and operating mechanisms of the Paris Agreement
- Identify the substantive linkages between adaptation, loss and damage, finance, technology, transparency and DRR
- Assess major achievements and implementation gaps in the international climate regime
- Examine Pakistan's climate-disaster risk profile, policy framework and institutional responsibilities
- Propose practical reforms through which Pakistan can convert climate commitments into district-level protection; and
- Develop evidence-based ideas for the Government of Pakistan to advance at COP31 in Türkiye

1.3 Scope and methodology

This is a qualitative policy-to-practice assessment. It reviews the Paris Agreement, the Sendai Framework, Pakistan's National Adaptation Plan, Pakistan's NDC 3.0, national disaster-management planning instruments and selected official international reports. It also draws operational lessons from Pakistan's disaster context, particularly the need to connect risk knowledge, forecasting, warning, early action, response, recovery and learning. The analysis is organized around institutional coherence, implementation capacity, finance and measurable resilience outcomes.

The document does not attempt to provide a full legal commentary on every provision of the Paris Agreement or a complete hazard assessment for every district. COP31 proposals are presented as recommended negotiating and partnership positions for Pakistan, not as predictions of negotiated outcomes. Time-sensitive conference information is current to 5 September 2026.

2. Evolution and Architecture of the Paris Agreement

2.1 From the UNFCCC and Kyoto Protocol to Paris

The UNFCCC, adopted in 1992, established the basic international framework for stabilizing greenhouse-gas concentrations while recognizing equity and common but differentiated responsibilities and respective capabilities. The Kyoto Protocol, adopted in 1997, introduced quantified emission-reduction commitments mainly for developed countries. Kyoto was historically important, but its limited coverage and changing global emissions profile constrained its ability to generate a universal response.

The Paris Agreement, adopted at COP21 on 12 December 2015 and entering into force in 2016, brought all Parties into a common system. It seeks to hold the increase in global average temperature well below 2 degrees Celsius above pre-industrial levels and pursue efforts to limit the increase to 1.5 degrees. It also aims to increase adaptive capacity and make finance flows consistent with low-emission and climate-resilient development. This wider architecture is essential for vulnerable developing countries because it recognizes that the climate challenge concerns resilience and support as well as mitigation (UNFCCC, 2015).

2.2 A legally binding process with nationally determined ambition

Paris is a legally binding treaty, but it does not impose one identical emissions target on every country. Parties must prepare, communicate and maintain successive NDCs, pursue domestic measures and report under agreed transparency arrangements. The ambition and policy mix within each NDC are nationally determined. This hybrid design enabled broad participation but also means that aggregate ambition depends on national choices.

The Agreement seeks progression through a recurring cycle: plan, implement, measure, report, review and enhance. NDCs are expected to represent progression and a Party's highest possible ambition. The enhanced transparency framework helps track action and support, while the Global Stocktake assesses collective progress every five years and informs subsequent action. Compliance is facilitative and non-punitive; political accountability, transparency, domestic governance and peer pressure are therefore central to effectiveness.

2.3 Core pillars and supporting mechanisms

The Agreement can be understood through four mutually dependent pillars. Mitigation limits future warming and therefore constrains the future intensity of climate-related hazards. Adaptation reduces vulnerability and strengthens resilience to impacts that are already occurring or unavoidable. Finance enables

implementation at scale. Technology development and transfer, together with capacity-building, provide the tools, skills and institutions necessary for delivery. Transparency and the Global Stocktake link these pillars through evidence and accountability.

For disaster managers, adaptation is the most direct entry point, but mitigation remains relevant because every additional increment of warming expands the scale and cost of managing risk. Likewise, finance without implementation capacity can produce delayed or unsustainable projects; technology without maintenance and trained staff can fail at the last mile. A coherent approach must connect all pillars to public planning, regulation, budgets and local services.

Implementation: A climate commitment is operational only when it has a responsible institution, a costed workplan, a financing source, reliable baseline data, a timeline and a measurable resilience outcome.

2.4 Cooperative approaches and Article 6

Article 6 allows voluntary cooperation between Parties, including internationally transferred mitigation outcomes, a UN-supervised crediting mechanism and non-market approaches. These arrangements may mobilize investment and support higher ambition, but they require robust accounting, environmental integrity, transparency, authorization and safeguards. Pakistan's carbon market engagement should therefore be governed through a credible national framework that prevents double counting, protects communities and aligns activities with national development priorities (UNFCCC, n.d.).

Article 6 is not a substitute for adaptation finance. Many essential DRR investments - evacuation systems, public climate information, resilient schools, community preparedness and protection of non-market ecosystem services - do not generate tradable emission reductions. Carbon revenue may complement selected resilience co-benefits, but public and grant-based finance remains necessary for adaptation, anticipatory action and loss and damage.

2.5 Transparency and the Global Stocktake

The enhanced transparency framework requires regular information on emissions and progress toward NDCs, while Parties should also provide information on climate impacts and adaptation as appropriate. The Global Stocktake reviews collective progress across mitigation, adaptation and means of implementation and support. This creates a direct role for disaster-management evidence: verified loss trends,

warning performance, district risk coverage, resilience investment and remaining capacity gaps can make national reporting more useful and improve the quality of future climate decisions (UNFCCC, 2015).

3. Disaster Risk Reduction and the Sendai Framework

3.1 Understanding disaster risk

A hazard does not automatically become a disaster. Disaster risk grows when people and assets are exposed, vulnerability is high and coping capacity is weak. The same rainfall may cause limited disruption in a well-drained, planned locality but serious loss in an informal settlement beside a nullah. The same heatwave may be manageable for a household with reliable electricity and water but life-threatening for an outdoor worker, an older person living alone or a family in a poorly ventilated house. DRR therefore means preventing new risk, reducing risk that has already accumulated and preparing for the risk that cannot be fully removed.

Climate change affects this equation by altering hazard characteristics and by intensifying stresses on water, food, health, ecosystems, infrastructure and livelihoods. It can also create compound and cascading risks: extreme heat may disrupt power and health services; heavy rainfall may trigger floods, landslides, disease outbreaks and supply-chain interruptions; drought can interact with food prices, migration and local conflict. Risk assessment must accordingly move beyond single hazards and static historical maps.

3.2 The Sendai Framework

The Sendai Framework 2015-2030 is the global blueprint for preventing new and reducing existing disaster risk. It establishes four priorities: understanding disaster risk; strengthening disaster-risk governance; investing in DRR for resilience; and enhancing preparedness for effective response while building back better in recovery, rehabilitation and reconstruction. Its seven global targets cover mortality, affected people, economic loss, critical infrastructure and basic services, national and local strategies, international cooperation, and access to multi-hazard early-warning systems and disaster-risk information (UNDRR, 2015).

Sendai is especially useful because it moves the discussion from policy to practice. Target G seeks greater access to multi-hazard early-warning systems and disaster-risk information by 2030. In Pakistan, however, a forecast issued from Islamabad or a provincial capital is only the start of the process. The message must reach the assistant commissioner, relevant line departments, Rescue 1122, local government,

schools, health facilities, community leaders and the people likely to be affected. It must also be clear enough to answer three questions: what is expected, who should act and by what time? A warning that does not lead to action is an incomplete warning.

3.3 Complementarity between adaptation and DRR

Climate change adaptation and DRR overlap substantially but retain different emphases. Adaptation addresses present and future climate impacts and may include gradual changes in ecosystems, agriculture, water management, health and infrastructure. DRR addresses climate-related and non- climate hazards and has established practice in preparedness, response and recovery. Integration is most useful where both fields share risk assessments, planning cycles, finance criteria, monitoring systems and local delivery mechanisms.

The goal is not to merge every institution or plan. It is to avoid parallel systems for the same communities and risks. A district should not maintain one climate-vulnerability assessment for an adaptation project, another hazard assessment for disaster planning and a third dataset for development investment. Shared standards and interoperable information allow different mandates to reinforce each other while preserving institutional accountability.

4. Linkages Between the Paris Agreement and DRR

4.1 Article 7: adaptation, resilience and reduced vulnerability

Article 7 establishes the global goal on adaptation: enhancing adaptive capacity, strengthening resilience and reducing vulnerability to climate change in the context of the Agreement's temperature goal. It recognizes adaptation as a global challenge with local, subnational, national, regional and international dimensions. National Adaptation Plans and adaptation communications provide vehicles for identifying needs, priorities, actions and support requirements.

For DRR institutions, Article 7 creates policy space to place risk assessments, resilient infrastructure, heat-health action plans, water security, ecosystem-based protection, early warning, social protection and local preparedness within the climate implementation agenda. It also provides a basis for measuring resilience outcomes rather than reporting only activities. Useful indicators include warning reach, lead time, evacuation capability, continuity of critical services, avoided losses, recovery time and coverage of vulnerable groups.

4.2 Article 8: averting, minimizing and addressing loss and damage

Article 8 recognizes the importance of averting, minimizing and addressing loss and damage associated with adverse climate impacts, including extreme-weather and slow-onset events. Areas of cooperation include early-warning systems, emergency preparedness, comprehensive risk assessment and management, risk insurance facilities, non-economic losses and resilience of communities, livelihoods and ecosystems. This language directly overlaps with the work of disaster management authorities. Averting loss and damage requires mitigation and prevention; minimizing it requires adaptation, preparedness and anticipatory action; addressing it requires response, recovery, rehabilitation, social protection, risk financing and support for losses that cannot be prevented. Credible access to loss-and-damage support therefore depends on reliable event attribution where appropriate, standardized damage-and-loss accounting, transparent beneficiary identification, safeguards and evidence that funds reach affected people.

4.3 Finance, technology, capacity and transparency

Articles 9, 10 and 11 address finance, technology and capacity-building. These provisions determine whether developing countries can obtain and sustain forecasting systems, resilient infrastructure, climate services, trained personnel and local implementation capability. Article 13's transparency framework and Article 14's Global Stocktake create demand for credible information on action, needs, support and outcomes. DRR agencies can contribute verified hazard, exposure, vulnerability, warning and loss data to these national reporting processes.

The relationship can be summarized as follows:

Paris element	Climate-policy function	Direct DRR application
Mitigation / Article 4	Limits future warming and hazard escalation	Scenario planning; resilient development assumptions; advocacy for ambitious global action
Adaptation / Article 7	Strengthens adaptive capacity and reduces vulnerability	Risk assessment; resilient infrastructure; preparedness; continuity of services; locally led resilience

Loss and damage / Article 8	Averts, minimizes and addresses unavoidable impacts	Early warning; emergency preparedness; loss databases; risk financing; recovery; non-economic loss
Finance / Article 9	Supports implementation and aligns flows	Bankable DRR pipelines; grants and concessional finance; prearranged and anticipatory finance
Technology / Article 10	Promotes climate technology development and transfer	Forecasting, sensors, geospatial analysis, interoperable data and resilient communications
Capacity / Article 11	Builds institutional and technical capability	Training, exercises, local planning, operations centres, maintenance and community capacity
Transparency and GST / Articles 13-14	Tracks collective progress and gaps	Verified risk and loss evidence; resilience indicators; learning; national reporting and GST inputs

Field Judgement: A family facing floodwater, heat stress or drought does not ask whether the response came under Paris, Sendai or a national plan. It judges government by whether the warning came in time, help reached fairly and essential services were restored.

5. Progress, Limitations and the Implementation Gap

5.1 Institutional progress under Paris

Paris has reshaped climate governance in several important ways. First, it established a common framework in which all Parties communicate national plans. Second, the recurring NDC cycle has increased the visibility of climate targets within governments and created expectations of progression. Third, adaptation has gained a stronger position beside mitigation through the Global Goal on Adaptation and associated frameworks. Fourth, the Fund for Responding to Loss and Damage created a dedicated institutional channel for vulnerable developing countries. Fifth, climate risk increasingly influences development planning, public investment and financial regulation. These achievements are best understood as governance

capacity rather than completed outcomes. A treaty can establish direction; an NDC can state ambition; a fund can create an access route; and a reporting framework can improve transparency. None of these automatically reduces vulnerability. Results depend on finance, technical capability, domestic coordination, local legitimacy, procurement, maintenance and accountability.

5.2 Emissions and adaptation gaps

The mitigation gap directly increases disaster risk. UNEP's 2025 assessment indicated that full implementation of current pledges would still imply warming of approximately 2.3-2.5 degrees Celsius over the century, with greater warming under policies then in place. Each additional fraction of warming raises the likelihood of extreme heat, heavy rainfall, drought and other climate impacts, increases adaptation costs and expands residual risk (UNEP, 2025b).

Adaptation finance remains far below estimated needs in developing countries. The problem is not only total volume. Countries face complex accreditation and proposal procedures, slow approvals, high transaction costs, limited project-preparation resources, inadequate grant finance, currency and debt risks, and weak support for maintenance. Small community interventions can have high protective value but are often difficult to aggregate into fundable programmes (UNEP, 2025a).

5.3 Data, technology and capacity constraints

Pakistan's departments often hold useful information, but it is kept in separate formats and systems. PMD may hold forecast data; irrigation departments hold river and canal information; health and education departments know the location of facilities; district administrations know local access constraints; and communities know which routes, settlements and households are most at risk. When these sources are not brought together, a technically sound hazard map may still miss the people and services that matter. Loss records also vary across provinces and events, while health, displacement, cultural and ecosystem losses are often under-recorded.

Technology is frequently treated as a procurement matter: buy a sensor, install a platform or establish an operations room. In practice, technology works only when trained officials can use it, departments can share data, recurring budgets cover maintenance, and standard operating procedures connect an alert with authority and action. This is particularly important in remote and resource-constrained districts where internet access, power supply and technical staffing may be

unreliable. Capacity-building should therefore be part of job descriptions, induction, refresher training, simulation exercises and performance review rather than a one-off workshop.

5.4 Political economy and governance

Climate and DRR programmes often cross administrative boundaries, while budgets and accountability remain sectoral. Short political and project cycles can favour visible construction over prevention, maintenance and institutional learning. Provinces and districts may be assigned responsibilities without predictable finance or technical staff. Internationally, geopolitical tension and competing fiscal pressures weaken trust and make climate finance less predictable. The central implementation challenge is therefore a combined shortage of resources, coordination, data quality, sustained capability and political incentives for prevention.

5.5 The 2026 negotiation and implementation landscape

The international process in 2026 is increasingly focused on implementation. The second Global Stocktake will commence at CMA 8 during COP31 and conclude in 2028. It will review collective progress for the 2024-2028 period and is expected to inform the next cycle of action and support. For Pakistan, the preparation phase is an opportunity to submit evidence on adaptation needs, implementation barriers, loss and damage, finance and tested DRR solutions rather than waiting for the final stocktake outcome (UNFCCC, 2026a).

Climate finance remains politically central. The New Collective Quantified Goal agreed at COP29 calls for developed countries to take the lead in mobilizing at least USD 300 billion annually for developing countries by 2035, alongside efforts by all actors to scale public and private finance to USD 1.3 trillion per year by 2035. For vulnerable countries, the quality of these flows - grant content, concessionality, predictability, accessibility and debt impact - will determine whether the figures translate into resilience (UNFCCC, 2024).

Loss-and-damage arrangements and Article 6 mechanisms are also moving from institutional design toward operation. Pakistan should prepare for this implementation phase by strengthening national access systems, safeguards, carbon accounting, project pipelines and loss information. The national negotiating position should avoid treating every finance source as interchangeable: mitigation markets, adaptation finance, humanitarian funding, disaster-risk finance and loss-and-damage support serve different purposes and require distinct accountability.

6. Pakistan's Climate-Disaster Risk and Governance Context

6.1 A compound and cascading risk profile

Pakistan's risk profile is closely tied to its geography and development realities. The Indus Basin sustains agriculture, energy, drinking water and major settlements, but it is also exposed to river flooding, water stress and changing snow and glacier conditions. Mountain districts face landslides, flash floods, glacial-lake hazards and difficult access during emergencies. Balochistan, Thar and other dry areas face recurring drought, livestock losses and pressure on groundwater. Karachi and other fast-growing cities face heat, drainage failure, encroachment on natural waterways and overloaded services. Coastal communities face erosion, salinity and storm-related risk. These are not isolated hazards; they affect food prices, migration, employment, health, education and public finances.

These hazards interact with socioeconomic vulnerability. Poor households often occupy risk-prone land, rely on climate-sensitive livelihoods, have limited savings and insurance, and face barriers to information, transport and public services. Women, children, older persons, persons with disabilities, displaced populations and remote communities may experience different warning, evacuation and recovery constraints. Inclusive risk assessment must identify these differences rather than treat population exposure as uniform.

6.2 Lessons from the 2022 floods

The 2022 floods illustrate how a climate-related shock can become a national development crisis. The event affected lives, housing, agriculture, transport, education, health, water and sanitation across multiple provinces and generated damages and economic losses exceeding USD 30 billion according to the Post-Disaster Needs Assessment. Recovery needs extended beyond replacing damaged assets; they required safer reconstruction, livelihood restoration, institutional reform and protection from future shocks (Government of Pakistan et al., 2022).

The central lesson is that disaster losses are shaped before the event. Land-use decisions, infrastructure standards, watershed condition, drainage, poverty, service coverage, warning reach and preparedness influence whether a hazard becomes catastrophic. Post-disaster assessments must therefore inform pre-disaster investment and not remain only funding documents for recovery.

6.3 National policy architecture

Pakistan has an established climate and disaster-governance structure. The Ministry of Climate Change and Environmental Coordination leads national climate policy and international engagement. NDMA provides national disaster-management policy, coordination and technical guidance. PDMAs translate this direction at provincial level, while DDMAs and district administrations coordinate much of the action on the ground. PMD provides weather and climate services; the Federal Flood Commission and irrigation departments contribute to flood management; Rescue 1122, Civil Defence, health, education, agriculture, livestock, social welfare and local-government institutions carry important operational responsibilities. NDRMF, civil society, academia, the private sector, media and communities also form part of the national resilience system.

The number of institutions is not the real problem. Climate and disaster risks naturally cut across sectors. The problem begins when one department assumes another will act, plans use different data, responsibilities are assigned without funds, or the district administration receives a warning without clear thresholds and authority. Coordination must therefore move beyond meeting minutes. It should be reflected in shared protocols, joint exercises, interoperable information, named focal persons, budget lines and clear activation authority.

6.3.1 NEOC: from climate intelligence to early action

NDMA's National Emergency Operations Centre is central to Pakistan's shift from reactive relief to anticipatory disaster management. It brings together continuous multi-hazard monitoring, climate and weather information, predictive modelling, seasonal forecasting and impact-based projections so that an emerging threat can be understood in operational terms. Working with SUPARCO, PMD, PDMAs and other technical and response agencies, NEOC can help answer the questions that matter before an emergency: where is the hazard likely to occur, who and what may be exposed, how severe could the impact be, when must decisions be taken, and which authority should act? NDMA's published hazard projections, seasonal outlooks and early warnings demonstrate the practical value of this national capability (NDMA, n.d.-a; NDMA, 2026a).

Its importance is not limited to an operations room in Islamabad. The real value of climate modelling and seasonal forecasting is realized when technical analysis reaches a deputy commissioner, irrigation officer, health department, Rescue 1122 unit or village committee in a form they can use. NEOC should therefore anchor a

national common operating picture, agreed warning thresholds and forecast-to-action protocols across national, provincial and district EOCs. Warnings should state likely impacts and required action, be accessible to different groups and languages, and be tested through exercises. Forecast performance and field feedback should then be reviewed after each season so models, messages and procedures improve over time.

6.3.2 NIDM: institutionalizing disaster-management learning

The National Institute of Disaster Management is the capacity-development arm through which awareness and learning can become part of the country's disaster-management system. Its role should cover induction and refresher courses for public officials, training of trainers, community awareness, simulation exercises, curricula and manuals, and capacity-building for responders and volunteers. Pakistan needs volunteers who understand local hazards, warning messages, evacuation, first aid, protection and referral procedures; it also needs officials who can plan, coordinate and learn under pressure. Training should be competency-based, inclusive and connected to the roles assigned in district and provincial plans, rather than counted only by the number of workshops held.

NIDM can also protect institutional memory. Staff transfers and short project cycles often cause hard-won lessons to disappear. A structured learning system standard curricula, certification, exercise records, after-action reviews, case studies and periodic recertification—would turn experience from floods, heatwaves, earthquakes, droughts and glacial hazards into better practice. This directly advances Sendai's emphasis on understanding risk and strengthening governance, while supporting Paris Agreement Articles 7 and 11 on adaptation and capacity-building. In this way, awareness raising and trained volunteers are not side activities; they are part of Pakistan's long-term climate-resilience infrastructure (NDMA, n.d.-b; UNFCCC, 2015; UNDRR, 2015).

6.3.3 CoE C2DM: bridging climate science, policy and practice

NDMA's Centre of Excellence in Climate Change & Disaster Management (CoE C2DM) provides the specialist bridge between climate knowledge and disaster-management practice. Its C2DM learning model combines climate science, risk assessment, adaptation and DRR, GIS and remote sensing, case studies, laboratory work and simulation. This makes the Centre well placed to convene government, PDMAs and DDMAs, universities, humanitarian organizations, the

private sector and community practitioners around applied problems rather than treating climate change as a purely environmental subject (NDMA, n.d.-c).

CoE C2DM should support applied research and professional learning in climate-risk analytics, impact-based forecasting, resilient infrastructure, anticipatory action, loss-and-damage evidence and climate-finance proposals. NEOC data and operational lessons can shape its courses; graduates and research partners can improve models, plans and field practice. This feedback loop can support the NDC and National Adaptation Plan, align the Paris and Sendai agendas, and prepare technical teams for climate negotiations.

6.4 NDC 3.0 as a measurable DRR opportunity

Pakistan's NDC 3.0 includes specific disaster-risk directions for 2030. It calls for multi-hazard vulnerability and risk assessment covering 100 per cent of the country, including all districts; expansion of flood, drought and extreme-weather early warning to all communities; community based DRR programmes in at least 100 districts; and upgrading national and local response capacity. These targets create a measurable bridge between Pakistan's Paris commitments and domestic disaster-management responsibilities (Government of Pakistan, 2025).

These targets need annual milestones. Risk coverage should mean updated, quality-assured data used in land-use, infrastructure, contingency and investment decisions—not maps alone. 'Early warning for all communities' should be measured by reach, accessibility, trust, lead time and protective action. CBDRM coverage should require functioning local plans, inclusive trained volunteers, exercises and links to official systems. Used in this way, NDC 3.0 can become Pakistan's shared results framework for measurable district-level protection.

7. Operationalizing Paris-DRR Linkages in Pakistan

7.1 One climate-disaster risk information architecture

Pakistan should develop one agreed approach for recording hazards, exposed people and assets, vulnerability, local capacity and disaster losses. This does not mean placing every dataset in one office. It means that PMD, NEOC, PDMAs, DDMAs, line departments and planning authorities use compatible standards and can exchange information when needed. NEOC should provide the operational climate-risk intelligence layer and national common operating picture, while a district risk profile should combine scientific data with local knowledge from revenue staff,

municipal services, health workers, teachers, community organizations and first responders.

Risk information should be decision-oriented. A district profile should identify who and what is exposed, thresholds for action, evacuation constraints, critical service dependencies, available shelters and transport, and priority resilience investments. Annual pre-monsoon, heat and drought reviews should update assumptions. Post-event data should feed back into risk models and investment priorities.

7.2 End-to-end early warning and anticipatory action

Pakistan has developed considerable forecasting and response capacity. The remaining challenge is to ensure that NEOC climate modelling, seasonal forecasts and impact-based projections lead to timely action in the district, tehsil, union council and village concerned. Forecasts should be connected with agreed thresholds, named decision-makers, standard operating procedures, communication channels and pre-arranged finance. SMS and social media are useful, but they cannot be the only channels. Mosque loudspeakers where appropriate, local radio, school networks, health workers, community volunteers and face-to-face communication may be essential, particularly for remote settlements, women with limited phone access, older persons and persons with disabilities.

Anticipatory action should be mainstreamed into national and provincial contingency planning. Once a forecast reaches a defined probability or impact threshold, institutions should be able to release funds and take pre-agreed action: evacuating livestock and people, protecting water points, prepositioning health and relief supplies, securing schools and hospitals, clearing drainage or providing temporary cash support. After-action review should compare forecasts, decisions, reach, timeliness and avoided losses.

The learning loop should be deliberate. NEOC and field agencies should document forecast skill, warning reach, decisions and operational bottlenecks. NIDM should convert recurring lessons into updated training for officials, responders and volunteers, while CoE C2DM should use the evidence for applied research, advanced courses and policy improvement. This connects technology with people and institutions—the combination required for an early-warning system to save lives.

7.3 Risk-informed public investment and resilient recovery

Climate and disaster-risk screening should become a routine part of Pakistan's public investment process. Federal PSDP and provincial ADP schemes, PC-I

documents and major municipal investments should explain the relevant hazards, future climate assumptions, vulnerable beneficiaries, continuity requirements and maintenance costs. A road should not be approved without considering future flood levels and drainage. A school or basic health unit in a heat- or floodprone district should be designed to remain safe and functional during emergencies. Retrofitting an existing facility may sometimes protect people faster and at lower cost than constructing a new building.

Recovery should follow build-back-better principles while remaining socially just. Safer standards must be matched with land, livelihood and affordability solutions; otherwise households may return to unsafe locations. Recovery frameworks should identify in advance the institutional lead, financing instruments, social and environmental safeguards, procurement options and mechanisms for community participation.

7.4 Resilience finance and project preparation

Pakistan needs a rolling pipeline of practical and costed resilience programmes, not a fresh list prepared only before each international conference. Provinces and cities often know what needs to be done but lack the technical support to convert an idea into a strong financing proposal. A national project-preparation facility could help them develop climate rationales, baselines, feasibility work, economic analysis, safeguards, procurement plans, maintenance arrangements and measurable results for domestic budgets, the GCF, Adaptation Fund, multilateral development banks, bilateral partners and the FRLD, as applicable.

A layered risk-financing strategy should combine budget contingencies, reserve mechanisms, contingent credit, insurance where appropriate, social protection and international support. Prearranged finance is particularly important for anticipatory action and rapid response. Grants and highly concessional finance should be prioritized for public goods, poor communities and interventions that do not generate revenue. Debt implications must be assessed transparently.

7.5 Local leadership, inclusion and accountability

Resilience is ultimately tested at local level. DDMAs, assistant commissioners, municipal institutions, union councils, line departments and communities should take part in risk assessment, warning design, preparedness, monitoring and learning. CBDRM should not remain a donor-funded activity that ends when a project closes. Community plans and volunteers must be linked with official contingency plans,

Rescue 1122 and other first responders. Volunteers need clear roles, basic equipment, safeguarding, training, recognition and duty-of-care arrangements.

Accountability should focus on outcomes. Annual resilience scorecards can report district risk assessment coverage, warning reach and lead time, percentage of critical facilities with continuity plans, anticipatory actions activated, vulnerable groups reached, finance disbursed before and after events, restoration time for essential services and completion of after-action recommendations. Public reporting can strengthen trust and reveal where support is most needed.

8. Way Forward for Pakistan and Proposed COP31 Pitches

8.1 Strategic direction

Pakistan should not go to COP31 with a vulnerability narrative alone. The human and economic case is already strong, but it must be matched by a clear offer for action. The delegation should carry verified evidence, costed priorities, a small number of programmes that can be implemented at scale, and a credible explanation of how finance will reach provinces, districts and communities. This approach allows Pakistan to speak firmly about climate justice while also demonstrating readiness, ownership and accountability.

COP31 will take place in Antalya, Türkiye, from 9 to 20 November 2026 and will mark the formal commencement of the second Global Stocktake, which is due to conclude in 2028. This creates two linked opportunities. Diplomatically, Pakistan can shape discussion on adaptation, finance, loss and damage, technology, capacity and implementation. Operationally, it can use the stocktake process to present evidence, identify gaps and align national delivery with the next cycle of collective ambition (UNFCCC, 2026a, 2026b).

8.2 Priority national reforms for disaster resilience

a. **Adopt a national Paris-Sendai implementation framework.** Translate NDC 3.0 and NAP priorities into a jointly owned results framework linking federal, provincial and district DRM plans, budgets and indicators.

b. **Complete decision-ready MHVRA coverage.** Cover every district by 2030 with quality-assured, updateable risk profiles that are used in land-use, infrastructure, contingency and investment decisions.

c. **Guarantee last-mile warning and action.** Define national service standards for warning reach, accessibility, lead time, trusted communication, decision thresholds and verified protective action.

d. Institutionalize anticipatory finance. Create forecast-triggered financing windows within national and provincial arrangements so pre-agreed action does not wait for disaster declaration.

e. Protect critical services. Risk-screen and retrofit hospitals, schools, water, power, communications and transport assets; require continuity plans and exercises.

f. Build a unified loss-and-damage evidence system. Standardize event identifiers, sector definitions, direct and indirect loss reporting, disaggregation and credible non-economic loss documentation.

g. Create a resilience project-preparation facility. Provide provinces, cities and sectors with technical, economic, fiduciary, safeguard and proposal-development support.

h. Scale locally led adaptation and CBDRM. Prioritize high-risk districts; connect community plans and volunteers to official warning, contingency and financing systems.

i. Institutionalize a national resilience learning cycle. Use NEOC evidence and after-action reviews to update NIDM training, volunteer standards and CoE C2DM research, professional courses and policy advice.

j. Use resilient social protection. Link registries, vulnerability data and forecast triggers so temporary cash and services can be deployed before and after shocks.

k. Report outcomes annually. Publish a concise national resilience scorecard and track whether exercises and disasters produce changes in procedures, budgets and infrastructure.

8.3 A phased national implementation roadmap

Time horizon	Priority deliverables	Principal actors
Immediate: Sep-Nov 2026	Establish a federal-provincial COP31 resilience task team; validate NDC 3.0 DRR baselines; select five to eight flagship programmes; prepare evidence briefs, concept notes and negotiation lines; document recent	MoCC&EC, NDMA, NEOC, NIDM, CoE C2DM, Foreign Affairs, Finance, Planning Commission, PDMAs, PMD and NDRMF

	loss and early-warning lessons.	
Near term: 20272028	Operationalize shared risk and loss standards; scale anticipatory action pilots; establish the project-preparation facility; embed NEOC-to-NIDM/CoE learning; risk-screen priority public investments; contribute evidence to GST2.	Federal and provincial governments, DDMAs, local governments, climate finance entities, universities and technical partners
Medium term: 20292030	Achieve all-district MHVRA coverage, early-warning reach to all communities and CBDRM in at least 100 districts; institutionalize maintenance, annual scorecards, independent evaluation and lessons for the post-2030 framework.	Whole-of-government with local authorities, communities, civil society, academia and private sector

8.4 Recommended COP31 pitch package for the Government of Pakistan

The following pitches should be framed as practical offers for partnership, supported by national evidence and scalable programme concepts. They are recommendations for Pakistan's position and outreach, not assumptions about the final COP31 agenda or outcome.

Proposed pitch	Offer / programme concept	International ask
1. Pakistan Climate and Disaster Resilience Compact	A multi-partner investment platform that bundles district risk information, resilient critical infrastructure, water security, heat action, ecosystem-based protection, CBDRM and social protection into a costed programme.	Request programmatic, multi-year and grant/concessional support tied to transparent resilience results.

2. Early Warning to Early Action for Every Community	A national scale-up built around NEOC climate modelling, seasonal and impact-based forecasting, PMD coordination, linked EOCs, inclusive communication, evacuation, prepositioning and forecast-triggered finance.	Position Pakistan as an implementation partner for Early Warnings for All, with last-mile action—not alerts issued—as the core metric.
3. Resilience Project Preparation and Access Facility	A facility that helps provinces, cities and sectors prepare climate rationales, feasibility studies, safeguards, economic analysis and fund applications.	Seek technical assistance and capitalization so access barriers do not prevent vulnerable districts from reaching finance.
4. Loss-and-Damage Evidence and Rapid Support Window	A national system for rapid, standardized and disaggregated damage, loss and needs information, including credible non-economic losses and slow-onset impacts.	Advocate simple, predictable and country-accessible FRLD procedures and support for national systems before disasters occur.
Proposed pitch	**Offer / programme concept**	**International ask**
5. Debt-Sensitive Resilience Finance	A package emphasizing grants, highly concessional finance, disaster clauses, guarantees and instruments suited to public-good adaptation.	Argue that climate-vulnerable countries should not deepen debt distress to protect populations from impacts they contributed little to creating.
6. South Asia and Hindu Kush-	Shared standards and cooperation on hydro-meteorology, glaciers,	Invite regional and international technical

Himalaya Risk Information Partnership	river basins, heat, dust, drought and transboundary risk communication.	partners to support open, interoperable and actionable climaterisk information.
7. Locally Led Adaptation and Community Resilience Window	Scaled finance for community risk mapping, women- and youth-led action, resilient livelihoods, local volunteers and small protective infrastructure.	Call for simplified access, direct local benefits and indicators that measure inclusion, trust and protective action.
8. Pakistan GST2 Resilience Evidence Offer	A structured contribution using NEOC warning and forecast evidence, district risk coverage, loss trends, finance needs, and NIDM/CoE C2DM learning from exercises and tested interventions.	Offer credible implementation evidence while highlighting global gaps in adaptation finance, technology and capacity support.

8.4 Negotiating principles and coalition strategy

- Lead with evidence and solutions: pair vulnerability statistics with costed programmes, clear safeguards, measurable outcomes and implementation responsibility.
- Prioritize finance quality as well as quantity: emphasize accessibility, predictability, grant and concessional content, speed, local reach and debt sustainability.
- Defend balance between mitigation and adaptation: stronger mitigation limits future risk, while adaptation finance must respond to impacts already being experienced.
- Separate carbon-market opportunity from adaptation need: Article 6 cooperation may complement finance, but it cannot replace public and grant-based support for adaptation and loss and damage.
- Coordinate across diplomacy and operations: negotiators should be supported by MoCC&EC, NDMA, NEOC, NIDM, CoE C2DM, Finance,

Planning, PMD, PDMAs and sector experts able to supply evidence and answer implementation questions.

- Build issue-based coalitions: work through the Group of 77 and China and with climate vulnerable developing countries, regional partners, humanitarian actors and finance institutions around shared proposals.
- Maintain a rights-based and inclusive lens: show how proposals protect women, children, older persons, persons with disabilities, displaced groups, workers and climate-sensitive livelihoods.

8.5 Pre-COP31 government action checklist

Readiness area	Required action before departure
National position	Approve a concise whole-of-government negotiation brief with priority asks, fallback positions and responsible leads.
Evidence pack	Prepare verified national and provincial risk, warning, loss, finance and implementation data with transparent methods.
Readiness area	**Required action before departure**
Project pipeline	Select a small number of high-readiness, scalable programmes and prepare two-page investment summaries and fuller concept notes.
Delegation readiness	Conduct technical simulations so negotiators and operational experts use consistent messages and can respond to finance and implementation questions.
Partnership outreach	Schedule targeted meetings with funds, multilateral banks, UN entities, bilateral partners, technical agencies and potential regional collaborators.
Public narrative	Communicate climate justice through human impact and credible solutions, avoiding a narrative of vulnerability without agency.
Post-COP mechanism	Assign owners and deadlines for converting announcements and contacts into proposals, financing decisions, implementation and public reporting.

9. Conclusion

For Pakistan, the Paris Agreement and the Sendai Framework should be treated as two parts of the same resilience agenda. Paris provides international direction, finance architecture, technology and capacity support, while Sendai explains how risk should be understood and reduced in practice. The national task is to connect these commitments with the systems government already uses: federal and provincial planning, PSDP and ADP allocations, PC-I preparation, monsoon and heatwave contingency plans, district administration, line departments and community institutions.

Pakistan has a strong justification for seeking greater, faster, and more accessible climate support. The country faces significant climate risks, urgent development challenges, and limited fiscal capacity to address growing impacts alone. However, its position will become more effective when it can clearly demonstrate how climate finance will be utilized, which institutions will manage implementation, how provinces and local governments will participate, and how progress and outcomes will be measured and reported.

The true measure of climate action is not the number of policies formulated or meetings conducted, but the extent to which it improves the lives of vulnerable people. Success will be reflected when farmers experience reduced losses, urban communities face fewer disruptions, children can continue their education safely, outdoor workers are better protected, and mountain communities receive timely support and recover with dignity.

Key Takeaway:

Pakistan’s climate commitments must translate into visible improvements in people’s lives through safer homes and schools, effective and understandable early warning systems, timely release of funds before disasters occur, continuity of essential services, and recovery processes that build stronger and more resilient communities.

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PARTICIPANT RESEARCH PAPER

Bridging Pakistan's Disaster Risk Governance Gap for Climate-Resilient Development

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Abstract

Pakistan has developed an expanding architecture for disaster risk reduction, climate adaptation, and sustainable development, yet recurring floods continue to reverse development gains. The central problem is not simply the absence of policies, forecasts, or technical knowledge; it is the weak translation of these capacities into coordinated action at district and community level. This paper argues that the district is the missing institutional link between national and provincial systems and exposed households. The 2022 floods show how poverty, unsafe settlement, livelihood dependence, gender inequality, weak infrastructure maintenance, and fragmented governance can convert a climate hazard into a development crisis.

At the same time, communities possess social networks and indigenous knowledge that can strengthen preparedness but remain weakly integrated into formal disaster governance. The paper proposes a shift from policy production to policy delivery: legally and financially empowered District Disaster Management Authorities; risk-sensitive district development and spatial planning; people-centred and gender-responsive early warning; integrated hazard and vulnerability data using remote sensing and AI/ML; and permanent mechanisms for community and indigenous knowledge.

Keywords: climate change adaptation; community resilience; disaster risk reduction; district disaster management authorities; sustainable development goals

1. Introduction

Pakistan's disaster experience presents a policy paradox. The country is highly exposed to climate-related hazards while contributing under one percent of global greenhouse gas emissions, and floods along the Indus Basin repeatedly generate losses that undermine development. The 2030 Agenda and Sendai Framework were designed as complementary agendas because disasters repeatedly undermine livelihoods, infrastructure, and human capital (UNDRR, 2015; UNDRR, n.d.). Pakistan's development indicators show the scale of this challenge: it ranked 137th of 166 countries in the 2024 UN Sustainable Development Report, with eight goals stagnant and three regressing, while an estimated 97 million people, roughly 40 percent of the population, live in poverty (United Nations Pakistan, 2025).

The 2022 floods exposed the contradiction with unusual clarity. More than 33 million people were affected, while damages exceeded USD 14.9 billion, economic losses were about USD 15.2 billion, and reconstruction needs were assessed at at least USD 16.3 billion (World Bank, 2022). These figures represent setbacks to poverty reduction, food security, water, housing, livelihoods, and climate adaptation. The question is therefore: if Pakistan already possesses policies, forecasting capabilities, and disaster institutions, why does disaster risk continue to translate into repeated development losses?

This paper argues that the answer lies substantially in the gap between policy and implementation. The Sendai Framework has limited formal alignment with SDG indicators, leaving development variables such as gender, education, and land tenure outside much disaster-risk monitoring (Chmutina et al., 2021). Within Pakistan, the same fragmentation appears institutionally: national and provincial systems generate policy and information, but district institutions often lack the authority, staffing, and predictable financing required to turn them into local action (Hote & Koike, 2025). The paper consequently examines flood risk, vulnerability, community resilience, institutional and scientific gaps, mitigation, and early warning through the question of how the last mile between policy and people can be strengthened.

The objectives are to: (1) examine the relationship between sustainable development and DRR; (2) assess socio-economic, gender, and institutional dimensions of flood vulnerability; and (3) propose district-level measures to strengthen climate resilience.

> ***"Resilience should ultimately be judged not by the number of frameworks produced, but by how effectively risk information, resources, and decisions reach people before and during a disaster."***

33M people affected by the 2022 floods (UN Pakistan, 2025)	**97M** Pakistanis living below the poverty line (World Bank, 2022)	**$30B+** in flood damages and economic losses (World Bank, 2022)	**137 / 166** Pakistan's rank on the 2024 UN SDG Report (UN Pakistan, 2025)

management, including NDMA, PDMAs, DDMAs, early-warning systems, and climate-risk information. The country also increasingly uses satellite data, GIS, remote sensing, and hydrometeorological forecasting to anticipate hazards. Yet repeated floods continue to produce major human, economic, and developmental losses.

This creates a paradox: institutional preparedness does not always translate into effective risk reduction. The challenge is therefore not simply the absence of policies, institutions, or technology, but their uneven implementation. National and provincial systems can generate policies, forecasts, and risk information, but these do not consistently reach vulnerable communities in actionable forms. At the district level, limited staffing, financing, coordination authority, and technical capacity can constrain preparedness and mitigation.

Consequently, early warnings may exist without adequate evacuation, land-use planning, infrastructure protection, or community preparedness.

Similarly, advanced risk information has limited value when local institutions lack the capacity to interpret and act upon it.

The 2022 floods demonstrated that hazard impacts are shaped by underlying poverty, exposure, vulnerability, and development deficits.

Effective resilience therefore requires moving beyond response capacity toward sustained risk reduction and prevention**.** The central challenge is to strengthen the link between national policy, district-level implementation, and household-level action.

2. When a Hazard Becomes a Development Crisis

Pakistan's flood risk is concentrated in the Indus Basin, where monsoon rainfall, glacier melt, river dynamics, and unplanned urban growth interact with exposed settlements

and livelihoods. Twenty-one major floods occurred between 1950 and 2011, and the 2010 floods affected roughly twenty million people across the country's four provinces (Shah et al., 2022). The 2022 floods demonstrated how climate variability and exposure can combine with pre-existing development deficits to produce systemic losses. Pakistan's climate reporting also identifies changing precipitation and glacier-related processes as factors that compound exposure (Government of Pakistan, 2024).

A hazard becomes a disaster through its interaction with exposure, vulnerability, and capacity; physical hazard alone does not explain the distribution of losses.

Poor households have fewer assets with which to recover; informal and floodplain settlements can have weaker protection; agriculture-dependent households face simultaneous losses of crops, livestock, and income; and borrowing for reconstruction can increase later debt. The result is a feedback loop in which disasters erode progress toward SDG 1 on poverty, SDG 2 on food security, SDG 6 on water, SDG 8 on livelihoods, SDG 11 on safe and resilient settlements, and SDG 13 on climate action (Chmutina et al., 2021; Government of Pakistan, 2024; World Bank, 2022).

Gender makes this risk distribution even more uneven. Research in Khyber Pakhtunkhwa found that women were frequently excluded from risk assessment and received warnings indirectly through male relatives, while social norms could restrict independent evacuation (Shah et al., 2022). This demonstrates why SDG 5 cannot be treated as separate from DRR. If assessments record damage but not who can receive warnings, evacuate, access relief, or recover, vulnerability remains partially invisible. Risk assessment must therefore move beyond physical exposure and incorporate the social conditions that determine whether households can act on available information.

3. The Missing Middle: Why Districts Matter

Table 1. The missing link between national/provincial disaster-risk systems and household- and village-level action.

Level	What exists	Where the link breaks	What is needed
National & Provincial Level	SDG data, Sendai targets, National DRR Strategy 2025–2030, climate and hazard information	Policies, data and technical capacity do not consistently translate into coordinated district-level implementation	Clear mechanisms for transferring information, resources and responsibilities to districts
District Level – The Missing Middle	District Disaster Management Authorities are responsible for local disaster risk management	Limited legal standing, no predictable budget, inadequate dedicated staff and weak authority to coordinate line departments	Legally empowered DDMAs with ring-fenced financing, staff, data access and coordination authority
Household & Village Level	Local warning networks, community coping practices, relief and rebuilding mechanisms	National/provincial information and resources do not consistently reach communities in an accessible, timely and inclusive form	Community-centred warning systems, local preparedness, inclusive planning and sustained district–community coordination

The central institutional weakness identified in this paper is the 'missing middle' between national policy and household action. Pakistan has national strategies, provincial institutions, technical agencies, and substantial experience with disaster response. Yet the district is where hazard information has to become a land-use decision, where an embankment has to be maintained, where a warning has to be translated and disseminated, and where vulnerable households have to be identified before a flood occurs.

> ***"The district is where hazard information has to become a land-use decision, where a warning has to be translated and disseminated — and where vulnerable households have to be identified before a flood occurs."***

District Disaster Management Authorities are not simply another administrative layer. They are the operational bridge through which climate information, development planning, early warning, preparedness, and local response can be integrated. However, the literature identifies recurring weaknesses in their dedicated staffing, predictable financing, and authority to coordinate line departments (Hote & Koike, 2025). This creates a situation in which better national data or stronger infrastructure cannot automatically produce better local outcomes. The institutional problem is one of implementation capacity and accountability.

The same pattern is visible in data. Hazard and vulnerability information varies in quality and coverage across provinces, while remote-sensing and machine-learning applications that could improve exposure mapping remain largely at pilot scale (Dimasaka et al., 2024; Hote & Koike, 2025). The priority should therefore not be technology for its own sake. AI and remote sensing become valuable when they support operational decisions: identifying exposed settlements, mapping changing flood footprints, improving vulnerability assessments, and supporting impact-based forecasting. Their effectiveness ultimately depends on institutions that can interpret the information and act on it.

4. Resilience Exists Where the System Does Not

A district-centred approach should not replace communities with another layer of government. Pakistani communities already possess resilience capacities that formal systems have often been slow to recognize. Along the Kabul and Indus Rivers in Khyber Pakhtunkhwa, households draw on generational knowledge of river behaviour and mutual aid to anticipate rising water, while research among the Khetran community in Balochistan documents traditional observation of seasonal and hydrological indicators as a local warning mechanism (Khetran et al., 2012; Shah et al., 2022).

NGOs can provide an important connecting function by translating technical information into locally usable messages and linking community capacities with government systems (Shah et al., 2023). The weakness is that these capacities are often project-based rather than institutionalized. Community knowledge may disappear from formal planning when funding ends. A resilient governance model should therefore treat communities not only as beneficiaries of disaster programmes but also as holders of risk knowledge, social capital, and response capacity. This supports the partnership principle embedded in SDG 17 and the people-centred orientation of the Sendai Framework (UNDRR, 2015; UNDRR, n.d.).

5. When Good Solutions Fail at the Last Mile

Pakistan's experience shows that the effectiveness of a disaster-risk intervention depends on how well it is matched to hazard, context, and institutional capacity. The Left Bank Outfall Drain in Sindh illustrates the point. The system was built to carry saline effluent to the Arabian Sea with a rated capacity of roughly 4,000 cusecs, but during the 2022 floods it faced flows of around 13,000 cusecs, more than three times its design capacity. Breaches in the connected Puran Dhoro channel contributed to prolonged flooding around Badin (Ebrahim, 2022). The case demonstrates that structural capacity without continuous risk monitoring, maintenance, and clear local responsibility can become a source of additional risk.

Table 2. Where the disaster risk reduction system in Pakistan is thinnest.

Gap area	What the evidence shows

Data quality	Hazard and vulnerability data vary widely across provinces; standardized, province-wide datasets remain incomplete (Hote & Koike, 2025; Dimasaka et al., 2024).
Institutional capacity	District Disaster Management Authorities lack dedicated staff, predictable financing, and authority to coordinate line departments (Hote & Koike, 2025).
Early warning design	Formal systems remain technocratic, with little integration of community risk perception or gender considerations (Shah et al., 2022).
Last-mile communication	Warnings are often untranslated and poorly coordinated between technical agencies and local authorities (Shah et al., 2023).
Community knowledge	Indigenous knowledge and informal coping practices are rarely documented or funded, so they stay outside formal planning (Khetran et al., 2012; Shah et al., 2023).

Early warning provides a contrasting example. Pakistan's meteorological forecasting contributed valuable lead time during the 2022 floods, demonstrating that technical forecasting can work (World Bank, 2022). Yet research found that warning systems remained predominantly technocratic and that women and some last-mile communities were not adequately included in risk assessment or warning delivery (Shah et al., 2022; Shah et al., 2023).

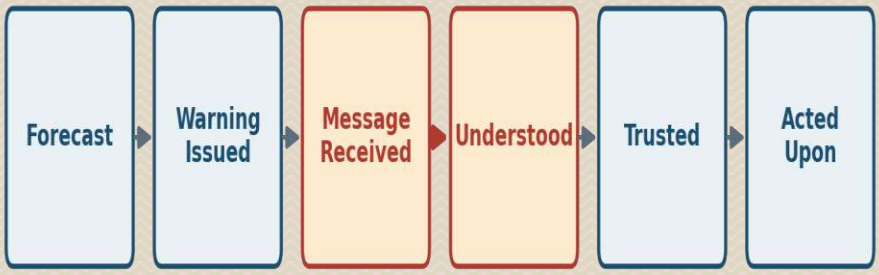
> ***"A warning only reduces risk when it is received, understood, trusted, and followed by an action that people are actually able to take."***

Nature-based approaches also demonstrate the importance of context. Pakistan's Billion Tree Tsunami restored roughly 350,000 hectares of watershed and degraded land and exceeded the province's Bonn Challenge commitment under independent monitoring (IUCN, 2017). Such approaches can strengthen watershed resilience and

reduce erosion, but they cannot replace embankment maintenance, drainage, and river-basin management. Overall, resilience depends on the interaction of infrastructure, ecosystems, information, institutions, and communities.

6. The Last Mile: From Forecast to Action

Pakistan's early-warning challenge can be understood as a chain: forecast, warning, message received, understood, trusted, acted upon. A technically accurate forecast can fail if any link is weak. Community-level research identifies untranslated warnings and poor coordination between technical agencies and local authorities as important barriers (Shah et al., 2023).



Pakistan's system is technically strong up to "received" and weakest at "understood" and "trusted" — the links that determine whether a household actually acts.

A people-centred system should combine scientific forecasting with multilingual and gender-responsive communication, community volunteers, local media, and trusted intermediaries. Women and marginalized groups should participate directly in risk assessment rather than being represented through household members, and communication channels should reflect the social and geographic realities of each district (Shah et al., 2022; Shah et al., 2023). Indigenous indicators should not replace scientific forecasting, but they can complement it by providing locally meaningful observations and strengthening community ownership.

Technology can strengthen this chain if it is integrated into decision-making. Remote sensing can improve flood and exposure mapping, while AI/ML can support identification of changing risk patterns and vulnerable areas (Dimasaka et al., 2024; World Meteorological Organization, 2022). Technology is an enabling capacity, not a

substitute for governance. Without trained district personnel, interoperable data, clear mandates, and trusted communication networks, sophisticated tools may simply produce better information that reaches the same institutional bottleneck.

7. From Disaster Management to Disaster Governance

The evidence suggests five mutually reinforcing reforms. First, District Disaster Management Authorities should receive clear legal standing, dedicated staffing, and ring-fenced financing, accompanied by transparent reporting and independent social audits to reduce the risk of elite capture (Hote & Koike, 2025). Second, disaster risk should be mainstreamed into district development, land-use, and spatial planning so that new exposure is not created through development decisions.

Third, early warning should be redesigned around people-centred and gender-responsive principles, with direct participation of women and marginalized groups and locally appropriate dissemination channels. Fourth, Pakistan should invest in standardized hazard and vulnerability datasets that can be updated through remote sensing and responsibly applied AI/ML. Fifth, provincial and district systems should create permanent mechanisms for documenting and using community and indigenous knowledge rather than relying on one-off consultations (Khetran et al., 2012; Shah et al., 2023).

These reforms are consistent with Pakistan's disaster policy architecture, including the National Disaster Risk Reduction Policy and the National Disaster Risk Reduction Strategy 2025-2030 (NDMA, 2013; NDMA, 2025). The strategic challenge is implementation. The better approach is empowered districts within clear national and provincial standards, supported by finance, data, oversight, and community participation.

8. Conclusion

Pakistan's recurring floods demonstrate that disaster resilience and sustainable development cannot be treated as separate policy agendas. The 2022 floods did not create poverty, weak infrastructure, gender inequality, or institutional fragmentation from nothing; they amplified vulnerabilities that already existed and reversed progress across

multiple SDG targets (Chmutina et al., 2021; United Nations Pakistan, 2025; World Bank, 2022).

Pakistan already has important foundations: national DRR and climate policies, technical forecasting capacity, significant infrastructure, community networks, and a growing policy emphasis on risk-informed development. The more persistent weakness is the translation of these assets into consistent action at the district and household level. Strengthening that missing middle offers a practical route to integrate SDG implementation, climate adaptation, and disaster risk reduction.

Ultimately, resilience should be measured not by how many strategies are written or technologies are acquired, but by whether a household receives a warning in time, understands it, can act on it, and has the resources to recover without falling deeper into poverty. For Pakistan, the decisive shift is therefore from producing more policy to making existing policy work at the last mile.

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PARTICIPANT RESEARCH PAPER

Smart Cities and Urban Disaster Risk Management Strategies: A Climate-Resilient Framework for Pakistan

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Abstract

Pakistan's rapid urbanization is occurring alongside increasing exposure to floods, heatwaves, earthquakes, drought, urban fires, water scarcity and other cascading hazards. Climate change is intensifying several hydro-meteorological extremes, while unplanned expansion, inadequate drainage, informal settlements, ageing infrastructure and fragmented governance convert hazards into disasters. This paper examines how smart-city approaches can strengthen urban disaster risk reduction (DRR) by combining risk-informed land-use planning, geographic information systems (GIS), Earth observation, Internet of Things (IoT) sensors, artificial intelligence (AI), digital twins, resilient infrastructure, nature-based solutions and people-centred early warning systems. The analysis argues that a smart city should not be defined by technology alone; it should be judged by its ability to reduce exposure and vulnerability, improve preparedness, protect essential services and include communities in decision-making. Pakistan's National Disaster Risk Reduction Strategy 2025–2030 provides an important policy basis for proactive, inclusive and technology-enabled resilience. Priority actions include interoperable urban risk-data platforms, climate-informed building and drainage standards, integrated command-and-control arrangements, last-mile warning systems, community-based preparedness and stronger municipal capacity. The paper proposes an integrated "One City—One Resilience Platform" model linking federal, provincial, municipal, technical and community institutions.

Keywords: Climate Change; Disaster Risk Reduction; Resilient Cities; Smart Cities; Urban Governance

1. Introduction

Cities concentrate people, infrastructure, economic activity and public services; consequently, the same concentration that creates economic opportunity can amplify disaster losses. The IPCC identifies rapid and poorly planned urbanisation, loss of green infrastructure and climate-blind infrastructure as important drivers of urban risk. Flooding is increased by extensive impervious surfaces, while heat is intensified by the urban heat-island effect. Local governments therefore have a central role in shaping exposure, vulnerability and adaptive capacity. (IPCC, 2022)

Pakistan faces a particularly complex urban risk environment. The country's urban population is projected to rise substantially, while climate-related hazards are becoming more consequential. The 2022 floods affected about 33 million people and generated more than US$30 billion in damage and economic losses, demonstrating how climate shocks can rapidly become development crises. More recently, the 2025 flash floods in Khyber Pakhtunkhwa exposed the continuing gap between hazard detection, warning dissemination and community response. (World Bank, 2022; World Bank, 2026)

The central problem is therefore not simply a shortage of infrastructure or technology. It is the weak connection between risk information, urban planning, infrastructure investment, emergency management and community action. This paper aims to assess how smart-city technologies and governance reforms can address this gap. Its objectives are to: (i) examine Pakistan's urban hazard and vulnerability profile; (ii) assess institutional, scientific and technological gaps; (iii) identify structural and non-structural DRR measures; (iv) evaluate people-centred early warning and risk communication; and (v) recommend an integrated, practical framework for climate-resilient Pakistani cities.

2. Regional Context & Hazard Profile

Pakistan's cities are exposed to multiple and interacting hazards. Riverine and pluvial flooding affect cities located along rivers as well as rapidly urbanizing areas where drainage capacity is exceeded. A World Bank assessment of Pakistani cities found substantial exposure to fluvial flooding and noted that settlement expansion has increased flood exposure; Lahore and several secondary cities in Punjab and Sindh are particularly vulnerable. (World Bank, 2024)

Heatwaves are another major urban threat because dense built-up areas, low vegetation cover and heat-absorbing materials can intensify thermal stress. Earthquakes remain a critical concern for Islamabad-Rawalpindi and other cities located near active fault systems. Coastal cities face sea-level rise, storm surge and saline intrusion, while northern urban and peri-urban settlements face flash floods, landslides and GLOFs. Drought and water scarcity can affect urban water supply and public health, while urban fires, air pollution and infrastructure failures create additional technological and environmental risks.

The disaster-risk concept can be represented as the interaction of hazard, exposure, vulnerability and capacity. A hazard becomes a disaster when exposed people and assets lack sufficient resilience and coping capacity. The Sendai Framework therefore emphasizes four priorities: understanding risk; strengthening risk governance; investing in resilience; and enhancing preparedness and Build Back Better recovery. Smart-city planning should operationalize these priorities rather than treating digitalization as an independent objective. (UNDRR, 2015)

Pakistan's National DRR Strategy 2025–2030 recognizes earthquakes, floods, droughts, heatwaves, forest fires, GLOFs and shifting monsoon patterns and calls for proactive planning, inclusive governance and technological innovation. This creates a strong policy entry point for linking smart-city development with national DRR objectives. (NDMA, 2025)

3. Risk & Vulnerability Assessment

Urban risk is unevenly distributed. Low-income households, informal-settlement residents, women, children, older persons, persons with disabilities, outdoor workers and people dependent on climate-sensitive livelihoods can experience greater exposure and fewer options for evacuation or recovery. The 2022 floods demonstrated the poverty dimension of disaster risk: World Bank analysis estimated that the disaster may have pushed as many as 9.1 million people into poverty, with poorer populations disproportionately affected. (World Bank, 2023)

Gender also shapes disaster vulnerability. Women may face restricted mobility, reduced access to information and finance, care responsibilities and safety risks during evacuation. Disaster shelters and warning systems that ignore these dimensions can

reproduce vulnerability even when technically sophisticated. Smart-city investments should therefore include gender-disaggregated risk data, accessible evacuation routes, safe shelters, complaint mechanisms and participation of women in local preparedness planning.

Critical urban infrastructure creates another layer of systemic vulnerability. Roads, bridges, drainage, water supply, electricity, telecommunications, hospitals and schools are interdependent. Failure of one network can trigger cascading failures across others. For example, flooding can disable electricity and communications, which then weakens pumping stations, traffic management, health services and emergency response. Risk assessment should therefore move from isolated hazard maps toward multi-hazard and infrastructure-dependency assessments.

A practical urban risk assessment should combine GIS-based exposure mapping, satellite imagery, building inventories, drainage-network data, demographic information, historical disaster records and climate projections. Risk indices should be updated periodically and made usable to planners, emergency managers and communities. The objective is not merely to produce maps but to convert evidence into zoning, infrastructure design, maintenance priorities, evacuation planning and investment decisions.

4. Community Resilience Factors

Technology cannot substitute for social capital. Neighbourhood networks, local leadership, volunteer groups, faith-based organisations, schools and community organisations often provide the first assistance during emergencies. Indigenous and locally developed coping practices can also contribute to resilience, particularly where formal services are limited.

Community participation should therefore be embedded in urban risk assessment and preparedness. Participatory mapping can identify blocked drains, unsafe buildings, flood pathways, heat refuges, vulnerable households and locally trusted communication channels. Community emergency response teams can support evacuation, first aid, fire safety and rapid needs assessment. Exercises and drills should be conducted before the hazard season, with special attention to women, children, older people and persons with disabilities.

Resilience is strongest when communities are treated as partners rather than passive recipients of warnings. A smart city should provide two-way communication: authorities issue alerts, while residents report blocked drains, rising water, damaged infrastructure and emerging hazards through mobile applications, hotlines or community platforms.

5. Scientific & Institutional Gaps

Pakistan's major gap is the limited integration of data and institutions. Planning authorities, municipal bodies, disaster management agencies, meteorological services, water utilities, electricity providers and emergency services frequently operate with separate datasets, mandates and systems. This can delay risk analysis and create conflicting decisions. Recent World Bank work on Punjab cities similarly highlights fragmented mandates, capacity gaps and weak investment planning as constraints on effective urban service delivery. (World Bank, 2026)

Technology adoption also faces limitations. AI and machine learning can improve rainfall-runoff forecasting, damage detection, traffic management and predictive maintenance, but they depend on reliable historical data, computing capacity, skilled personnel and transparent validation. Poor-quality or biased data can produce misleading risk scores. Cybersecurity, privacy, interoperability and vendor lock-in are additional concerns. ITU's recent work on smart and autonomous cities emphasises that AI, digital twins, IoT and advanced connectivity must be accompanied by governance, ethics, cybersecurity, interoperability and human oversight. (ITU, 2025; ITU, 2026)

The appropriate approach for Pakistan is therefore not technology-first but risk-first. Digital systems should be selected against clearly defined resilience outcomes, with open standards and institutional ownership. Capacity building should focus on municipal GIS, data management, climate-risk screening, emergency operations, procurement and maintenance—not only on purchasing hardware.

6. Mitigation Strategies & Best Practices

6.1 The Urban Risk Atlas & Tri-Zone Policy

Urban mitigation should combine structural and non-structural measures. Structural measures include climate-resilient roads and bridges, upgraded stormwater drainage, retention and detention ponds, flood protection, resilient water and wastewater systems, safe shelters, fire-resistant infrastructure and seismic strengthening. However, grey

infrastructure alone can transfer risk downstream or encourage development in hazardous areas. The IPCC recommends combining engineering approaches with nature-based solutions and risk-informed planning. (IPCC, 2022)

6.2 Transitioning from Grey to Green-Grey Infrastructure

A practical Pakistani model is “green + grey” drainage: green roofs, permeable pavements, rain gardens, restored natural drains, detention ponds, rainwater harvesting and recharge wells can reduce runoff while providing water-management benefits. Land-use controls should protect floodplains, drainage corridors and environmentally sensitive areas. Building codes should incorporate seismic safety, heat resilience, fire safety, energy efficiency and flood-resistant design. Cities must replace conventional concrete-and-discharge drainage with integrated Sustainable Urban Drainage Systems (SUDs). This framework intercepts runoff using a cascading natural treatment train: Rainwater connects to Green Roofs, which divert into Permeable Pavements, continuing into Rain Gardens, Detention Ponds, Recharge Wells, and finally entering engineered Stormwater Drainage arrays.

Smart technologies can strengthen these measures through sensor-based drainage monitoring, automated water-level gauges, satellite-based flood mapping, asset-management systems and digital twins. These tools should support preventive maintenance and scenario testing rather than merely displaying information. International experience also demonstrates the value of integrating climate resilience into water, sanitation and municipal-service investments. Pakistan’s Punjab Inclusive Cities Program, for example, combines urban services, drainage and institutional capacity with resilience objectives in secondary cities. (World Bank, 2025)

7. Risk Communication & Early Warning

A warning is effective only when people receive, understand and act upon it. The Early Warnings for All initiative defines four essential pillars: disaster-risk knowledge detection, observation, monitoring, analysis and forecasting; warning dissemination and communication; and preparedness and response capabilities. (WMO, 2024)

For Pakistani cities, early warning should be multi-channel and last-mile focused. Alerts can combine cell broadcast/SMS, mobile applications, social media, sirens, mosque announcements, radio, television, public-address systems and trained community focal

points. Messages should be short, location-specific, action-oriented and available in appropriate local languages. Accessibility features should support people with hearing, visual or mobility limitations.

Smart-city emergency operations centers can integrate rainfall forecasts, river and drainage sensors, satellite observations, traffic conditions, hospital capacity and citizen reports on a common dashboard. Pre-agreed triggers should activate anticipatory actions such as opening shelters, clearing drainage bottlenecks, positioning rescue teams and protecting critical assets. The 2025 flash floods illustrate the urgency of strengthening this “last mile”: the speed of extreme events can leave communities with little time to react when warnings do not reach them. (World Bank, 2026)

8. Policy Recommendations

a. Establish a One City—One Resilience Platform.

Create an interoperable urban risk platform connecting NDMA/PDMAs, local governments, planning authorities, technical agencies, utilities, emergency services and communities. GIS, remote sensing, IoT and risk registers should feed a common decision-support environment.

b. Make risk information mandatory in urban planning.

Require multi-hazard risk screening for master plans, land-use changes, major infrastructure and public investment projects. Development permissions should account for flood, seismic, heat, fire and water-scarcity risks.

c. Strengthen municipal capacity and finance.

Provide local governments with dedicated DRR and climate-adaptation budgets, technical staff and asset-management systems. Resilience should be treated as a recurrent service responsibility, not only a post-disaster project.

d. Adopt green + grey infrastructure.

Priorities integrated drainage, detention, permeable surfaces, rainwater harvesting, recharge, urban trees and wetland/open-space protection alongside conventional engineering.

e. Build people-centered early warning systems.

Align city-level systems with Early Warnings for All, including last-mile communication, inclusive evacuation plans, drills and anticipatory action triggers.

f. Use AI and digital twins responsibly.

Develop pilot applications for flood forecasting, heat-risk mapping, infrastructure inspection and emergency logistics, with human oversight, cybersecurity, data-quality controls and transparent performance evaluation.

g. Institutionalize community participation.

Use participatory risk mapping, neighborhood response teams and citizen reporting. Ensure women and vulnerable groups are represented in resilience committees and planning processes.

h. Develop measurable resilience indicators.

Track indicators such as drainage functionality, warning lead time, percentage of critical assets risk-screened, emergency response time, tree/green-space coverage, resilient-building compliance and recovery time for essential services.

9. Conclusion

Pakistan's urban disaster challenge is increasingly a climate-resilience challenge. Rapid urbanization, exposed infrastructure, environmental degradation and social inequality interact with floods, heatwaves, earthquakes, water scarcity and other hazards to produce systemic risk. The solution is not simply to make cities more digital; it is to make urban decision-making more risk-informed, inclusive, anticipatory and accountable.

Smart-city technologies can provide the connective tissue for this transformation. GIS and Earth observation can reveal exposure; IoT can provide real-time monitoring; AI can support forecasting and prioritization; digital twins can test scenarios; and integrated communication systems can connect warnings to action. Yet technology will be effective only when supported by capable institutions, reliable data, resilient infrastructure, community participation and sustainable finance.

For Pakistan, the priority should be to move from fragmented projects toward integrated urban resilience systems. The National DRR Strategy 2025–2030, the Sendai Framework and Early Warnings for All provide complementary policy foundations. A "One City—One Resilience Platform" approach can connect federal, provincial, municipal, technical and community capacities. Ultimately, the smartest city is not the city with the most sensors; it is the city that uses science, technology, social capital and

good governance to anticipate risk, protect vulnerable people, maintain essential services and recover stronger after disasters.

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Appendix A. Indicative Urban Multi-Hazard Risk Matrix

Hazard	Primary Exposure	Key Vulnerability	Smart-City Tool	Priority Action
Urban/pluvial flood	Low-lying settlements, roads, drainage	Blocked drains, impervious surfaces	Rain gauges, water-level sensors,	Green+grey drainage; flood alerts

			GIS, satellite mapping	
Heatwave	Dense built-up areas, outdoor workers	Low tree cover, heat-island effect	Heat sensors, satellite thermal data, heat-risk maps	Heat action plans; cooling/green infrastructure
Earthquake	Buildings, lifelines, schools/hospitals	Code non-compliance, weak structures	GIS inventory, structural monitoring, digital twin	Seismic strengthening; enforcement
Drought/water scarcity	Water supply systems, households	Leakage, over-extraction, low storage	Smart meters, water monitoring, forecasting	Demand management; rainwater/recharge
Urban fire	Dense commercial/residential areas	Unsafe buildings, access constraints	GIS, CCTV, smart alarms, routing	Fire-safe design; emergency access
Flash flood/landslide	Hilly/peri-urban settlements	Slope instability, weak warning reach	EO, rainfall radar, sensors, alerts	Hazard zoning; last-mile warning

Appendix B. Proposed One City—One Resilience Platform

Federal: NDMA / Planning / Climate-related ministries → Provincial: PDMAs + Planning & Development + line departments → Metropolitan/Local Government: urban planning + development authorities + municipal services → Technical Agencies: GIS, meteorology, water, power, transport, health and emergency services → Communities + private sector + academia. The platform should support five functions: risk knowledge; monitoring and forecasting; planning and investment screening; early warning and emergency coordination; and post-disaster learning and recovery.

PARTICIPANT RESEARCH PAPER

Multiple-Hazard Risk in Jamshoro District

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Abstract

Jamshoro District in Sindh faces a multi-hazard risk profile in which riverine flooding and extreme heat can disrupt communities, livelihoods, infrastructure and essential services. This paper examines these two hazards through a desk-based assessment using official government data and recent institutional and academic evidence. The 2022 flood provides a clear local reference point: the Provincial Disaster Management Authority (PDMA) Sindh documented substantial inundation across Jamshoro, including 918.73 km² of inundation in its 14 September 2022 provincial assessment and 875.95 km² in its 23 September assessment. Pakistan Meteorological Department (PMD) bulletins further show that Jamshoro is exposed to severe heat conditions; on 25–31 May 2026, maximum temperatures of 44–47°C were forecast for the district, approximately 4–6°C above normal. The analysis argues that risk should not be understood only as the probability of an individual hazard. Exposure, social vulnerability, infrastructure dependence and limited coping capacity determine how hazards translate into losses. Priority actions therefore include integrated floodplain management, climate-resilient infrastructure, heat-health action planning, impact-based early warning, last-mile communication and stronger district-level risk data. The paper concludes that Jamshoro would benefit from a single multi-hazard risk-management framework linking hazard monitoring, vulnerable-population mapping, infrastructure protection and community preparedness.

Keywords: Climate change; disaster risk reduction; extreme heat; Jamshoro; riverine flooding

1. Introduction

Disaster risk in Pakistan is increasingly shaped by the interaction of climatic extremes with population exposure, poverty, infrastructure deficits and limited adaptive capacity. The 2022 floods demonstrated the scale at which hydro-meteorological hazards can affect Sindh, while recurrent heatwaves have highlighted a second, less visible but serious threat to health, productivity and essential services. The World Bank notes that Sindh is particularly vulnerable because of its geographical, climatic and socioeconomic conditions, and that flood-affected communities often face inadequate health, water, sanitation, schooling and electricity services (World Bank, 2022).

Jamshoro is strategically important because its settlements, agricultural areas, transport links and public services exist within a landscape influenced by the Indus River system and extreme summer temperatures. Pakistan Bureau of Statistics data from the 2023 Census place the district population at 1,117,216, meaning that a large and diverse population forms the exposure base for disaster-risk planning (Pakistan Bureau of Statistics [PBS], 2023). However, population alone should not be treated as risk: risk is produced through the interaction of hazard, exposure and vulnerability.

The problem addressed in this paper is therefore not simply whether Jamshoro experiences floods or heatwaves. The more important question is how these hazards affect communities and infrastructure, where vulnerabilities are concentrated, and how disaster risk reduction can be organized around multiple hazards rather than isolated emergency responses. The purpose is to synthesize available evidence and identify practical priorities for district-level climate adaptation and DRR. The scope is deliberately focused on riverine flooding and extreme heat, using Jamshoro-specific evidence where available and clearly distinguishing it from broader Sindh and Pakistan evidence.

1.1 Research Objectives

• Assess the principal exposure and vulnerability characteristics associated with riverine flooding and extreme heat in Jamshoro.

• Examine likely socioeconomic, health, livelihood and infrastructure impacts of the two hazards.

• Identify community resilience, institutional and data-related gaps relevant to disaster risk reduction.

• Recommend integrated mitigation, early-warning and policy measures appropriate to the district.

2. Regional Context & Hazard Profile

Jamshoro lies in Sindh, a province where riverine flooding, heat extremes and socioeconomic vulnerability can overlap. The 2022 flood illustrates the flood component of this risk. PDMA Sindh's provincial inundation assessment recorded Jamshoro at 918.73 km² inundated on 14 September 2022 and 875.95 km² on 23 September 2022, based on 15-metre satellite imagery. These values represent preliminary inundation snapshots rather than a permanent flood-risk boundary and should not be interpreted as the proportion of the district that was continuously flooded (PDMA Sindh, 2022).

The scientific literature also shows that the 2022 Pakistan flood resulted from a combination of extreme precipitation and antecedent conditions, while the event exposed the country's high vulnerability to large-scale flooding (Nanditha et al., 2023). For Sindh, the consequences were particularly severe because agriculture, housing and basic services are closely tied to flood-prone landscapes.

Extreme heat represents a different type of hazard. Unlike a rapidly rising river, heat can develop over several days and produce cumulative physiological and infrastructure stress. PMD reported on 25, 28 and 31 May 2026 that maximum temperatures in Jamshoro were expected to reach 44–47°C, with temperatures 4–6°C above normal under heatwave conditions (Pakistan Meteorological Department [PMD], 2026). A national spatial assessment also classified Jamshoro in a moderate heatwave-hazard category, although such national zoning should be interpreted as a comparative hazard index rather than a direct measure of current local risk (Khan et al., 2023).

In DRR terminology, a hazard is a potentially damaging physical event or process; exposure refers to people, property, infrastructure and other assets located in hazard-prone areas; vulnerability describes the physical, social, economic and environmental conditions that increase susceptibility; and disaster risk reflects the potential losses arising from these interacting conditions. This distinction matters in Jamshoro because a high hazard does not automatically produce high losses where exposure and

vulnerability are low, while moderate hazards can produce serious impacts where coping capacity is weak.

3. Risk & Vulnerability Assessment

The district's 2023 population of 1.117 million establishes a substantial human exposure base (PBS, 2023). Flood exposure is spatially concentrated along riverine and low-lying areas, while heat exposure can be much more widespread because high temperatures affect outdoor workers, households, public facilities and transport systems across the district. Consequently, the two hazards differ in spatial pattern but can converge through shared infrastructure and service systems.

Flooding can disrupt livelihoods through crop losses, livestock impacts, household damage, road interruption and reduced access to markets. The World Bank's assessment of Sindh emphasizes the importance of agriculture to provincial livelihoods and notes that socioeconomic deprivation and weak access to services increase disaster vulnerability (World Bank, 2022). For Jamshoro, this means that flood impacts should be assessed not only by physical damage but also by the duration of service disruption and the ability of households to recover.

Heat creates a different burden. Extreme temperatures increase the risk of heat exhaustion, heatstroke and dehydration and can reduce the capacity of people to work outdoors. Evidence from Pakistan shows that heatwaves can place substantial pressure on health systems. For example, research from Karachi documented increased heat-related illness and challenges in emergency healthcare during periods of extreme heat (Saleem et al., 2024). Evidence from Sindh also indicates that heatwaves can disrupt routine health-service delivery, with rural areas experiencing stronger reductions in outreach immunization activity during heatwave periods (Siddiqi et al., 2025). These studies are not Jamshoro-specific, so they should be used as regional evidence rather than as estimates of local disease burden.

Vulnerability is also socially differentiated. Older adults, children, people with disabilities, individuals with pre-existing health risks, low-income households and outdoor workers may have fewer options for avoiding heat or recovering from flood losses. Gender can shape exposure and access to resources through differences in mobility, caregiving roles, employment and access to information. However, Jamshoro-specific sex-

disaggregated disaster-impact datasets were not identified in the evidence reviewed; therefore, gender-specific impacts should be investigated through local surveys and administrative data rather than assumed.

Infrastructure creates an important common pathway. Flooding can damage roads, drainage, irrigation and public facilities, while heat can increase cooling demand, water demand and stress on health and electricity services. When infrastructure systems are already weakened by one hazard, their capacity to absorb a second stressor can decline. This is the central multi-hazard concern: risk is not necessarily additive, because service disruption can reduce coping capacity and amplify the consequences of subsequent hazards.

4. Community Resilience Factors

Community resilience depends on more than physical infrastructure. Social networks, local knowledge, trusted leaders, neighbourhood-level cooperation and previous disaster experience can influence whether warnings are received and acted upon. During floods, community members may have detailed knowledge of local routes, elevated areas, water movement and safe evacuation locations. During heatwaves, households may rely on locally developed strategies such as changing work hours, seeking shade and sharing water. Such practices should be documented and incorporated into formal preparedness planning rather than treated as substitutes for public services.

Participation is especially important for last-mile preparedness. A warning is ineffective if people do not understand what action is required, cannot evacuate, lack transport, or distrust the issuing institution. People-centred DRR therefore requires two-way communication: authorities provide timely information while communities identify practical constraints and local solutions. The World Meteorological Organization (WMO) and United Nations Office for Disaster Risk Reduction (UNDRR) emphasize that multi-hazard warning systems should connect risk knowledge, monitoring and forecasting, communication, and preparedness and response capabilities (WMO, 2025; UNDRR, 2023).

5. Scientific & Institutional Gaps

A major limitation for Jamshoro is the uneven availability of district-scale, integrated risk data. Official flood inundation mapping provides valuable spatial evidence, but a single inundation snapshot does not explain household-level losses, recovery time, road accessibility, health outcomes or the distribution of vulnerable groups. Similarly, PMD temperature forecasts demonstrate heat hazard, but district-specific heat-health surveillance and infrastructure vulnerability data are less readily available in the public domain.

The second gap is the separation of hazard information across institutions. Flood forecasting, heat warnings, health surveillance, infrastructure management and local government planning may use different datasets and communication chains. A multi-hazard approach requires interoperable information so that a decision-maker can see which settlements, roads, schools, health facilities and water systems are simultaneously exposed.

Third, advanced technologies such as GIS, remote sensing, automated sensors and machine-learning models can improve forecasting and hotspot identification, but technology alone cannot solve institutional problems. AI/ML models require quality historical data, validation, maintenance and transparent governance. For Jamshoro, the immediate priority should be reliable foundational datasets—high-resolution exposure maps, critical-infrastructure inventories, population vulnerability indicators and consistent impact records—before highly complex predictive systems are scaled.

6. Mitigation Strategies & Best Practices

Flood risk reduction should combine structural and non-structural measures. Structural priorities include maintaining and upgrading flood protection and drainage infrastructure, protecting critical road links, and improving the resilience of water and public-service facilities. Non-structural measures should include land-use planning, floodplain risk mapping, evacuation-route planning, routine drills and household preparedness. The experience of Sindh's post-2022 recovery shows the value of rebuilding infrastructure and housing to higher resilience standards rather than restoring pre-disaster conditions alone (World Bank, 2025).

For extreme heat, district authorities should implement a heat-health action plan linked to PMD forecasts. Practical measures include heat-risk communication, water and

cooling access at high-exposure locations, adjusted work schedules for outdoor labour, preparedness of emergency departments, protection of schools and vulnerable groups, and monitoring of heat-related illness. Public facilities should also be assessed for passive cooling, ventilation, shade and reliable electricity and water access.

The best approach is to combine these measures into a multi-hazard resilience programme. Critical facilities should be screened for both flood and heat exposure; evacuation and shelter plans should consider whether facilities remain usable during extreme heat; and infrastructure investment should consider both water and thermal stresses.

7. Risk Communication & Early Warning

Jamshoro requires an end-to-end, people-centred multi-hazard early-warning system rather than separate messages for separate hazards. UNDRR defines multi-hazard warning systems as systems that account for hazards occurring alone, simultaneously, cascadingly or cumulatively over time (UNDRR, 2017). WMO's Early Warnings for All framework organizes the system around four linked functions: risk knowledge; detection, monitoring and forecasting; warning dissemination and communication; and preparedness and response capabilities (WMO, 2025).

At district level, warnings should be impact-based. Instead of communicating only '44–47°C', authorities should explain who is most exposed, what services may be affected, and what actions should be taken. Similarly, flood warnings should identify expected inundation areas, roads at risk, safe routes and the timing of required action. Messages should use multiple channels—including mobile communication, local radio, mosques or community networks, health workers and local administration—to reduce dependence on a single digital platform.

8. Policy Recommendations

1. Develop a Jamshoro District Multi-Hazard Risk Atlas integrating flood inundation, heat hazard, population vulnerability and critical infrastructure.

2. Create a district-level multi-hazard coordination mechanism linking PDMA/NDMA structures, district administration, PMD, health, irrigation, local government and emergency services.

3. Prioritize protection and climate-resilient upgrading of roads, hospitals, schools, water systems, electricity facilities and evacuation routes.
4. Operationalize a district heat-health action plan using PMD forecasts and predefined triggers for public-health and labour-protection actions.
5. Strengthen floodplain management and maintain updated evacuation maps based on satellite inundation evidence and local knowledge.
6. Establish a common disaster-impact database recording location, affected population, infrastructure damage, service disruption and recovery time.
7. Use GIS and remote sensing as routine decision-support tools, while applying AI/ML selectively after data quality and validation requirements are met.
8. Design inclusive warning and preparedness programmes that explicitly address women, older adults, children, people with disabilities and outdoor workers.
9. Conduct annual multi-hazard drills that test not only evacuation but also continuity of health, water, electricity and communication services.

9. Conclusion

Jamshoro's risk profile demonstrates why disaster management should move from hazard-by-hazard response toward integrated risk reduction. The district has documented exposure to large-scale riverine flooding, while PMD evidence confirms that extreme heat can reach severe levels. The two hazards differ in onset and spatial expression, but both can disrupt livelihoods, health, transport, water, electricity and public services.

The evidence also shows the limits of available data. Jamshoro-specific flood and temperature information is sufficiently strong to establish hazard exposure, but detailed household-level vulnerability, gender-disaggregated impacts, heat-health outcomes and infrastructure failure data remain insufficient in the publicly available evidence reviewed for this paper. This is not a reason to delay action; it is a reason to improve the evidence base while implementing practical DRR measures.

A resilient Jamshoro should therefore be planned around shared systems rather than isolated hazards. Integrated risk mapping, resilient infrastructure, heat-health preparedness, floodplain management, community participation and people-centred multi-hazard early warning can reduce both direct impacts and cascading service

disruptions. Such an approach is consistent with the Sendai Framework's emphasis on understanding disaster risk, strengthening governance, investing in resilience and enhancing preparedness. The strategic objective should be prevention and risk reduction before disaster, not only response after impact.

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Appendix A. Evidence Snapshot

Hazard	Jamshoro Evidence	Primary Source	Interpretation
Riverine flooding	918.73 km² inundated (14 Sep 2022); 875.95 km² (23 Sep 2022)	PDMA Sindh (2022)	Satellite-based snapshots demonstrate substantial spatial exposure; not a permanent risk boundary.
Extreme heat	44–47°C forecast; 4–6°C above normal during May 2026 heatwave conditions	PMD (2026)	Confirms severe heat exposure and need for heat-health preparedness.
Population exposure	1,117,216 people (2023)	PBS (2023)	Defines the district population base; actual risk varies spatially.
Multi-hazard warning	Four pillars: risk knowledge; monitoring; communication; preparedness/response	WMO (2025); UNDRR (2023)	Provides an internationally recognized framework for integrated early warning.

PARTICIPANT RESEARCH PAPER

Japan's Earthquake Preparedness Model:
Best Practices Developing Countries Can Adapt

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Abstract

Japan's earthquake-preparedness system is the product of more than a century of disaster-driven reform, beginning with the 1923 Great Kantō earthquake and continuing through the 2011 Tohoku disaster. This paper reviews how Japan converted repeated seismic losses into an integrated system built on five reinforcing pillars: engineering (seismic building codes), technology (the Earthquake Early Warning network), social infrastructure (self-help, mutual-help, and public-help community structures), financing (retrofit subsidies and low-interest loans), and international cooperation. Comparative evidence from the 2011 Tohoku earthquake, the 2015 Gorkha earthquake in Nepal, and the 2023 Türkiye-Syria earthquake shows that construction quality and code enforcement, not magnitude, explain the wide gap in death tolls between comparable events. The paper concludes with a three-phase, resource-sequenced road map through which developing countries facing similar seismic hazard but shorter reform timelines can adapt Japan's model to their own institutional and financial constraints.

Keywords: Building Codes; Community Resilience; Disaster Risk Reduction; Earthquake Early Warning; Seismic Retrofitting

1. Introduction

Japan lies at the junction of four tectonic plates and is among the most seismically active countries in the world. Its disaster history, however, is also a policy history: each major earthquake since 1923 has been followed by a specific structural, technological, or institutional reform. Many developing countries face comparable seismic exposure but lack a mechanism for converting disaster losses into durable structural reform, and as a result experience far higher casualty rates for earthquakes of similar or lower magnitude than Japan now records. This gap motivates the present study.

The objective of this paper is to examine how Japan's century-long evolution of earthquake policy produced an integrated resilience system, to identify the specific pillars underlying that system, and to derive phased, resource-sensitive recommendations that developing countries can realistically adopt. The scope of the analysis is limited to seismic (earthquake) preparedness and draws comparative evidence primarily from Nepal (2015) and Türkiye-Syria (2023) to illustrate where the model succeeds or fails to transfer.

2. Regional Context and Hazard Profile

Japan's earthquake history illustrates a repeating pattern of disaster followed by reform. The 1923 Great Kantō earthquake killed more than 105,000 people and produced Japan's first modern seismic design rules. The 1968 Tokachi-oki earthquake exposed weaknesses in reinforced-concrete construction, leading to stricter standards in 1971. The 1978 Miyagi earthquake led to the 1981 Shin-Taishin (New Seismic) Standard, a substantially higher bar for lateral force resistance. The 1995 Great Hanshin-Awaji (Kobe) earthquake killed 6,434 people, with 97 percent of collapsed buildings predating the 1981 code, and triggered both a national retrofitting law and, in 2000, mandatory foundation and connector requirements for wooden houses. The Japan Meteorological Agency's Earthquake Early Warning system went nationwide in 2007 and was tested at scale during the 2011 Tohoku earthquake, in which building collapse was minimized.

In hazard terminology, the hazard itself (the physical earthquake) cannot be reduced, but exposure and vulnerability can. Japan's history shows that its principal policy lever has consistently been vulnerability reduction, chiefly through building codes and retrofit

financing, rather than any attempt to alter the underlying hazard. This distinction is central to the transferability argument developed later in this paper.

3. Risk and Vulnerability Assessment

The 1995 Kobe earthquake remains the clearest illustration of how vulnerability, not hazard magnitude, drives disaster losses. Of the buildings that collapsed, 97 percent had been built before the 1981 seismic standard took effect. The Japanese government committed an estimated $58 billion to housing, infrastructure, and public-facility recovery; rebuilding the city's main expressway took 21 months, and full port reconstruction took 26 months. Beyond the direct death toll, the earthquake disrupted livelihoods dependent on the port and transport corridors, displaced households, and disproportionately affected residents of older, non-retrofitted wooden housing, a group that in Japan, as elsewhere, skews toward elderly and lower-income populations. These socio-economic and gendered dimensions of vulnerability directly informed the 1995 Retrofitting Law and the 2000 wood-frame revision.

Comparative data reinforce the point. Japan's 2011 Tohoku earthquake (M9.0) caused roughly 22,000 deaths, overwhelmingly from the tsunami rather than building collapse. Nepal's 2015 Gorkha earthquake (M7.8) caused approximately 9,000 deaths, mostly from the collapse of largely non-engineered masonry construction. The 2023 Türkiye-Syria earthquake, also M7.8, caused approximately 59,000 deaths despite a comprehensive building code existing on paper, because of uneven enforcement. Exposure to informal, non-engineered, or poorly enforced construction not the magnitude of the hazard is the dominant factor explaining the difference in outcomes across these three events of comparable or greater energy release.

4. Community Resilience Factors

Japan's social infrastructure for disaster resilience rests on three reinforcing layers: jijo (self-help), in which households maintain emergency kits and know evacuation routes; kyojo (mutual help), in which neighborhood jishubo associations coordinate street-level response and cover a high share of households; and kojo (public help), under which, since 2013, every municipality can adopt a jointly developed Community Disaster Management Plan. Eight million disaster-preparedness booklets have been distributed

to households in Tokyo alone, one channel among several that keep these three layers connected.

The clearest evidence of community resilience in practice is the so-called "Miracle of Kamaishi." Following attitude-based disaster education introduced in the city's schools in 2004, roughly 3,000 students evacuated to high ground on their own initiative during the 2011 Tohoku earthquake; only five school-age deaths were recorded citywide, and none occurred at school, even as the city as a whole lost more than 1,000 residents. The curriculum rested on three principles: do not be fixated on assumptions, since hazard maps and seawalls are guides rather than guarantees; do your best with the information available in the moment; and take the initiative rather than waiting to be told. This case demonstrates that social capital and indigenous knowledge, translated through drilled rather than purely informational education, produce measurable survival outcomes independent of infrastructure spending.

5. Scientific and Institutional Gaps

Several gaps constrain the transfer of Japan's model to developing-country contexts. Empirical data on the seismic performance of informal and indigenous housing techniques remain limited in most developing countries, which hampers evidence-based codification rather than outright prohibition of vernacular methods. Institutional enforcement capacity is frequently the binding constraint: the Türkiye-Syria case shows that a comprehensive code on paper is insufficient without compliance mechanisms. Very few developing countries operate a dense, ground-truthed seismometer network comparable to the Japan Meteorological Agency's roughly 4,235 stations, built at an estimated cost of $500 million, and the application of artificial intelligence and machine learning to rapid damage assessment and early-warning signal processing remains largely unexplored in lower-resource settings.

6. Mitigation Strategies and Best Practices

Japan's mitigation approach combines structural and non-structural measures. Structurally, the 1981 Shin-Taishin standard raised lateral force resistance requirements, the 2000 wood-frame revision mandated continuous concrete strip foundations and metal joint connectors for wooden houses, and the 1995 Retrofitting Law funded the upgrading of older housing stock through assessment subsidies,

retrofit-cost subsidies, tax reductions, and low-interest loans. Non-structurally, the Earthquake Early Warning system provides a lead time of roughly 11 seconds at 100 kilometers from the epicenter and roughly 3.2 seconds at 30 kilometers, sufficient to automatically slow high-speed trains, halt factory assembly lines, and pause elevators at the nearest floor.

Japan has also exported elements of this model through the Japan International Cooperation Agency (JICA), which has supported disaster-risk-reduction programs since the 2015 Sendai Framework: grant aid and training to build the Philippines' PHIVOLCS monitoring capacity, a two-decade program that built Nepal's Disaster Prevention Technical Centre, the 1982 Sabo Technical Center in Indonesia, and post-disaster response support to Pakistan and Türkiye following the 2005 and 2023 earthquakes. These cases show structural, technological, and human-capacity measures functioning as mutually reinforcing components of a single system rather than as substitutes for one another.

7. Risk Communication and Early Warning

The Japan Meteorological Agency's Earthquake Early Warning system detects the fast, weak P-wave that precedes an earthquake's slower and more destructive S-wave, instantly estimates epicenter and magnitude, and broadcasts a warning via television, radio, and mobile networks nationwide before damaging shaking arrives. Operational since 2007, it has been used during the 2011 Tohoku and 2024 Noto Peninsula earthquakes and is now a global benchmark referenced by early-warning systems in Mexico City and Los Angeles.

For developing countries, the central challenge is less the absence of any warning capability than weak last-mile communication to rural, low-income, or otherwise vulnerable populations, a gap reflected in the comparatively higher tolls in Nepal and Türkiye-Syria. A people-centred and gender-sensitive early-warning system in a lower-resource setting requires layered dissemination channels, including mobile networks, community loudspeakers, and local associations, rather than reliance on a single high-technology channel, together with a phased seismometer build-out concentrated in the highest-risk urban corridors.

8. Policy Recommendations

Adapting Japan's model exposes seven structural gaps in developing-country contexts, each with a corresponding policy response drawn from Japan's experience:

- Informal, non-engineered housing dominates the stock → recognize and upgrade indigenous construction techniques (e.g., dhajji dewari) rather than banning them.
- Codes exist on paper but enforcement is weak → introduce streamlined, risk-tiered building-control and permitting processes.
- No dedicated fund exists for retrofitting older buildings → establish a 1995-law-style program of subsidies, tax relief, and low-interest loans.
- Little or no seismic early-warning infrastructure → phase seismometer investment starting in the highest-risk urban corridors.
- Disaster education is knowledge-only, not drilled → adopt attitude- and drill-based curricula on the Kamaishi model.
- Neighborhood mutual-aid structures are thin → formalize community disaster-management plans and local associations.
- Institutional capacity and financing are short-term → pursue long-horizon technical cooperation rather than one-off post-disaster aid.

These measures can be sequenced in three phases. Phase 1 (immediate) focuses on enforcement and finance: risk-tiered code enforcement, a retrofit fund combining subsidies and low-interest loans, and formal recognition of indigenous safe-building techniques. Phase 2 (five years) focuses on warning and training: a seismometer network in the highest-risk corridors, drill-based school curricula, and formal neighborhood mutual-aid associations. Phase 3 (decades) focuses on cooperation and institutionalization: long-horizon technical cooperation on the JICA model, community disaster-management plans in every municipality, and continuous code revision after every damaging earthquake.

9. Conclusion

Japan took roughly a century to build its earthquake-preparedness system, but developing countries facing comparable seismic exposure need not follow the same timeline if they sequence reform deliberately. The comparative evidence from Tohoku, Gorkha, and Türkiye-Syria confirms that code compliance and enforcement, not

earthquake magnitude, explain the wide gap in mortality outcomes across broadly similar events. Preparedness is not a single reform but an integrated system: building codes protect structures, early-warning systems protect the seconds before shaking arrives, and community networks protect people in between. For developing countries, adapting Japan's model means integrating science-based codes, adaptive early-warning technology, indigenous knowledge, and social capital, sequenced according to available institutional and financial capacity, rather than attempting to replicate any single element in isolation.

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PARTICIPANT RESEARCH PAPER

Integrated Water Resources Management (IWRM) for Drought Risk Reduction: Operationalizing the Sendai Framework in Asia and Africa

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Abstract

Drought is a critical climate hazard affecting water security, agriculture, and socioeconomic development in arid regions of Asia and Africa. This research paper examines the implementation of the Sendai Framework for Disaster Risk Reduction (2015–2030) using Integrated Water Resources Management (IWRM) principles for drought risk reduction. It compares vulnerable hydrological areas, including the Horn of Africa, the Sahel, Southern Africa, and major river basins in Asia, focusing on how to mitigate drought risk through multi-sectoral water accounting, catchment governance, nature-based solutions, and community-centric multi-hazard early warning systems (MHEWS). The study identifies challenges like data silos, underused AI/ML models, and fragmented river-basin agreements. It emphasizes the need for proactive risk reduction by integrating scientific modelling with indigenous knowledge and empowering local water user associations. Policy recommendations aim to enhance anticipatory drought financing, improve early-warning systems, and align national water policies with disaster risk reduction efforts to support the Sendai Framework and Sustainable Development Goal (SDG) 6.5 (UN-Water, 2021).

Keywords: Climate Change Adaptation, Disaster Risk Reduction, Drought Governance, Integrated Water Resources Management, Sendai Framework.

1. Introduction

1.1 Background and Rationale

Drought is a slow-onset climatic hazard characterized by extended deficits in rainfall, soil moisture, and hydrological reserves, whose cumulative impacts cascade across key socioeconomic and environmental sectors, a trend increasingly exacerbated by anthropogenic climate change, particularly in vulnerable agrarian regions (Cap-Net et al., 2020; FAO, 2023; UNDRR, 2022). Although traditional drought management has relied heavily on reactive humanitarian aid and post-crisis relief, these short-term measures fail to address root systemic vulnerabilities and foster long-term dependency (Lunga, 2025; SADC Secretariat et al., 2022; Verbist et al., 2016). Consequently, the global disaster management community is shifting toward proactive, risk-informed governance frameworks designed to build structural resilience before crisis onset (UNDRR, 2022).

1.2 Problem Statement

The *Sendai Framework for Disaster Risk Reduction (2015–2030)* outlines four crosscutting priorities for building systemic resilience (UNDRR, 2022). However, a significant operational gap remains: disaster management institutions frequently operate in isolation from water allocation authorities, agricultural ministries, and river basin commissions (Cap-Net et al., 2020). Integrated Water Resources Management (IWRM), defined by the Global Water Partnership as a process promoting the coordinated development and management of water, land, and related resources to maximise economic and social welfare without compromising ecosystem sustainability, provides the operational architecture necessary to bridge this divide (FAO, 2023). Despite its clear theoretical synergy with Sendai priorities, the institutionalisation of IWRM as a drought-reduction mechanism remains uneven and under-resourced across Asia and Africa (UN-Water, 2021; Verbist et al., 2016).

1.3 Purpose and Objectives

This study aims to formulate an evidence-based framework for integrating Integrated Water Resources Management (IWRM) into drought risk reduction strategies across drought-prone regions of Asia and Africa by aligning IWRM pillars with the Sendai Framework's four priorities. To support this objective, the research analyses

comparative hazard profiles and socio-economic vulnerabilities across both regions, identifies key scientific, technological, and institutional barriers to proactive drought management, and synthesizes international best practices and community resilience mechanisms into actionable policy recommendations for water authorities and disaster planners.

1.4 Scope

The analytical scope of this research encompasses catchment, national, and transboundary river-basin scales in Sub-Saharan Africa and South, Southeast, and Central Asia.

2. Regional Context & Hazard Profile

2.1 Conceptual Definitions of Risk

To evaluate drought within disaster risk reduction discourse, the disaster risk architecture defined by UNDRR (2022) is operationalized:

Disaster Risk = Hazard x Exposure x Vulnerability x Capacity

- **Hazard:** The physical drought phenomenon is characterized by its onset speed, magnitude, duration, and spatial extent, related to rainfall deficits, agricultural moisture shortages, and hydrological streamflow or groundwater deficits. (Cap-Net et al., 2020).
- **Exposure:** The presence of people, agricultural livelihoods, livestock assets, infrastructure, and ecological services in drought-prone geographical zones.
- **Vulnerability:** The vulnerability of a community or system to adverse effects from drought due to structural, economic, institutional, and socio-cultural factors.
- **Capacity:** The collective combination of physical, technological, institutional, and social resources available to anticipate, cope with, and recover from drought stress.

2.2 African & Asian Regional Profile & Historical Trends

In Africa, the Horn of Africa, the Sahelian belt, and Southern Africa face acute drought risks driven by climate phenomena such as the El Niño–Southern Oscillation (ENSO) and Indian Ocean Dipole (IOD), overlaid onto high rainfed agricultural dependency (AUC,

2017; UNDRR, 2024). Over 60% of the continent's surface area lies within transboundary river and lake basins (e.g., Zambezi, Niger, Nile, Lake Chad), where upstream drought shocks rapidly induce downstream crises.

In Asia, particularly South and Central Asia, drought manifests through combined surface water shortages and catastrophic groundwater over-extraction (UNESCAP, 2021). The intensification of Asian Monsoon variability has heightened seasonal drought exposure in the Indus-Ganges-Brahmaputra basins and the Lower Mekong, threatening the food security of hundreds of millions of smallholder farmers (ASEAN, 2020; UNDRR AsiaPacific, 2021).

3. Risk & Vulnerability Assessment

3.1 Socio-Economic Impacts and Food Security

Drought severely disrupts rural and national economies in developing regions (FAO, 2023). Crop failures lead to reduced farm revenues, food price inflation, and depleted grain reserves. In Africa's drylands, livestock prices plummet while staple cereal prices rise, harming household purchasing power (Verbist et al., 2016). In Asia, prolonged drought results in smallholder indebtedness, distress land sales, and macroeconomic impacts that lower rural consumer demand and hinder national GDP growth (FAO, 2023).

3.2 Livelihood Disruption and Displacement

Hydrological stress leads to migration from degraded rural areas to urban informal settlements lacking water and sanitation services. In East and West Africa's arid and semi-arid lands, resource scarcity often sparks violent clashes between pastoralists and agriculturalists over limited water points and grazing reserves. In Asia, rural out-migration changes demographic structures, leaving behind the elderly and infants in climate stressed agro-ecosystems.

3.3 Gender Dimensions and Vulnerable Groups

Drought impacts are influenced by socio-cultural and gender inequalities, particularly affecting women and girls in rural Africa and Asia who are primarily responsible for water collection. During droughts, distances for water retrieval can increase significantly, leading to physical exhaustion, heightened risks of gender-based violence, and school dropouts for young girls. Additionally, traditional land and water tenure systems often

exclude female smallholders from water-user associations and irrigation credit schemes, limiting their ability to adapt (Cap-Net et al., 2020).

4. Community Resilience Factors

4.1 Indigenous Knowledge Systems (IKS) and Local Coping Mechanisms

Local communities in arid and semi-arid zones have developed effective methods to adapt to climatic changes (Lunga, 2025). In Southern and Eastern Africa, traditional agropastoralists use biological indicators—like the flowering of acacia trees and animal behaviour—to predict rainfall and adjust planting dates (Lunga, 2025; SADC Secretariat et al., 2022). In South Asia, historical practices such as subterranean cisterns, *kunds,* stepwells, and gravity-flow channels have ensured community water access during dry spells.

4.2 Social Capital and Community Water Governance

Informal institutional networks and mutual aid systems are critical safety nets during slowonset crises. Customary water sharing rules, such as rotational livestock watering and shared labour for desilting dams, help prevent resource exhaustion (Lunga, 2025). Community-Managed Sand Dams in Kenya, Zimbabwe, and Ethiopia demonstrate effective local adaptation by capturing sand during flash floods to store water underground, reducing evaporation losses and ensuring clean drinking water during extended dry seasons.

5. Scientific & Institutional Gaps

5.1 Hydrological Data Gaps and Observation Deficits

A major challenge in implementing Integrated Water Resources Management (IWRM) for drought mitigation is the inadequate hydro-meteorological observation networks in developing regions (Verbist et al., 2016). In many African and Central Asian river basins, the number of functional automatic weather stations, streamflow gauges, and groundwater observation wells is well below World Meteorological Organisation (WMO) standards (Cap-Net et al., 2020). Geopolitical sensitivities and lack of standardized data formatting often hinder transboundary data sharing, making downstream riparian states vulnerable to sudden water allocation cuts during droughts.

5.2 Technological Limitations and Underutilization of AI/ML

Remote sensing and satellite observation (e.g., GRACE groundwater anomalies, MODIS/Sentinel vegetation health indices) have advanced, but their integration into local water management is limited. Advanced computational tools, such as AI and ML for drought forecasting and surface-groundwater modelling, are often not utilized by public disaster management agencies due to insufficient infrastructure and technical capacity.

5.3 Institutional Silos and Governance Fragmentation

Drought risk governance is compromised by institutional fragmentation (UNDRR, 2022). In many Asian and African countries, drought management is handled reactively by Civil Protection or Disaster Management Agencies under Ministries of Interior, while water allocation and agricultural irrigation fall under the Ministries of Water and Agriculture, respectively. This leads to conflicting mandates, uncoordinated budgets, and competing data platforms, causing delays during drought emergencies (Cap-Net et al., 2020).

6. Mitigation Strategies & Best Practices

6.1 Structural and Nature-Based Solutions (NbS)

Proactive IWRM combines engineering and Nature-based Solutions (NbS) to improve water retention and storage (Cap-Net et al., 2020):

- **Managed Aquifer Recharge (MAR):** This involves injecting excess runoff and treated wastewater into aquifers to create protected water reserves (FAO, 2023).
- **Landscape Restoration and Wetland Re-naturalization:** Restoring degraded watersheds through reforestation and buffer restoration reduces erosion and improves stream flows (Lunga, 2025).
- **Distributed Micro-Storage Infrastructure:** Building decentralized ponds and check dams captures rainfall for supplemental irrigation during dry spells (Cap-Net et al., 2020).

6.2 Non-Structural Water Governance Interventions

Non-structural interventions focus on managing water demand and ensuring equitable allocation (FAO, 2023):

- **Dynamic Reservoir Rule Curves:** Adjusting reservoir operations based on seasonal climate forecasts prioritizes conservation ahead of droughts (ASEAN,

2020).

- **Drought-Conscious Water Allocation Tariffs:** Implementing tiered tariffs and emergency quotas during scarcity reduces wasteful water use in agriculture and industry.
- **Crop Diversification and Climate-Smart Agriculture:** Shifting from water intensive crops to drought-resilient ones lowers irrigation demand (FAO, 2023).

7. Risk Communication & Early Warning

7.1 Integrated Hydro-Meteorological Monitoring and Multi-Hazard Early Warning Systems (MHEWS)

Operational drought monitoring requires tracking meteorological, hydrological, and agricultural indicators using standard indices (Cap-Net et al., 2020; Verbist et al., 2016):

- **Standardized Precipitation Index (SPI):** Quantifies precipitation deficits across multiple timescales (1, 3, 6, 12, and 24 months).
- **Standardized Precipitation Evapotranspiration Index (SPEI):** Integrates temperature and potential evapotranspiration (PET) data, capturing the compounding effect of heatwaves on soil moisture depletion.
- **Vegetation Condition Index (VCI) & Soil Water Index (SWI):** Tracks real-time agricultural crop stress and pasture degradation via satellite imagery.

7.2 People-Centred, Gender-Sensitive Risk Communication and Last-Mile Delivery

Early warning information is ineffective unless translated into actionable, localised advisories that reach end-users ahead of the hazard impact (UNDRR, 2022). Peoplecentred Early Warning Systems (EWS) must address social barriers by engaging women and marginalised groups directly. Communicating probabilistic scientific forecasts in local languages via community radio, SMS bulletin networks, visual village warning flags, and agricultural extension workers ensures that smallholder farmers can adjust cropping patterns, protect livestock herds, and implement water-conservation measures before acute dry conditions set in.

8. Policy Recommendations

To operationalize the Sendai Framework through IWRM across Asian and African disaster risk management frameworks, the following policy interventions are recommended:

1. **Establish Institutional Platforms for Cross-Sectoral Drought Governance:** Formally anchor Catchment Management Agencies (CMAs) and River Basin Organisations (RBOs) within National Disaster Management Platforms, aligning statutory mandates between Water, Agriculture, Environment, and Finance ministries in accordance with Sendai Framework Priority 2 (ASEAN, 2020; UNDRR, 2022).
2. **Implement Forecast-based Action (FbA) and Anticipatory Financing:** Institutionalise automatic contingency financing mechanisms—such as droughtindexed parametric catastrophe insurance and crisis modifier budgets—that release pre-arranged funding directly to water utilities and community water groups immediately upon reaching pre-agreed SPEI/SPI trigger thresholds.
3. **Modernise Hydro-Meteorological Infrastructure and AI/ML Capabilities:** Invest in automated telemetry, open-access national hydrological databases, and machine-learning predictive modelling tools to upgrade national and transboundary multi-hazard early warning systems.
4. **Scale Up Nature-Based Solutions and Decentralized Groundwater Buffers:** Allocate at least 15% of national climate adaptation and disaster risk reduction capital budgets toward landscape restoration, sand dams, check dams, and Managed Aquifer Recharge (MAR) systems.
5. **Institutionalize Inclusive Water Stewardship and Indigenous Knowledge Systems:** Mandate a minimum of 40% female representation on local water user committees, legally protect customary communal water rights, and integrate indigenous climate observation indicators into official early warning bulletins (Lunga, 2025).

9. Conclusion

Drought is a slow-onset systemic disaster that exacerbates water stress, food insecurity, ecological degradation, and poverty across vulnerable regions of Asia and Africa.

Traditional reactive crisis response models are insufficient for addressing these escalating risks in a changing climate. This research demonstrates that operationalising Integrated Water Resources Management provides a robust, science-based, and equitable foundation to implement the four priorities of the Sendai Framework for Disaster Risk Reduction. By shifting from fragmented emergency management to coordinated, basin-wide water governance, enhancing hydrological observation systems, deploying nature-based storage solutions, and bridging scientific modelling with indigenous community knowledge, national governments can build resilient water systems capable of mitigating drought shocks, protecting livelihoods, and achieving sustainable development across Asia and Africa.

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Supplementary Annexes

Annex A: Comparative Drought Vulnerability Checklist (Africa vs. Asia)

Dimension	African Drylands (Sahel, Horn, SADC)	Asian River Basins (Indus, Ganges, Mekong)
Primary Hydrological Vulnerability	High inter-annual rainfall variability; low soil moisture storage; high evaporative demand.	Monsoon break periods; transboundary upstream downstream tensions; deep aquifer over-pumping.
Livelihood Exposure	Rain-fed smallholder farming; extensive transhumant pastoralism.	Irrigated grain agriculture; high population density; intensive aquaculture.
Storage & Infrastructure Buffer	Low per-capita artificial water storage capacity; high reliance on shallow boreholes and ephemeral pans.	Massive multi-purpose reservoir capacity; extensive canal networks; heavy reliance on motorised tube-wells.

Key Governance Bottleneck	Limited hydrometeorological monitoring stations; funding constraints for local catchment boards.	Institutional silos between surface water and groundwater agencies; transboundary data sharing restrictions.
Priority IWRM Intervention	Decentralized sand dams; catchment agroforestry; community drought contingency funds.	Managed Aquifer Recharge (MAR); real-time satellite water accounting; volumetric irrigation pricing.

Annex B: Integrated Drought Risk Governance & Last-Mile Dissemination Flowchart

Drought Early Warning & Response System

1. DATA COLLECTION

Satellite images track plant health and soil moisture

- Weather stations measure rainfall and temperature
- Water meters monitor wells and reservoirs

2. Risk Analysis

- Calculate drought severity scores.
- Use AI to forecast upcoming weather patterns.
- Map out vulnerable communities and high-risk areas

3. Decision & Funding

Government agencies review risk levels together.

- Declare warning levels (Normal, Alert, or Emergency).
- Automatically release emergency funding when thresholds are hit.

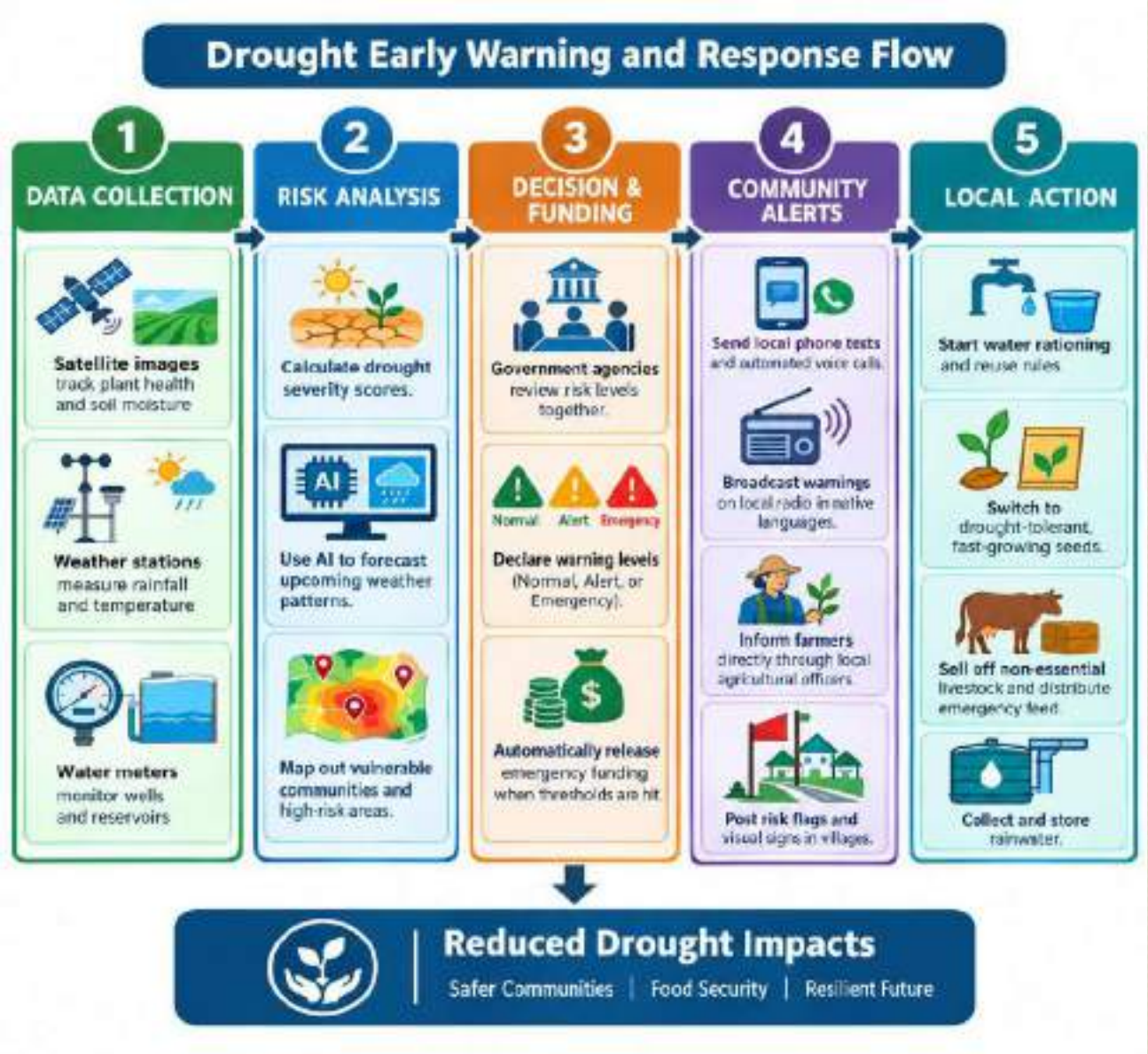
4. Community Alerts

- Send local phone texts and automated voice calls.
- Broadcast warnings on local radio in native languages.

- Inform farmers directly through local agricultural officers.
- Post risk flags and visual signs in villages.

5. Local Action

- Start water rationing and reuse rules.
- Switch to drought-tolerant, fast-growing seeds.
- Sell off non-essential livestock and distribute emergency feed.
- Collect and store rainwater.



PARTICIPANT RESEARCH PAPER

Riverine Flooding Along the Chenab River

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Abstract

Riverine flooding is one of the most significant hazards affecting Pakistan, particularly communities located along major rivers and floodplains. The Chenab River is an important component of the Indus Basin and supports agriculture, irrigation, settlements, transportation and economic activity across Punjab. At the same time, communities along its floodplain remain exposed to high river flows, intense monsoon rainfall, upstream flows, erosion, floodplain encroachment and infrastructure limitations. This paper examines the causes, exposure, vulnerability and impacts associated with Chenab flooding and assesses disaster-management measures that can reduce future risk. The analysis highlights the importance of early warning, evacuation planning, community-based disaster risk reduction, resilient infrastructure, humanitarian coordination and climate-resilient development. A people-centred approach that combines scientific forecasting, local knowledge, community participation and institutional coordination is required to reduce loss of life, livelihood disruption and economic damage. Strengthening preparedness before the flood season is therefore essential for building resilient communities along the Chenab.

1. Introduction

Flooding is among the most frequent and destructive natural hazards affecting Pakistan. The country's extensive river network, seasonal monsoon rainfall, agricultural dependence and settlement patterns contribute to significant exposure to flood hazards. Riverine flooding occurs when river discharge exceeds the capacity of the channel and water spreads across surrounding floodplains.

The Chenab River is one of the major rivers of the Indus Basin and has considerable importance for Pakistan's agricultural and economic systems. Within Punjab, the river passes through an extensive alluvial plain containing agricultural land, settlements and critical infrastructure. Punjab's disaster-management authorities maintain flood-risk information and maps for important Chenab reaches, including Marala–Khanki, Khanki–Qadirabad and Qadirabad–Chiniot (PDMA Punjab, n.d.).

Based on the June and July weather forecasts and river flow reports, 6-8 districts have been placed on high alert due to the increasing water level in the River Chenab. The River Chenab enters Pakistan through Head Marala (Sialkot) and Daily Avg water inflow at Head Marala is almost 2 lacs (Cusec) (high flood), while max. limit reached 2.9 Lac (Cusec) on (22/07/26) till now.

1. Sialkot
2. Wazirabad
3. Hafizabad
4. Chiniot
5. Jhang
6. Gujrat

❖ High Alert districts along the **River Chenab**

2. Regional Context & Hazard Profile

The Chenab is an important river within the Indus Basin. Its catchment includes mountainous areas as well as plains, and river flows are influenced by rainfall and seasonal snow and ice melt. After entering Pakistan, the river flows through Punjab and supports irrigation and agricultural production. The same river system can generate severe hazard conditions when exceptionally high flows occur.

Historical flooding demonstrates the scale of the hazard. NDMA records indicate that during the 2014 flood, peak discharges at Marala, Khanki and Qadirabad were approximately 861,454, 947,099 and 903,504 cusecs respectively (NDMA, 2024). A Remote Sensing and GIS study of the Lower Chenab Plain found extensive inundation during the 2014 event and examined the duration and spatial distribution of floodwater (Sadiq et al., 2020).

The main hazard drivers include heavy monsoon rainfall, high upstream flows, snow and glacier melt, riverbank erosion, floodplain encroachment, land-use change and inadequate drainage or protective infrastructure. The risk can be understood through three connected concepts: hazard, exposure and vulnerability. Hazard refers to the probability and magnitude of damaging river flows; exposure refers to people and

assets located in hazard-prone areas; and vulnerability refers to the conditions that increase the likelihood of harm and reduce the ability to cope and recover.

3. Risk & Vulnerability Assessment

Chenab flood risk is unevenly distributed. Rural settlements, agricultural communities and households with limited resources can face greater consequences because their homes and livelihoods are closely connected to flood-prone land. Agriculture is particularly important because crops, livestock, machinery, stored grain and irrigation infrastructure can all be damaged during inundation.

Flooding also creates indirect economic effects. Damage to roads and bridges can isolate communities and delay emergency assistance, while disruption of markets, education and health services can continue after floodwaters recede. Poorer households may have fewer savings or assets available for reconstruction, increasing the duration of recovery.

Vulnerability is also shaped by social and gender factors. Women, children, older people, persons with disabilities and people requiring medical assistance may face additional barriers during evacuation and in temporary shelters. Women and families may require privacy, safe sanitation and appropriate healthcare arrangements. Livestock should also be included in evacuation planning because animals can represent a major component of rural household assets.

4. Community Resilience Factors

Community resilience is a major component of flood-risk reduction because local residents are frequently the first people to respond when a disaster occurs. Communities possess knowledge of local roads, waterways, vulnerable households, safe locations and seasonal flood behaviour. Such local knowledge can complement scientific forecasting and official warning systems.

Social networks can support evacuation, temporary shelter, food distribution and assistance to vulnerable households. Community volunteers can help disseminate warnings and support first aid, water rescue and evacuation. Regular training, mock exercises and community-based disaster-risk-reduction programmes can transform local knowledge and social capital into practical response capacity.

Resilience should therefore be developed before the emergency. Communities need clear evacuation routes, identified safe locations, emergency communication arrangements and trained local responders. Indigenous and locally developed coping practices should be documented and integrated where they are safe and consistent with scientific risk information.

5. Scientific & Institutional Gaps

A major challenge in flood-risk management is the gap between available scientific information and its effective use at community level. River monitoring and forecasting are essential, but warnings only reduce risk when they are timely, understandable and actionable.

Technology can strengthen this process. Remote sensing and GIS have demonstrated value in mapping flood extent and assessing damage, including analysis of the 2014 Lower Chenab flood (Sadiq et al., 2020). Artificial intelligence and machine-learning approaches may further support rainfall-runoff prediction, inundation mapping and impact forecasting, but their effectiveness depends on reliable historical and real-time datasets, technical capacity and institutional ownership.

Institutional coordination is another critical gap. Flood management involves meteorological agencies, irrigation departments, disaster-management authorities, district administrations, rescue services, humanitarian organizations and communities. Basin-wide approaches are important because downstream conditions are strongly influenced by upstream flows. Weak coordination can lead to delays, duplication or uneven distribution of resources.

6. Mitigation Strategies & Best Practices

Flood-risk reduction should combine structural and non-structural measures. Structural measures include the inspection and strengthening of vulnerable embankments, bridges, drainage systems and other protective infrastructure.

Non-structural measures include land-use regulation, flood-risk mapping, preparedness planning, public awareness, community training, evacuation exercises and insurance or other financial-risk mechanisms. Floodplain management is especially important because uncontrolled development increases exposure and can obstruct natural flood pathways.

7. Risk Communication & Early Warning

An effective early-warning system must connect hazard monitoring with clear decisions at household and community level. River levels, rainfall and upstream flows should be continuously monitored, while warning thresholds should trigger predefined actions. Warnings should reach communities through multiple channels, including SMS, mobile applications, local administration, mosques and community announcements, radio and television, social media and trained community volunteers.

Risk communication should use simple local language and clearly explain what people should do, where they should go and when they should evacuate. Communication must be inclusive and gender-sensitive, ensuring that women, older people, persons with disabilities and other vulnerable groups can receive and act on warnings.

8. Policy Recommendations

- Strengthen basin-wide flood forecasting, river monitoring and early-warning systems.
- Integrate flood-risk maps into land-use planning and regulate development in high-risk floodplains.
- Establish and regularly update community evacuation routes, shelters and vulnerable-household databases.
- Expand community-based disaster-risk-reduction programmes, including first aid, water rescue and evacuation training.
- Use GIS, remote sensing and responsibly developed AI/ML tools to improve hazard and impact assessment.
- Strengthen coordination among NDMA, PDMA, irrigation, meteorological, district, rescue and humanitarian institutions.
- Pre-position emergency shelter, water, sanitation, medical and logistics resources before the monsoon season.
- Protect drinking-water sources and include livestock protection in emergency planning.
- Promote climate-resilient agricultural practices and livelihood recovery mechanisms.

- Conduct regular multi-agency simulation exercises and post-event reviews to improve preparedness.

9. Conclusion

Riverine flooding along the Chenab River is a significant disaster-management challenge in Pakistan. The hazard is influenced by monsoon rainfall, upstream flows, snow and ice melt and river dynamics, while disaster impacts are intensified by exposure, floodplain development, infrastructure limitations and social vulnerability.

The evidence indicates that effective flood-risk reduction requires more than emergency response. Early warning, evacuation planning, community preparedness, resilient infrastructure, floodplain regulation, scientific monitoring and institutional coordination must operate as an integrated system. Communities should be treated not only as beneficiaries of relief but as active partners in preparedness and response.

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PARTICIPANT RESEARCH PAPER

Multi-Hazard Risk Assessment in Dadu District: Interactions Between Flooding, Drought, Water Security, and Livelihood Vulnerability

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Abstract

The District Dadu is located at southern Sindh and located between the Indus River floodplain and the Kirthar hill, its population is exposed to flash flooding from hill torrents, riverine inundation, and drought in its arid kachho area. This study examines connection between hazards of flooding and drought and the risks of disasters to water and rural livelihoods. On the basis of post-flood 2022 assessments, drought evaluations, and studies on Sindh's hydro climatic instability, the research finds that the most affected population of Dadu is are the vulnerable groups, livestock keepers, fishing community and small farmers that have low capacity of recovery during disasters and the repeated occurrence of these disasters create water scarcity and financial instability among these groups. It is also observed that the administration or authorities are more focused on providing relief and less attentive towards risk reduction, early warning systems, and spread awareness towards all the communities in their local languages. The study suggests an integrated, evidence-based governance strategy that invests in community-centered early warning and livelihood diversification, builds institutional capacity at the district level, and approaches flood and drought management as a single continuum.

Keywords: Dadu, Multi-Hazard Risk, Flood, Drought, Vulnerability, Water Security, Livelihood.

1. Introduction

Sindh province has recently been disproportionately affected by climate-related disasters, and Pakistan is regularly placed among the nation's most vulnerable to them. The Dadu district is an example of a trend that is becoming more prevalent throughout the province: a single administrative unit that experiences two seemingly incompatible dangers within the same climate cycle: catastrophic flooding and prolonged drought. While drought conditions in the district's western Kachho belt have independently caused water scarcity, livestock loss, and outmigration, the 2022 monsoon floods flooded much of the region. Floods and droughts are often treated as independent hazard categories in Pakistan's current disaster management strategy, necessitating separate response methods. This approach runs the danger of ignoring the compounding effect that each hazard has on the other and on community resilience. The purpose of this article is to analyze how flooding, drought, water security, and livelihood vulnerability interact in the Dadu district and to determine how effective the current risk reduction and early warning systems are. With reference to national and provincial disaster management frameworks, such as those of PDMA Sindh and NDMA, the scope encompasses the district's physical hazard profile, socioeconomic vulnerability, community coping capacity, and policy gaps.

2. Regional Context & Hazard Profile

Dadu district, which was created in 1931 from Larkana district, had a population of around 1.74 million, a literacy rate of just over 47%, and about 75% of its residents lived in rural areas as of the 2023 census. The geology of the district separates it into two

areas: a riverine region along the Indus that is susceptible to seasonal and flash flooding, and the desert Kachho foothills of the Kirthar range, where rainfall is irregular and limited and rain-fed agriculture depends on erratic hill torrents. The largest freshwater lake in Pakistan, Lake Manchar, is situated on the Dadu-Jamshoro border and has historically supported thousands of fishing families. The district suffered greatly from the 2022 floods, which were among the worst in Sindh, after a monsoon season that saw the province receive many times its usual August rainfall. Households in the same district struggle to get even the minimal minimum of water required daily for drinking and livestock, according to drought assessments. Comparing flood and drought susceptibility within a single region is crucial to understanding Dadu's disaster risk profile.

3. Risk & Vulnerability Assessment

Sindh suffered greatly socioeconomically because of the 2022 floods; the province bore the brunt of the nation's flood damage, with over 150,000 homes devastated in Dadu district alone. According to provincial data compiled by the International Labour Organization, millions of people in flood-stricken Sindh lost their jobs or faced economic disruption, with agriculture-the foundation of Dadu's rural economy-being most badly hit. Around Lake Manchar, a fishing hamlet that was previously home to over 50,000 people living on 2,000 houseboats has become much smaller. The release of tainted drainage water into the lake, which damaged fish stocks and made many families give up fishing completely, is the main cause of this reduction. Similar vulnerabilities, such as households having to travel long distances for drinking water, livestock losses reported in the range of a fifth to a quarter of animal populations during dry spells, and an increase in illnesses related to nutrition and water, with children and pregnant women being particularly vulnerable, are revealed by drought assessment work in Dadu. Vulnerability is increased by low literacy, high poverty, a lacklustre housing stock, and limited access to formal financial institutions, which would typically allow households to recoup assets after a shock. Since floods and droughts frequently affect the same dwellings in a brief amount of time, the capacity to recover from one disaster is usually exhausted before the next one happens.

4. Community Resilience Factors

Dadu communities have created coping strategies tailored to a dual-hazard setting. Rain-fed farming methods and raising livestock serve as a buffer in the Kachho, with animals acting as a liquid asset that can be sold during difficult times. However, once drought reduces the supply of water and food, this technique itself becomes vulnerable. Because places without canal irrigation rely almost entirely on seasonal rain, rainwater gathering is nevertheless a significant, although restricted, local practice. The remaining fishing families around Lake Manchar have demonstrated their ability to adapt by switching to different sources of income and, in certain situations, moving to embankments or coastal regions with superior water quality. Planting and migration decisions at the household level are still influenced by indigenous knowledge of seasonal flood and drought patterns. However, these mechanisms function primarily without external institutional support, and their limitations are becoming more apparent: permanent outmigration, livestock die-offs, and the collapse of lake ecosystems all show that informal community resilience is no longer adequate to absorb the frequency and intensity of current hazard cycles.

5. Scientific & Institutional Gaps

Effective multi-hazard management in Dadu is hampered by several structural flaws. Satellite-based rainfall products and climate model outputs are increasingly used to address data gaps in Sindh due to the lack of ground-based meteorological and hydrological monitoring. However, there is little integration of this data into district-level planning. In addition to the lack of standard operating procedures for disseminating early warnings through media and other last-mile channels, limited manpower and technical capabilities have been cited as operational barriers in recent multi-agency reviews of PDMA Sindh's district operations. The application of artificial intelligence and machine learning methods for drought and flood forecasting is still mostly limited to research environments rather than being put to practical use by district or provincial authorities. More generally, despite this imbalance being repeatedly noted in provincial climate vulnerability assessments, disaster management investment in Pakistan continues to focus on rescue, relief, and rehabilitation after a hazard occurs rather than on disaster risk reduction measures that would reduce exposure and vulnerability beforehand.

6. Mitigation Strategies & Best Practices

To address Dadu's exposure to compound hazards, both structural and non-structural interventions are required. In addition to targeted flood protection embankments in the riverine belt and small-scale water storage or check-dam structures in the Kachho to capture hill-torrent flow for use during dry periods, structural priorities include rehabilitating drainage infrastructure, specifically resolving the discharge conflicts associated with the Left Bank Outfall Drain system that have degraded Lake Manchar and obstructed natural drainage in flood-prone areas. Community-based disaster risk reduction training, assistance with livelihood diversification for farming and fishing households, and official incorporation of livestock insurance or restocking programs after drought or flood losses are examples of non-structural approaches. Combining socioeconomic, institutional, and physical interventions can enhance household-level resilience, as demonstrated by international experience, such as farmer-adaptive drought response techniques recorded in northwest Bangladesh. This strategy is obviously relevant to Dadu's Kachho communities. Another institutional best practice that other provinces should adopt is capacity-building for PDMA and District Disaster Management Authority employees, especially in hazard forecasting and community participation.

7. Risk Communication & Early Warning

Systems that are people-centered, gender-sensitive, and provided in the Sindhi language, which is spoken by the great majority of the district's residents, are necessary for effective early warning in Dadu. The lack of official procedures for disseminating warnings through local media and the lack of trust between communities and disaster management organizations are two current gaps found in recent provincial-level studies, both of which postpone protective action at the household level. Involving female community leaders directly in warning distribution and response planning would increase the reach and credibility of alerts, as women in Dadu are usually primarily responsible for home health and water collection. Mobile phone warnings, community radio, and trained local volunteers should all be used in last-mile communication techniques, especially in the more remote Kachho communities where hill-torrent flooding can occur with extremely short lead times.

8. Policy Recommendations

- Adopt a district-level integrated flood-drought governance approach that views the two risks as related stages of a single hydroclimatic cycle rather than as distinct crises.
- In accordance with Sindh's provincial disaster management framework and Pakistan's Climate Change Policy, invest more in disaster risk reduction than in post-disaster aid.
- To make up for the lack of ground observation networks, incorporate satellite-based rainfall and drought monitoring data into regular PDMA and DDMA planning.
- Increase institutional capacity at the district level by hiring more qualified personnel and establishing formal standard operating procedures for early warning communication.
- Encourage early warning and last-mile communication systems that are gender-sensitive, community-centered, and in the local language.
- To restore the fishing sector and lessen reliance on a single fragile resource, fund Lake Manchar's ecological repair and livelihood diversification.

9. Conclusion

The Dadu district serves as an example of how flooding and drought are two manifestations of the same underlying hydroclimatic instability that affects the same vulnerable population rather than separate threats. Household assets, water security, and livelihoods have all been negatively impacted by the 2022 floods and the drought conditions that were independently recorded in the district's kachho tracts; recovery from one hazard is often halted by the arrival of the other. Despite their resourcefulness, community coping mechanisms are becoming increasingly overwhelmed by the frequency and intensity of these occurrences. Moving away from a relief-centered response model and toward integrated, science-based planning that incorporates satellite monitoring, strengthened district institutions, community knowledge, and inclusive early warning systems is necessary to build durable resilience in Dadu. This strategy is in line with the larger disaster risk reduction priorities of PDMA Sindh and NDMA.

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PARTICIPANT RESEARCH PAPER

Measuring Community Resilience: Indicators, Frameworks, and Applications for Disaster Risk Reduction in Pakistan

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Abstract

Community resilience is also an important focus of disaster risk reduction (DRR) but is challenging to define and measure. This paper explores the various measures, indicators and frameworks of community resilience and its applications in the context of Pakistan. It examines the current dominant measurement strategies, Baseline Resilience Indicators for Communities (BRIC), PEOPLES and Composite index methods, and discusses the intersection of social capital, indigenous knowledge and community participation and their influence on resilience capacities. Considering the evidence based on the recurrent flooding disaster in Pakistan, the paper highlights the data gaps, institutional capacity gaps, and lack of adoption of participatory tools and technology like GIS and AI/ML tools in real-life scenarios. It states that measuring resilience should shift from national measures to locally tailored, multi-dimensional measures that integrate objective measures with community-based evaluation. Policy recommendations include enhancing the institutionalization of resilience measurement in national and district planning, district-level scaling down, establishment of community led resilience scorecards, gender and vulnerability dis-aggregation, and use of AI/ML based tools. The paper summarizes the critical need for science-based locally grounded measurement to focus investments that can enhance community resilience in Pakistan. Community resilience, disaster risk reduction and indicators were the keywords used in the project.

1. Introduction

The ability to be resilient is a key concern of disaster risk reduction (DRR) policy in today's world, as climate change increases the severity of natural hazards. Pakistan is known for world's most hazard-prone countries and vulnerable to flooding, earthquakes, droughts, cyclones, heatwaves, and new hazards like glacial lake outburst floods (GLOFs) and changing monsoon patterns (National Disaster Management Authority [NDMA], 2025b). The Sendai Framework for Disaster Risk Reduction 2015-2030 places emphasis on building resilience at all levels, meanwhile Pakistan's National Disaster Management Plan 2025 promises to "involve in integrated planning and empower communities" (NDMA, 2025a). Even with this policy, there is limited consensus about the concept of community resilience, and it is not often operationalized in a systematic way. The lack of measurement means decision makers are unable to create baselines, monitor change over time, compare communities, or effectively target investments (Cutter et al., 2010; Camacho et al., 2023). The purpose of this paper is to tackle the issue of measuring the level of community resilience. Its aims to explore the frameworks, indicators and applications for measuring community resilience and their applicability in Pakistan. To define community resilience and its key dimensions, review of key measurement frameworks, applications of the measurement frameworks including in Pakistan and gaps and policy recommendations. The scope deals with community level resilience against natural hazard, specifically flooding using international frameworks and Pakistani evidence.

2. Regional Context & Hazard Profile

Hazard profile is basically the reflection of Pakistan's geophysical location and climatic variability. The country is exposed to recurrent floods, earthquakes, droughts, cyclones, heat waves and other climate-related hazards like GLOFs and alteration of monsoons (NDMA, 2025b). The 2010 floods were a historic event to devastate the entire country and the 2022 floods submerged one-third of the country, impacted 33 million people and displaced 8 million people (Jamshed et al. 2017; Aleha et al. 2024). From international definition, risk is the product of hazard, exposure, and vulnerability, which are defined as: a hazard is a potentially damaging physical event, exposure is the presence of people and assets in a physical situation that exposes them to the possibility of harm, and vulnerability are the physical, social, economic, institutional, environmental, and attitudinal conditions that may

make a person or thing susceptible to harm (Rasool et al., 2024). The literature reveals that there has been increasing interest in vulnerability and capacity assessment at community level in Pakistan especially in Khyber Pakhtunkhwa and Punjab, which has shown multidimensional vulnerability and low level of resilience (Jamshed et al., 2017; Raza & Abouhatab, 2025). High population density alongside floodplains, reliance on rain-fed agriculture, poor adaptive capacity, and their combination contribute to making Pakistan's vulnerabilities into recurrent disasters. These evaluations are tracking and enhancing community resiliency through empirical measures.

3. Risk & Vulnerability Assessment

The socio-economic impact of flooding as experienced during the 2022 floods is captured as follows; a third of the country was flooded, 33 million people were affected, 8 million people were displaced and significant damage occurred on housing, agriculture and infrastructure (Aleha et al., 2024). Losses resulting from floods have adverse impacts on the livelihoods and food security of the affected population, especially of the smallholder farming households which tend to have low resilience index scores (Raza & Abouhatab, 2025). In addition, a multidimensional vulnerability assessment of flood-prone rural communities in Dera Ismail Khan revealed that approximately 40% of the respondents were highly vulnerable due to their age distribution, household income, infrastructure of the area and their risk perception (Shah et al., 2025). Communities in southern Punjab with a closer location to the Chenab River were found to be more vulnerable from an attitudinal and institutional perspective, which was associated with the poor perception of flood risk, low preparedness and limited institutional trust and awareness (Rasool et al., 2024). An AHP-BRIC evaluation of urban communities in KPK revealed that the social resilience of all the communities studied was highest while the psychological resilience was lowest. (Khan et al., 2026 Flooding endangers food security, with the loss of livestock and standing crops, and the loss of household savings to contribute towards debt. Vulnerable groups like women, children, the elderly and persons with disabilities are hit harder and gender specific aspects influence the exposure and ability to recover (NDMA, 2013).

4. Community Resilience Factors

Social capital, which includes networks, norms, and trust to support collective action, is a repeatable factor in community resilience (Aldrich & Meyer, 2014). On the other

hand, bonding, bridging and linking ties enable communities to organize their resources, disseminate information and coordinate their recovery in disaster contexts, ranging from Kobe to New Orleans (Aldrich, 2012), recent research on social capital mechanisms, including collective action, disaster preparedness, and information communication (Zhao et al., 2024). Local coping strategies and indigenous knowledge are also significant. Traditional weather forecasting and flood water management in the agrarian societies of the Koh-e-Suleiman range in Pakistan help them adapt to flash floods (Hussain et al., 2025); traditional DRR practices in the northern part of Pakistan support the community's preparedness (Ali et al., 2021). Community participation and community networks, such as village organizations and local leadership, build resilience capacities through equitable resource distribution and speedy mobilization of the neighborhood (Partelow, 2020; Roque et al., 2020). The ability to do these things is also unevenly distributed: Communities that have active local groups and networks, and that do have strong local institutions, do better; communities that are isolated and marginalized are at greater risk.

5. Scientific & Institutional Gaps

The approaches to measuring community resilience are not well agreed upon and there is no standard procedure for creating composite indicators (Asadzadeh et al., 2017). However, a systematic review of the most replicated framework, BRIC, identified none of the studies completed all the methodological steps recommended and the median quality score was 60% with sensitivity analysis and missing data being the main weaknesses identified (Camacho et al., 2023). Indicators are frequently being used without validation against resilience outcomes (Gu et al., 2023). In Pakistan, data availability and quality remain major constraints, and the adoption of advanced tools such as GIS, remote sensing, and AI/ML in resilience assessment is still limited. Limited digitization of hazard and census data, inconsistent indicator definitions across different districts, and weak technical capacity further constrain the construction of reliable composite indices at scale. Institutionally, disaster management remains relay largely on top-down approach and fragmented, with limited technical capacity at district level and weak integration of DRR into development planning (Jamshed et al., 2017; Zia & Wagner, 2015). These gaps limit the ability to operationalize resilience measurement in practice.

6. Mitigation Strategies & Best Practices

International experience offers transferable best practices. The BRIC framework has been adapted to national and local scales in Norway, Chile, England, and Taiwan, demonstrating that composite indices can be tailored to local data and contexts (Scherzer et al., 2019; Bronfman et al., 2023; Camacho et al., 2024). The PEOPLES framework provides a hierarchical, indicator-based approach for measuring community resilience across seven dimensions, applied to urban communities (Renschler et al., 2010; Kammouh et al., 2019). More reliable and locally useful measurement of resilience can be obtained by downscaling it to finer scale, e.g. census tracts (Derakhshan et al., 2022). The National DRR Strategy 2025-2030 includes community-based training, community-based DRR, and technological innovation, and community-level DRR programmes help to build youth and women's preparedness (NDMA, 2025b). Awareness, training and preparedness (NDMA, 2013) are non-structural measures that are complemented with structural measures such as dykes, safer construction and retrofitting. Community based DRM in which local actors lead the planning and response has been found effective and should be scaled up in Pakistan.

7. Risk Communication & Early Warning

Early warning involves more than making technical forecasts; it involves communication and last mile dissemination that is people centered and gender responsive. The following were reported in the surveyed communities in Pakistan, many community members did not listen to the warning signals, some community members misunderstood the warning signal, many communities did not have access to the necessary items, and there was a lack of participation by the social groups in emergency preparedness (Shah et al., 2023). Observation of weather, wind, and animal movements continue to play a vital role in early warning for responding in time in remote communities (Hussain et al., 2025). The mobile network is least effective in remote and mountainous regions; the need to disseminate information is most clearly felt in these areas, where community-based means of communication (mosques, schools, village committees) are needed. Studies of the Indus basin suggest that warnings need to be translated into local languages, that two-way information exchange needs to be created, and that people centered, bottom-up strategies are needed to achieve the goals.

8. Policy Recommendations

The national community resilience index relies on validated indicators (Camacho et al., 2023; Cutter et al., 2010; Gu et al., 2023) should be institutionalized in NDMA, PDMAs, and DDMAs to measure resilience at a national level, with local versions of the index. Other than this baseline, five additional measures are suggested. First one is that district level indices should be downscaled to union council and village level, since DRR works at finer level of measurement, which is more reliable and useful for local planning purposes (Derakhshan et al., 2022). Secondly, it is important to have a community-led resilience scorecard, as a participatory complement to the national scorecard. It is possible that many resilience frameworks are top-down and objective and there is a documented lacuna in participatory approaches (Tariq et al., 2021), and that communities in Pakistan are often unaware of their own risks and lack tools to measure their resilience (Aleha et al., 2024). A standardized scorecard, to be filled in by communities and updated regularly, would help raise awareness of risk and provide local knowledge up to district planning. Third, scores should be used as monitoring and evaluation data to demonstrate the return on resilience investment: before and after intervention scores would indicate whether a programme is an effective investment in resilience and continue to get funding. (McConkey & Larson, 2022; Rözer et al., 2023). Fourth, resilience indicators need to be disaggregated by gender, disability and age, as overall community measures can mask within-community differences and not breaking down indicators will increase inequality (Adams et al., 2025). Research in Bangladesh indicates that women are weaker on resilience than men and the assessment should be gender based (Chisty et al. 2021). Fifth, AI/ML and satellite remote sensing should be used to make use of at least near real time resilience assessment and early warning; satellite, census and IoT data, when combined with AI/ML, provide real-time monitoring of disasters and improve disaster forecasting (Luxshi, 2024). These are implemented but not executed within the existing NDMA mechanism.

9. Conclusion

Measurement is a methodologically unsettled and context-dependent measure of community resilience. This paper has demonstrated that leading frameworks like BRIC and PEOPLES give structured, indicator-based approaches, and that integrated indexes and participatory approaches have complementary strengths. The evidence from Pakistan suggests that social capital, indigenous knowledge and community participation are fundamental capacities that contribute to resilience, but

resources are scarce, institutions are weak and technology is limited in its application, thus making it difficult to systematically measure these elements. Science based planning, based on validated indicators, locally adapted frameworks is a fundamental element for targeting DRR investment. Combining social capital, indigenous knowledge and technology within a truly integrated and participatory approach is the most promising way to create true community resiliency in Pakistan.

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PARTICIPANT RESEARCH PAPER

The One Health Approach and Climate-Sensitive Diseases: A Systematic Review of Global Evidence, Mechanisms, and Cross-Sectoral Responses

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Abstract

Background: Climate change is intensifying the emergence and spread of infectious diseases sensitive to temperature, precipitation, and extreme weather. The One Health approach, coordinated since 2022 by the Quadripartite of FAO, UNEP, WHO, and WOAH, offers an integrated framework for addressing these threats at the human-animal-environment interface.

Objective: This review synthesizes evidence on the mechanisms linking climate change to climate-sensitive diseases and evaluates how the One Health approach is being applied — and where it falls short — in surveillance, governance, and response.

Methods: A structured literature search was conducted across biomedical and environmental health sources (PubMed/PMC, ScienceDirect, MDPI, Springer Nature, Frontiers, The Lancet, Science Advances) and institutional repositories (WHO, FAO, WOAH, UNEP), following PRISMA 2020 principles. Seventy-four records were screened; thirty-six sources, including several systematic and scoping reviews, met inclusion criteria and were retained for thematic synthesis.

Results: Climate change is altering the range and seasonality of vector-borne diseases such as malaria and dengue, increasing zoonotic spillover through land-use change, reshaping water-borne disease incidence via flooding and drought, and accelerating antimicrobial resistance through rising temperatures. Early-warning tools such as WHO's EWARS-csd show operational promise, but integrated One Health governance remains fragmented, particularly in low- and middle-income countries.

Conclusion: The evidence linking climate change to disease across the human-animal-environment interface is substantial, but translation into functioning One Health governance lags behind the science. Integrated surveillance, cross-sectoral financing, and climate-informed early-warning systems are priority actions.

Keywords: One Health; climate change; climate-sensitive diseases; zoonotic spillover.

1. Introduction

Climate change has moved from a projected environmental risk to a documented driver of present-day disease burden. The World Health Organization estimates that 3.6 billion people already live in areas highly susceptible to the health effects of climate change, with roughly 250,000 additional deaths per year projected between 2030 and 2050 from undernutrition, malaria, diarrhoea, and heat stress alone (World Health Organization, 2023). Rising temperatures, altered precipitation, and more frequent extreme weather events are reshaping the ecological conditions governing vectors, pathogens, and reservoir species (Oliveira-Filho et al., 2025). These shifts rarely respect the boundary between human, animal, and environmental health — a lesson reinforced by COVID-19, recurring zoonotic outbreaks, and the persistence of antimicrobial resistance (AMR).

The One Health approach responds to this interconnection. Endorsed by the Quadripartite of the Food and Agriculture Organization (FAO), the United Nations Environment Programme (UNEP), the World Health Organization (WHO), and the World Organisation for Animal Health (WOAH) since 2022, One Health is defined as an integrated approach that sustainably balances the health of people, animals, plants, and ecosystems (World Organization for Animal Health, 2026). Zinsstag et al. (2018) frame climate change as a "threat multiplier" operating across all three One Health domains simultaneously — a dynamic visible in recurring Rift Valley fever outbreaks, where a single climatic anomaly floods mosquito breeding sites, stresses livestock, and strains public health infrastructure at once (Kassem et al., 2025). This review synthesises current evidence on: (1) the mechanisms linking climate change to climate-sensitive disease; (2) the disease categories most affected; (3) how One Health is being operationalized in response; and (4) the gaps that remain, particularly for low- and middle-income countries.

2. Methods

This review followed a structured narrative synthesis informed by PRISMA 2020 reporting principles (Page et al., 2021). Searches covered biomedical and environmental health literature (PubMed/PMC, ScienceDirect, MDPI, Springer Nature, Frontiers, The Lancet, Science Advances) and institutional sources (WHO, FAO, WOAH, UNEP), combining climate-change terms with One Health and disease-specific terms (zoonotic disease, vector-borne disease, water-borne disease, antimicrobial resistance, Rift Valley fever, dengue, malaria, cholera, Nipah virus), prioritizing literature from 2015-2026. Sources were included if peer-reviewed or from an authoritative institutional body, and if they reported an explicit relationship between a climate variable and a health outcome. Seventy-four records were screened; thirty-six sources - including several systematic and

scoping reviews - met inclusion criteria and were synthesized thematically into the five categories in Table 1. As a narrative rather than meta-analytic synthesis, this review does not pool effect sizes and relies substantially on existing reviews rather than independent primary-study screening; any bias in those underlying reviews is inherited here.

3. Conceptual Framework

The Quadripartite defines One Health as recognizing the interdependence of human, animal, plant, and environmental health, operationalized through a Joint Plan of Action and scientifically guided by the One Health High-Level Expert Panel (OHHLEP) (Geneva Environment Network, 2025). Climate change intersects with this framework through three overlapping pathways. Direct ecological pathways operate through temperature- and precipitation-sensitive vector and pathogen life cycles, since mosquitoes and similar vectors are ectotherms whose development and survival are governed by ambient conditions. Indirect ecological and land-system pathways operate through climate-linked deforestation, agricultural expansion, and resource scarcity, which push wildlife, livestock, and human populations into closer contact and elevate zoonotic spillover risk (Prezode Initiative, 2026). Systemic and infrastructural pathways operate through extreme-weather damage to water, sanitation, and health systems, independent of any direct climatic effect on the pathogen itself (Levy et al., 2016). These pathways interact rather than operate in isolation: Rift Valley fever outbreaks in East Africa illustrate how a single rainfall anomaly can activate all three simultaneously (see section 4.5).

4. Results: Thematic Synthesis

4.1 Global Burden and Trends

The evidence linking climate change to health outcomes has grown exponentially since the first studies on climate, dengue, cholera, malaria, and yellow fever appeared in 1991 (Oliveira-Filho et al., 2025). Vector-borne and zoonotic diseases together constitute the largest thematic cluster in this literature. Global dengue incidence illustrates the trend: reported cases rose from roughly 6 million in 2023 to over 14.6 million in 2024, the highest ever recorded in twelve months (Climate Change Academy, 2026). Table 1 summarises the five major categories of climate-sensitive disease addressed here.

Table 1. Categories of climate-sensitive disease and their One Health relevance.

Disease category	Primary climatic drivers	Illustrative diseases	One Health relevance

Disease category	Primary climatic drivers	Illustrative diseases	One Health relevance
Vector-borne	Rising temperature, altered rainfall, humidity, extreme weather	Malaria, dengue, chikungunya, West Nile virus, Lyme disease, Rift Valley fever	Vector ecology spans wildlife, livestock, and human reservoirs
Water-borne	Flooding, heavy rainfall, drought	Cholera, typhoid, leptospirosis, diarrhoeal disease	Sanitation and livestock run-off intersect with human exposure
Zoonotic (spillover)	Habitat loss, deforestation, land-use change	Nipah virus, Ebola virus disease, avian influenza, Rift Valley fever	Wildlife-livestock-human interface is the core surveillance target
Food-borne / food security	Heat stress, drought affecting agriculture	Salmonellosis, mycotoxin exposure, malnutrition-linked susceptibility	Agri-food systems connect livestock, crops, and human nutrition
Climate-amplified AMR	Temperature-driven gene transfer, extreme weather disrupting sanitation	Multidrug-resistant Enterobacteriaceae, resistant Vibrio, Aeromonas spp.	AMR moves across human, animal, and environmental reservoirs

4.2 Vector-Borne Diseases

Vector-borne disease is the most extensively documented category. As ectotherms, mosquitoes and ticks are directly sensitive to temperature, which governs development, survival, and biting frequency (Impact of Climate Change on the Global Dynamics of VB Infectious Diseases, 2025). A systematic review of 178 studies found range expansions in 118 mosquito species across six continents, though fewer than 10% statistically tested climate's causal role relative to land-use change and human-aided dispersal (A systematic review of climate-change driven range shifts in mosquito vectors, 2025). Sub-Saharan Africa carries roughly 90% of the global malaria burden, and Anopheles vectors have shifted their range an average of 4.7 km poleward and 6.5 m upward in elevation per year over the past century (A One Health Approach to Climate-Driven Infectious Diseases in Sub-Saharan Africa, 2025). Dengue shows comparable acceleration: Aedes

aegypti and Aedes albopictus have expanded into parts of Europe and North America, with climate change alone projected to newly expose 298-460 million people globally. Extreme events amplify this acutely - malaria cases in South Asia rose fivefold after 2022 flooding, and El Niño-driven conditions preceded a 130% dengue surge in Peru during 2023-2024 (CAS, 2026). West Nile virus and Lyme disease show that this expansion extends into temperate latitudes previously considered unsuitable for transmission (Editorial: Climate Change and the Spread of VBD, 2024).

4.3 Zoonotic Spillover and Land-Use Change

Zoonotic diseases account for an estimated 75% of emerging infectious diseases (World Health Organization, 2025). Climate change elevates spillover risk both directly, through shifting reservoir-species ranges, and indirectly, by interacting with deforestation, agricultural intensification, and urbanization to increase human-wildlife contact (Geographical and Ecological Drivers of Zoonotic Viral Spillover, 2026). Nipah virus spillover from bats to pigs to humans is linked to habitat-driven shifts in bat foraging and roosting behaviour (Climate Change and Zoonotic Disease Outbreaks, 2025). Ebola virus disease shows a parallel pattern: index cases in West and Central Africa between 2004 and 2014 occurred predominantly in hotspots of recent forest fragmentation (The Nexus Between Forest Fragmentation in Africa and Ebola Virus Disease Outbreaks, 2016). A cross-cutting risk assessment of high-consequence pathogens - including Ebola, Nipah, Rift Valley fever, and Zika - identified climate change as one of five interacting anthropogenic drivers of zoonotic emergence, alongside population dynamics, livestock production, agricultural intensification, and biodiversity loss (Assessing the Risk of Diseases with Epidemic and Pandemic Potential in a Changing World, 2025).

4.4 Water-Borne, Food-Borne Disease, and Antimicrobial Resistance

Water-borne disease is strongly linked to flooding and heavy rainfall, which overwhelm sanitation infrastructure and contaminate drinking water. A systematic review of 141 studies found consistent increases in diarrhoeal disease following heavy rainfall and flooding (Levy et al., 2016), a pattern repeated across West African cholera outbreaks (Cholera Amid the Climate Crisis, 2026) and after Cyclone Idai in Mozambique and Cyclone Ana in Malawi, the latter causing over 1,200 cholera deaths (Health Inequalities in Primary Care: SADC Region, 2025). In Borno State, Nigeria, climate-driven flooding has simultaneously fuelled waterborne disease and food insecurity, compounding malnutrition in a reinforcing cycle (Aborode et al., 2025). In Bangladesh, diarrhoea, dengue, cholera, malaria, and malnutrition together account for the overwhelming

majority of documented climate-sensitive disease burden (Understanding Climate-Sensitive Diseases in Bangladesh, 2025).

Antimicrobial resistance is increasingly recognized as climate-sensitive in its own right, projected to cause approximately 10 million deaths annually by 2050 (Antimicrobial Resistance in the Era of Climate Change, 2025). Rising temperatures accelerate horizontal resistance-gene transfer, while extreme weather disrupts the water and sanitation systems that shape antibiotic exposure (Climate Change and Antimicrobial Resistance: Application of One Health Approach, 2025). A food-safety-focused review found that 86% of studied countries exceeded high-risk resistance thresholds, with resistant Vibrio and Aeromonas species in aquaculture identified as key climate-sensitive AMR sentinels (Antimicrobial Resistance and Climate Change in the One Health Food Safety Paradigm, 2025).

4.5 Case Study: Rift Valley Fever in East Africa

Rift Valley fever (RVF) exemplifies these interacting pathways in practice. Bayesian spatial modelling shows RVF risk in Africa follows a seasonal pattern strongly tied to El Nino-driven rainfall, concentrated in South Africa and Kenya (Redding et al., 2017). In northern Tanzania, livestock infection rates predict human seropositivity closely enough that veterinary surveillance functions as an effective early-warning signal for human outbreaks (Inter-epidemic Rift Valley Fever Virus Infection Incidence, 2017). In Egypt, rising temperatures and altered rainfall have expanded mosquito breeding habitat, elevating RVF transmission risk to both livestock and humans, with direct economic consequences for farmers (Kassem et al., 2025). RVF illustrates the practical value of integrating veterinary and human surveillance - a condition still inconsistently met across affected countries.

4.6 Governance, Surveillance, and Equity

Translating this evidence into response depends on functioning surveillance and governance. The WHO's EWARS-csd platform predicts dengue outbreaks roughly twelve weeks in advance and has been piloted in Mexico, Burkina Faso, Colombia, Ethiopia, India, Senegal, and Thailand for dengue, malaria, and meningitis prediction (World Health Organization, TDR, n.d.). A systematic review of early-warning system development identified recurring barriers: fragmented epidemiological, entomological, and meteorological data; limited stakeholder capacity; and constrained real-time computing infrastructure (Challenges and Strategies for Climate-Informed Early Warning Systems, 2025). Table 2 summarises the principal One Health pillars relevant to climate-sensitive disease response.

Table 2. One Health pillars relevant to climate-sensitive disease response.

Pillar	Core function	Example mechanism
Joint surveillance	Integrated monitoring across human, animal, environmental sectors	EWARS-csd (WHO/TDR); GeoSeeq genomic monitoring platform
Cross-sector governance	Shared mandates and budgets across ministries	Quadripartite (FAO-UNEP-WHO-WOAH) Joint Plan of Action
Early-warning systems	Linking climate/weather forecasting to outbreak alerts	EWARS-csd dengue prediction (~12 weeks lead time)
Research & genomic tracking	Coordinated pathogen and vector surveillance	OHHLEP priority-setting; phylodynamic virus tracking

Governance case evidence confirms these barriers persist even where policy commitments exist. In Botswana, implementation has been slowed by fragmented institutions, weak surveillance integration, and resource constraints despite formal One Health policy adoption (Governing One Health Under Climate Pressure, 2026) - a pattern echoed in South African surveillance systems, which remain under-resourced and poorly integrated with environmental health data despite digital tools such as DHIS2 (Communicable Disease Surveillance in South Africa and LMICs, 2025). These constraints fall hardest on low- and middle-income countries, which bear a disproportionate climate-sensitive disease burden despite contributing minimally to global emissions: the death rate from extreme weather in vulnerable regions is fifteen times higher than in less vulnerable ones (World Health Organization, 2023).

5. Discussion

Three themes recur across this evidence. First, climate change rarely acts alone: it interacts with land-use change, agricultural intensification, and infrastructural weakness to produce compounded risk, most visible in zoonotic spillover and flooding-related outbreaks. Second, evidence strength varies by category - vector-borne and water-borne disease rest on decades of epidemiological literature, while zoonotic spillover and AMR remain comparatively under-studied from a climate perspective, with most reviews explicitly citing sparse or heterogeneous data (Intersections Between Climate Change and Antimicrobial Resistance, 2024). Third, and most consequential for policy, a persistent gap separates the sophistication of the science from the maturity of One

Health governance: proven tools such as EWARS-csd remain piloted rather than universal, and governance case studies from Botswana and South Africa report the same structural barriers, suggesting the limiting factor is institutional and financial rather than technical.

Where One Health mechanisms are adequately resourced, results are encouraging - veterinary RVF surveillance and EWARS-csd dengue prediction both demonstrate real operational value. But the broader pattern is one of aspirational policy commitment, reflected in the Quadripartite's 2023 Call to Action, running ahead of the institutional coordination and sustained financing needed to operationalize it at scale. Remaining research gaps include a shortage of experimental studies on vector-pathogen thermal biology, limited land-use-specific spillover data, under-representation of sub-national data relative to national and global-scale studies, and few analyses that integrate all three One Health domains within a single framework (Oliveira-Filho et al., 2025). Addressing these gaps, alongside structural integration of veterinary, environmental, and human surveillance data, is essential to closing the gap between One Health's stated scope and its current evidence base.

6. Recommendations

- Scale up climate-informed early-warning systems such as EWARS-csd beyond pilot countries, prioritizing the highest-burden regions.
- Mandate structural integration of veterinary, environmental, and human surveillance data rather than relying on voluntary coordination.
- Establish dedicated, multi-year One Health financing, separate from emergency outbreak-response budgets.
- Direct research funding toward under-studied areas: vector-pathogen thermal biology, land-use-specific spillover pathways, and longitudinal AMR-climate surveillance.
- Strengthen laboratory and health-information capacity in low- and middle-income countries as a precondition for effective global surveillance participation.
- Embed climate-sensitive disease risk explicitly within national climate adaptation plans, not solely within the health sector.

7. Conclusion

This review has synthesized evidence that climate change is a substantial and accelerating driver of disease across every major climate-sensitive category - vector-borne, water-borne, zoonotic, food-borne, and antimicrobial resistance - through increasingly well-characterized ecological, land-system, and infrastructural pathways.

The One Health approach, formalized through the FAO-UNEP-WHO-WOAH Quadripartite, offers a conceptually sound framework for addressing these interconnected risks. Yet a persistent gap separates policy commitment from operational reality: proven early-warning tools remain confined to pilot implementation, governance remains fragmented in the highest-burden countries, and research investment has not matched the framework's multi-sectoral ambition. Closing this gap through integrated surveillance, dedicated financing, and targeted research represents one of the most consequential global health priorities of the current decade.

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PARTICIPANT RESEARCH PAPER

Biological and Epidemic Hazards in Pakistan
Disease Outbreak Risk, Early Warning, and Disaster Preparedness

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Abstract

Pakistan faces recurring biological and epidemic hazards shaped by climate variability, fragile health infrastructure, and complex disaster governance. This systematic review synthesizes peer-reviewed and institutional literature published between 2020 and 2026 on disease outbreak risk, early warning systems, and disaster preparedness in Pakistan. Following PRISMA-informed search principles across PubMed/PMC, institutional repositories, and relevant journals, eighteen sources were retained for thematic synthesis. Findings show that flood-driven outbreaks of cholera, dengue, and malaria, the persistence of wild poliovirus, and the climate-sensitive tick-borne zoonosis Crimean-Congo haemorrhagic fever constitute the country's principal epidemic-prone hazards. Early-warning mechanisms such as the Disease Early Warning System and polio environmental surveillance demonstrate real operational value but remain constrained by fragmented data systems and resource gaps. Disaster preparedness, coordinated by the National Disaster Management Authority under the Sendai Framework, has strengthened institutionally but continues to lag behind the scale of recurrent climate-driven health emergencies. Integrated surveillance, cross-sectoral financing, and equity-explicit planning are recommended.

Keywords: Pakistan; biological hazards; epidemic risk; early warning systems; disaster preparedness; climate change; disease surveillance

1. Introduction

Pakistan ranks among the most disaster- and climate-vulnerable countries in the world, while simultaneously carrying one of the highest burdens of vaccine-preventable and vector-borne disease in South Asia. The country's exposure to floods, heatwaves, droughts, and glacial lake outburst floods intersects directly with epidemic risk. The catastrophic 2022 floods, which submerged roughly one-third of the country and affected 33 million people, were followed within weeks by outbreaks of cholera, dengue, malaria, and acute watery diarrhoea across flood-affected districts (Alied et al., 2023). At the same time, Pakistan remains one of only two countries where wild poliovirus transmission has never been interrupted, and it carries a rising burden of Crimean-Congo haemorrhagic fever (CCHF), a climate-sensitive tick-borne zoonosis with case-fatality rates exceeding 40% in some hospital series (Abid et al., 2025).

These overlapping biological and epidemic hazards test a disaster-management architecture that has evolved substantially since the 2005 earthquake and 2010 floods, most visibly through the National Disaster Management Authority (NDMA) and its alignment with the Sendai Framework for Disaster Risk Reduction (Government of Pakistan NDMA, 2025). Yet recurring health emergencies, most recently the 2022 flood-related disease surge and the 2023-2024 resurgence of wild poliovirus, raise persistent questions about whether early-warning systems and preparedness planning are translating into a genuine reduction of outbreak risk on the ground.

This review synthesises literature published between 2020 and 2026 to address three questions: first, which biological and epidemic hazards pose the greatest documented risk in Pakistan; second, how effectively early-warning and surveillance systems are detecting and responding to these hazards; and third, how disaster preparedness structures are addressing, or failing to address, the compounding relationship between climate-driven disasters and disease outbreak risk. The review pays particular attention to the equity dimensions of these hazards, since women, children, and older adults are repeatedly identified as bearing a disproportionate share of the resulting health burden. It also considers the extent to which digital and text-based surveillance innovations are beginning to supplement Pakistan's traditional facility-based reporting infrastructure.

2. Methods

This review followed a structured narrative synthesis informed by PRISMA 2020 reporting principles. Searches covered PubMed/PMC, journal publishers including The Lancet, BMJ Global Health, Nature Scientific Reports, and PLOS ONE, and institutional

repositories including WHO, WHO EMRO, NDMA, ReliefWeb, and Amnesty International, using combinations of the terms “Pakistan,” “disease outbreak,” “epidemic,” “early warning,” “disaster preparedness,” “flood,” “Crimean-Congo haemorrhagic fever,” “polio,” and “COVID-19,” restricted to sources dated 2020 to 2026. Sources were included if they reported empirical, surveillance, or policy evidence specific to Pakistan's biological or epidemic hazard landscape. Eighteen sources meeting these criteria were retained for thematic synthesis, covering flood-related disease outbreaks, zoonotic and vector-borne disease, vaccine-preventable disease surveillance, pandemic preparedness, and disaster governance. As a narrative rather than meta-analytic review, this synthesis does not pool quantitative effect estimates and relies substantially on the framing and findings reported in the underlying sources.

3. Results

3.1 Flood-Driven Outbreaks and Water- and Vector-Borne Disease

Pakistan's most extensively documented epidemic hazard in the 2020-2026 literature is the disease surge that follows major flooding. The 2022 floods, described as among the country's most catastrophic in decades, displaced millions of people and were followed by epidemics of cholera, cryptosporidiosis, rotavirus infection, generalised diarrhoea, and typhoid and paratyphoid fever, alongside a sharp rise in malaria and dengue fever (Alied et al., 2023). Stagnant floodwater created ideal mosquito breeding conditions approximately six to seven weeks after the flood peak, driving a delayed but severe malaria resurgence, while overcrowded shelters with inadequate water and sanitation facilitated faecal-oral disease transmission and outbreaks of acute conjunctivitis and skin infection (Dreadful Infectious Disease Outbreaks Threaten Flood-Ravaged Pakistan, 2023). The World Health Organization reported that ten per cent of Pakistan's health facilities were damaged or destroyed by the floods, leaving more than eight million people in need of urgent health assistance and enabling outbreaks of measles and rubella across thirty-one districts (World Health Organization, 2022).

The health consequences extended well beyond the acute flood period. A 2025 review found that fragmented surveillance infrastructure in submerged districts obscured the true disease burden for months afterward, particularly for non-communicable conditions and reproductive and mental health, while women and girls faced a disproportionate burden of unmet health needs (From 2022 to 2025: Preventing the Escalating Health Crisis of Pakistan's Floods, 2025). Reproductive health services were especially disrupted, with flood-affected women reporting reduced access to maternal care, family planning, and menstrual hygiene resources during and after displacement, and with rapid assessments

documenting widespread destruction of the antenatal and obstetric infrastructure on which rural women depended (Waseem et al., 2025; Ashraf et al., 2024). Beyond flooding, dengue has become endemic and increasingly severe in urban centres such as Karachi, with clinical data collected between 2021 and 2023 showing that a substantial minority of hospitalized patients developed warning signs or severe disease requiring intensive management (Alied et al., 2023). Vulnerability mapping further shows that these risks are unevenly distributed across the country: Balochistan, characterized by high climate sensitivity and low adaptive capacity, together with parts of southern Punjab and Sindh, faces disproportionate exposure to flood-related diarrhoeal disease, drought-related malnutrition, and heat-related illness (Hafiz Waqar & Xuesong, 2023).

3.2 Zoonotic and Vector-Borne Hazards: Crimean-Congo Haemorrhagic Fever

Crimean-Congo haemorrhagic fever has emerged as one of Pakistan's most consequential climate-sensitive biological hazards in the recent literature. A decade-long analysis of laboratory-network data collected between 2012 and 2023 identified 547 confirmed cases concentrated in three cities with high rates of human and animal migration, with a case-fatality rate of 45.8 per cent among patients admitted to a major tertiary-care hospital (Abid et al., 2025). The same study found a statistically significant positive correlation between ambient temperature and case counts in Karachi and Quetta, and identified seasonal livestock migration around the Eid-ul-Adha festival as a recurring amplifier of transmission risk (Abid et al., 2025). A parallel 2024 review described CCHF as a “silently ringing bell” within Pakistan's public health system, noting the absence of a dedicated national surveillance database and calling for sentinel surveillance to be embedded within medical and community-health curricula to improve early detection and clinician awareness (Jamil et al., 2024).

CCHF exemplifies the compounded biological, epidemic, and climate hazard structure recurring throughout this review: its tick vector's range and seasonal activity are climate-sensitive, its amplification depends on largely unregulated cross-border and domestic livestock movement, and its detection depends on a health system with limited diagnostic and reporting capacity outside major urban tertiary-care centres (Abid et al., 2025; Jamil et al., 2024). Both studies note that nosocomial transmission, particularly among healthcare workers exposed to infected blood or bodily fluids before diagnosis, adds a further layer of risk that standard infection-control protocols in smaller district hospitals are often not equipped to manage. These same structural features recur across other biological hazards examined in this review, including wild poliovirus transmission and pandemic-prone respiratory disease.

3.3 Early Warning and Surveillance Systems

Pakistan's principal disease early-warning mechanism, the Disease Early Warning System, was established after the 2005 earthquake and substantially expanded following the 2010 floods to cover more than half of the national population; more recent reporting confirms that proactive, DEWS-informed measures continued to help avert major cholera outbreaks after subsequent flooding events, although the system's case definitions and reporting standardization have required repeated revision to remain reliable. For vaccine-preventable disease, Pakistan relies heavily on environmental wastewater surveillance to detect silent wild poliovirus circulation: the World Health Organization reported that positive environmental samples rose from 125 in 2023 to over six hundred in 2024, alongside a more than twelve-fold increase in confirmed paralytic cases over the same period, concentrated in the historical reservoirs of Karachi, Peshawar, and Quetta (World Health Organization, 2025). Despite an expanded environmental surveillance network and more than 412,000 vaccinators mobilised in 2024, the Programme’s own emergency action plan acknowledges that Pakistan remains off track to interrupt transmission, citing operational and security-related access constraints alongside persistent community vaccine hesitancy (Pakistan Polio Eradication Programme, 2024).

For COVID-19, Pakistan's national coordination relied on a Public Health Emergency Operations Centre that was later redesignated as the National Command and Operations Centre; a formal assessment of this coordination architecture scored overall inter-agency emergency response coordination at only forty-nine per cent, highlighting persistent gaps in multi-departmental information-sharing despite the system's relative success in containing early pandemic waves (Nature Scientific Reports, 2023; Noreen et al., 2021). Alongside these facility-based mechanisms, researchers have begun piloting complementary digital tools: a text-mining system named BIOPAK Flasher was developed to scan local-language news media for early signals of epidemic-prone disease activity, addressing a longstanding blind spot in which outbreak signals reported only in regional languages were missed by conventional surveillance channels (BIOPAK Flasher, 2021). Collectively, these findings suggest that Pakistan's early-warning architecture performs a genuine and measurable risk-reduction function but remains constrained by fragmented data systems, incomplete facility-level reporting, and uneven investment across competing disease programmes.

3.4 Disaster Preparedness and Governance

Institutionally, disaster preparedness in Pakistan is coordinated by the NDMA, established in 2007 and operating through a three-tiered federal, provincial, and district

structure aligned with the Sendai Framework for Disaster Risk Reduction (Government of Pakistan NDMA, 2025). The newly adopted National Disaster Risk Reduction Strategy 2025-2030 explicitly frames climate-related hazards, including floods, heatwaves, and glacial lake outburst floods, as core national risks and commits to strengthening early-warning systems and anticipatory action across all provinces (Government of Pakistan NDMA, 2025). A quantitative vulnerability assessment applying the Sendai Framework's four priority areas to Pakistan found that environmental and socioeconomic vulnerability factors were significant predictors of climate-driven mortality, and recommended integrating vulnerability-ranking tools directly into subnational disaster planning processes (Hafiz Waqar & Xuesong, 2023).

However, the literature consistently identifies a gap between institutional design and operational outcomes. The World Health Organization's Climate and Health Vulnerability Assessment for Pakistan recommended establishing an intersectoral platform to monitor climate-related health risks and a climate-informed disease early-warning and response system, together with a national risk register for climate-health hazards and seasonal climate outlooks to inform health-sector programming, a set of recommendations that, as of the assessment, had not yet been fully implemented (World Health Organization, 2024). Similarly, a 2025 review found that despite the ambitions of the new national strategy, older adults and young children, the groups at highest risk from extreme heat and flood-related disease, continue to face significant gaps in healthcare access, emergency evacuation planning, and social protection, gaps the review attributes partly to under-investment in disaggregated health data collection (Amnesty International, 2025). For pandemic preparedness specifically, health-system stewardship reviews argue that Pakistan's COVID-19 response relied disproportionately on short-term tactical measures rather than durable investment in primary health care-based emergency capacity, a shift the authors argue is essential for genuine future pandemic readiness and one that requires sustained political commitment beyond the acute phase of any single outbreak (Zaidi & Hussain, 2025).

4. Discussion

Across these four thematic areas, three patterns emerge. First, Pakistan's epidemic risk is structurally compounded by climate exposure: flooding, heat, and shifting precipitation patterns do not act as isolated hazards but as amplifiers of water-borne, vector-borne, and zoonotic disease risk, a relationship most clearly documented for CCHF and for flood-associated cholera, dengue, and malaria (Abid et al., 2025; Alied et al., 2023). Second, early-warning and surveillance systems in Pakistan demonstrate real but partial

effectiveness: the Disease Early Warning System and polio environmental surveillance both generate genuinely actionable signals, yet each is undermined by fragmented reporting, incomplete geographic coverage, and constrained diagnostic capacity outside major urban centres (Jamil et al., 2024; World Health Organization, 2025). Third, and most consequential for policy, disaster preparedness governance has matured considerably under the NDMA and the Sendai Framework, but the persistence of wild poliovirus, recurring flood-driven epidemics, and unimplemented climate-health recommendations indicate that governance structures have not yet closed the gap between policy commitment and operational capacity (Government of Pakistan NDMA, 2025; World Health Organization, 2024).

A further recurring theme is equity. Across flood response, reproductive health, and climate vulnerability literature, women, children, and older adults consistently bear a disproportionate share of the resulting health burden, reflecting both biological vulnerability and unequal access to services during emergencies (Waseem et al., 2025; Amnesty International, 2025). This pattern suggests that future early-warning and preparedness investment in Pakistan cannot be treated as demographically neutral; it must explicitly account for differential exposure and unequal access to care if it is to meaningfully reduce the country's overall epidemic burden.

5. Conclusion and Recommendations

This review demonstrates that Pakistan's biological and epidemic hazard landscape between 2020 and 2026 is dominated by three interacting threats: flood-driven water- and vector-borne disease outbreaks, persistent wild poliovirus transmission, and the climate-sensitive zoonosis Crimean-Congo haemorrhagic fever. Early-warning systems such as the Disease Early Warning System and polio environmental surveillance provide a demonstrable, if incomplete, risk-reduction function, while disaster governance under the NDMA and the Sendai Framework has strengthened institutionally without yet matching the scale of recurring climate-driven health emergencies.

To close this persistent gap, four actions are recommended. First, climate-informed disease early-warning systems should be integrated directly into the NDMA's national risk-monitoring architecture rather than remaining housed separately within the health sector alone, ensuring that seasonal climate outlooks routinely inform outbreak-response planning. Second, CCHF and other zoonotic disease surveillance should be expanded beyond major tertiary-care centres into rural and cross-border livestock-trading areas where transmission risk is highest, supported by targeted clinician training. Third, polio environmental surveillance should be sustained and expanded while directly addressing

the operational and community-trust barriers that drove the 2023-2024 resurgence, including renewed investment in community engagement. Fourth, equity-explicit planning for women, children, and older adults should be embedded into all flood and heatwave preparedness protocols, supported by disaggregated data collection during emergencies. Sustained, cross-sectoral investment across these four areas, matched by durable political commitment beyond individual outbreak cycles, is essential if Pakistan is to reduce its recurring burden of climate-driven epidemic disease in the years ahead.

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PARTICIPANT RESEARCH PAPER

Private Sector Engagement in Disaster Risk Reduction and Business Continuity Planning

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Abstract

Disasters increasingly disrupt private enterprises that employ most of the workforce and operate critical supply chains, yet business continuity planning (BCP) remains inconsistent, particularly among small and medium enterprises (SMEs). This paper examines the extent of private sector engagement in disaster risk reduction (DRR), identifies the principal barriers to BCP adoption, and reviews the public-private coordination mechanisms currently in place. Drawing on policy frameworks, case evidence, and institutional practice, the analysis finds that SMEs — which make up more than 90 percent of enterprises — face disproportionate closure risk after disasters due to weak preparedness, limited insurance uptake, and near-total exclusion from formal DRR platforms, while larger firms with certified BCP systems recover markedly faster and, in doing so, support wider community resilience. The paper recommends formal private-sector representation in national DRR governance, incentive-linked BCP certification, subsidized risk-assessment technology for SMEs, and stronger last-mile risk communication. It concludes that integrating the private sector as an active partner, rather than a passive stakeholder, is essential to building resilient economies and communities.

Keywords: Business continuity, disaster risk reduction, early warning systems, private sector, resilience.

1. Introduction

Disasters increasingly disrupt economies rather than only communities, and the private sector — which drives most employment, service delivery, and supply chains — sits at the centre of that disruption. Yet national DRR frameworks remain largely public-sector centred, with limited formal roles for businesses in planning, early warning, or recovery governance. Over 90 percent of enterprises worldwide are SMEs, and most operate without a written business continuity plan, leaving them acutely exposed when a hazard event strikes.

The consequences of this gap are significant: business closures after disasters weaken local livelihoods, erode tax revenue, and slow community-wide recovery, since a shuttered enterprise is also lost wages, lost services, and a broken link in a local supply chain. This paper's problem statement is that despite the private sector's outsized economic role, it remains largely absent from formal DRR platforms and BCP adoption remains inconsistent, particularly among smaller firms.

The purpose of this research is to assess the extent of private sector engagement in DRR, identify the barriers that prevent broader BCP adoption, and recommend public-private policy measures that close this gap. The objectives are therefore threefold: to assess current private sector engagement in DRR; to identify barriers to BCP adoption, especially among SMEs; and to recommend concrete public-private policy measures. The scope covers both large firms and SMEs across formal DRR and BCP frameworks, on the rationale that continuity of business is continuity of community — resilient enterprises sustain jobs, services, and recovery after a hazard event.

2. Regional Context & Hazard Profile

Disaster risk is conventionally understood through four linked concepts. A hazard is a process or event with the potential to cause loss of life, injury, or economic disruption. Exposure refers to the people, assets, and enterprises located in hazard-prone areas. Vulnerability describes the conditions that increase susceptibility to a hazard's damaging effects. Risk is the resulting potential loss of life, livelihood, or assets — a function of hazard, exposure, and vulnerability combined.

Regional trends are intensifying this risk profile for businesses specifically. Rapid urbanization and industrial growth concentrate enterprises in flood plains, coastal zones,

and seismic belts, while aging infrastructure and dense informal settlements raise exposure for micro and small enterprises in particular. Historical events — floods, earthquakes, cyclones, and the COVID-19 pandemic — have repeatedly disrupted supply chains and forced business closures, exposing how thin the margin for continuity really is. The literature increasingly reflects a shift toward 'resilience by design' and growing recognition of formal continuity standards such as ISO 22301, though adoption of these standards remains concentrated among larger, better-resourced firms.

3. Risk & Vulnerability Assessment

The socio-economic impact of business disruption is severe and, for many enterprises, permanent. Evidence reviewed in this study indicates that 43 percent of businesses never reopen after a major disaster, that over 90 percent of enterprises are SMEs operating with limited financial reserves, and that roughly one in three supply chains is disrupted following a regional hazard event. These disruptions ripple through the wider economy in several ways: livelihood disruption occurs as lost wages and jobs follow even temporary enterprise closures; food security risk rises as damage to agro-processing, storage, and retail and distribution networks disrupts the supply of essential goods; and cascading effects emerge as single-site suppliers create bottlenecks that stall entire local and regional supply chains. Long recovery timelines for uninsured, undiversified small businesses deepen community-level poverty well beyond the initial disaster event.

Vulnerability within the private sector is unevenly distributed. Micro and informal enterprises with no legal registration or insurance access, women-owned businesses that are often home-based or embedded in informal markets, single-site and single-supplier businesses with no operational backup, and migrant and low-income workers dependent on daily or seasonal informal income are all disproportionately exposed. Exposure factors include location in flood plains, coastal, or seismic zones with high business density; susceptibility stems from reliance on a single site, supplier, or market without diversification; and vulnerability is compounded by the absence of a BCP, limited insurance, and constrained access to post-disaster credit. The gender dimension is particularly acute: women entrepreneurs face compounded barriers, including limited collateral, mobility constraints, and exclusion from formal recovery finance, that leave women-led enterprises among the slowest to recover after a hazard event.

4. Community Resilience Factors

Businesses draw on several forms of social capital and local coping capacity that complement, and sometimes substitute for, formal DRR systems. Business networks — chambers of commerce and trade associations — coordinate mutual aid and shared

resources among members during and after a disaster. Indigenous and locally accumulated knowledge informs siting, timing, and supply-chain redundancy decisions in ways that formal risk assessments do not always capture. Community participation occurs where businesses join local DRR committees and preparedness drills alongside residents, embedding continuity planning within the broader community's resilience effort rather than treating it as a separate, firm-level concern.

Resilience capacities such as financial reserves, insurance uptake, and diversified suppliers cushion the shock of a hazard event for the firms that possess them, but these capacities remain concentrated among larger and better-capitalized enterprises. The result is a two-tier resilience landscape: businesses embedded in strong local networks and formal continuity systems recover quickly and help sustain community-wide recovery, while isolated, under-capitalized micro and small enterprises — despite often possessing valuable local hazard knowledge — lack the formal backing to translate that knowledge into durable continuity.

5. Scientific & Institutional Gaps

Several scientific, technological, and institutional gaps constrain private sector DRR engagement. Research gaps persist in the limited data available on private DRR investment and its return, especially for SMEs, making it difficult to build the evidence base needed to justify continuity spending to small business owners. Technology limits are evident in the weak adoption of AI/ML tools for supply-chain risk prediction outside large firms, leaving smaller enterprises without access to increasingly important predictive capabilities.

Institutional weakness is perhaps the most consequential gap: there is no unified public-private coordination body in most national DRR systems, and regulatory incentives for BCP adoption remain unclear or absent. This is compounded by data gaps, since no standardized BCP reporting or business hazard-loss database exists at the national level in most contexts, leaving policymakers unable to track adoption or target support where it is most needed. Closing these gaps requires joint investment: shared hazard data platforms, subsidized SME technology access, and a standing public-private coordination mandate that gives businesses a structured channel into national DRR planning.

6. Mitigation Strategies & Best Practices

Mitigation strategies for business continuity span both structural and non-structural measures. Structural measures include retrofitting facilities to hazard-resistant building codes, building redundant power, water, and IT infrastructure, and diversifying facility locations away from high-hazard zones. Non-structural measures include written and

tested business continuity plans, business interruption insurance paired with supplier diversification, and staff training, evacuation, and preparedness drills that keep continuity plans operational rather than theoretical.

International and national best practices offer transferable models. The Sendai Framework's Priority 3 explicitly calls for private investment in DRR, while UNDRR's ARISE network mobilizes businesses as resilience partners worldwide. Japan's BCP certification scheme links preparedness directly to public recognition and financing, creating a tangible incentive for firms to formalize continuity planning, and the ISO 22301 business continuity management standard is increasingly adopted by mid-size firms seeking a recognized benchmark. At the community level, chamber-led 'business resilience circles' have proven effective at spreading preparedness know-how to SMEs that would otherwise lack access to formal continuity expertise.

7. Risk Communication & Early Warning

Effective risk communication for businesses follows a four-stage pathway from detection to protective action. Hazard monitoring first generates sector-specific risk bulletins; these are then relayed through trusted networks, with chambers of commerce and trade associations acting as relay nodes that reach businesses formal government channels often cannot. Gender-sensitive, plain-language alerts delivered by SMS or app then reach owners directly, including informal and women-led firms that are frequently excluded from conventional communication channels. Finally, pre-agreed business protocols translate the alert into action, triggering shutdown, backup, or relocation steps that have been planned in advance rather than improvised under pressure.

What determines whether a warning becomes protective action is community engagement, not technology alone. A sector-specific bulletin that never reaches an informal, home-based, or women-led business is of limited value regardless of its technical accuracy; the relay function performed by chambers of commerce, trade associations, and local business networks is therefore as important to last-mile risk communication as the underlying hazard science.

8. Policy Recommendations

The findings above point toward an integrated public-private governance agenda. Six recommendations follow directly from the evidence reviewed.

S. No	Recommendation	Rationale
1	Integrated Governance	Give the private sector a formal seat on national and local DRR platforms rather than an informal or advisory

S. No	Recommendation	Rationale
		role.
2	Incentivized BCP	Link tax or procurement incentives to certified business continuity plans to accelerate adoption beyond large firms.
3	Technology Access	Subsidize AI/ML-based risk-assessment tools for SMEs and informal firms currently priced out of predictive technology.
4	Institutional Strengthening	Establish a joint public-private DRR coordination unit with a clear, standing mandate.
5	Community Participation	Require business input in local hazard and land-use planning processes.
6	Evidence-Based Policy	Build a national BCP registry to track adoption and target support where it is most needed.

These recommendations respond directly to the institutional and technological gaps identified above. Formal governance representation and a standing coordination unit address the current absence of a unified public-private DRR body; incentive-linked certification and subsidized technology access address the cost and awareness barriers that keep BCP adoption concentrated among larger firms; and a national BCP registry, paired with mandatory business input into local hazard and land-use planning, would give policymakers the evidence base currently missing to target support and track progress over time.

9. Conclusion

The private sector is not a bystander in disaster risk; it is a decisive actor whose preparedness shapes community-wide recovery. Evidence reviewed in this paper shows that certified BCP firms recover markedly faster than uncertified ones, that SMEs — which make up the overwhelming majority of enterprises — remain largely excluded from formal DRR platforms, and that this exclusion translates directly into closure risk, lost livelihoods, and slower community recovery after a disaster.

Science-based planning, grounded in accurate hazard and vulnerability data, must guide business investment in resilience, while social capital and indigenous knowledge remain powerful, low-cost complements to formal risk assessment. Technology — from AI-enabled risk mapping to people-centred early warning — must be made accessible to SMEs, not reserved for large firms alone. An integrated approach linking government,

businesses, and communities offers the surest path to resilient economies: when businesses plan for disasters, communities recover faster, and treating the private sector as a full partner in disaster risk reduction is not optional but essential.

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PARTICIPANT RESEARCH PAPER

Anticipatory Actions for Heatwaves in Pakistan: Current Interventions and Future Enhancements

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Abstract

Heatwaves have become a recurring climate-related hazard in Pakistan, creating serious risks for human health, livelihoods, agriculture, water availability, electricity systems and community well-being. The 2015 Karachi heatwave, which resulted in more than 1,200 deaths and over 50,000 heat-illness cases, highlighted the consequences of inadequate preparedness. Since then, Pakistan has gradually moved from a mainly reactive approach towards anticipatory action, in which forecasts are used to trigger preparedness measures before extreme heat reaches its peak. The development of the Karachi Heatwave Management Plan in 2017, forecast-based financing pilots from 2022, and the National Disaster Management Authority (NDMA) Heatwave Guidelines 2024 represent important steps in this transition. The 2025 Start Ready activation further demonstrated the value of pre-arranged financing, reaching six locations across four provinces. However, gaps remain in health-data systems, permanent cooling infrastructure, geographical coverage, protection of outdoor workers, electricity continuity and outcome measurement. International experience from Ahmedabad and France shows that coordinated heat-health action can reduce mortality. Pakistan should therefore strengthen early warning, expand anticipatory financing, establish vulnerable-person registries and permanent cooling centres, and measure illnesses and deaths prevented rather than only activities completed.

Keywords: Anticipatory Action; Climate Change; Disaster Risk Reduction; Heatwaves; Pakistan

1. Introduction

Pakistan is increasingly exposed to extreme heat because of rising temperatures, climate variability, urbanization, water stress and socioeconomic vulnerabilities. Heatwaves are not only a health emergency; they also affect livelihoods, agriculture, education, electricity demand and essential services. People living in poorly ventilated housing, informal settlements and areas with limited access to water and healthcare face particularly high risks.

The 2015 Karachi heatwave became a major turning point. Research found that Karachi residents were 17.68 times more likely to die from a heat-related cause during June 2015 compared with the previous year. This demonstrated the need to move beyond emergency response towards preparedness and prevention.

Pakistan's approach has subsequently developed through heatwave management planning, early warnings, provincial standard operating procedures, forecast-based financing and national guidelines. This paper examines the country's current anticipatory actions, their achievements and limitations, and possible future enhancements. The study focuses on heatwave risk from a climate-change, disaster-management and disaster-risk-reduction perspective, with additional attention to health, community resilience and the psychological burden of extreme heat.

2. Regional Context & Hazard Profile

Pakistan has experienced repeated severe heat events. The 2015 Karachi heatwave caused more than 1,200 reported deaths and over 50,000 heat-illness cases. Karachi also experienced a reported heatwave-related death toll of around 65 over three days in 2018, although the figure was disputed by health authorities. Jacobabad reached approximately 51°C in 2019. Around 400 deaths were reported across Sindh and Punjab in 2020, while approximately 90 deaths were reported in 2022. In 2024, Nawabshah, Hyderabad and Karachi experienced temperatures above 49°C.

A hazard refers to the extreme heat itself. Exposure refers to people, infrastructure and livelihoods located in affected areas. Vulnerability refers to the social, economic, physical and health conditions that increase the likelihood of harm. Risk results from the interaction of the hazard, exposure and vulnerability.

Pakistan's anticipatory journey has developed through several stages: the 2015 Karachi disaster increased national attention; the Karachi Heatwave Management Plan was introduced in 2017; forecast-based anticipatory action was piloted in 2022; and NDMA Heatwave Guidelines 2024 strengthened the national framework.

3. Risk & Vulnerability Assessment

Heatwaves create interconnected health, socioeconomic and environmental risks. The most immediate impact is heat-related illness and death. Extreme heat can cause dehydration, heat exhaustion and heatstroke, while increasing stress on people with existing health vulnerabilities. The 2015 Karachi event demonstrated how quickly extreme heat can overwhelm emergency departments and morgues.

Livelihoods are also significantly affected. Outdoor workers, including construction workers, agricultural labourers, street vendors and other informal-sector workers, may lose approximately two to four hours of safe outdoor working time during peak heat. Reduced working hours can directly reduce household income, particularly for people who depend on daily wages.

Agriculture faces additional risks. The 2024–25 pre-monsoon period brought temperatures approximately 4–6°C above normal in parts of Sindh, southern Punjab and Balochistan. Heat stress during important crop-growth stages can affect wheat and cotton production. At the same time, heat increases water demand, making the combination of heat and water scarcity particularly dangerous for communities and agricultural systems.

Electricity systems are another part of the risk cycle. Extreme heat increases demand for cooling, while power outages can remove access to fans, air conditioning and refrigeration. This creates a feedback loop in which higher temperatures increase electricity demand and outages increase heat exposure.

Vulnerability is not equally distributed. Older adults, children, outdoor workers and residents of informal settlements are among the groups facing higher exposure. Low-income households may have fewer options for cooling, reliable electricity, clean water and healthcare. Women may also face additional barriers because of mobility restrictions, household responsibilities and unequal access to resources.

The psychological and cognitive effects of heat require greater attention. Extreme temperatures can contribute to irritability, sleep disruption, fatigue, reduced concentration and psychological distress. Children may experience reduced concentration during very hot school days, while school closures can disrupt routines. Despite these concerns, Pakistan's current heatwave monitoring focuses more strongly on mortality and physical illness than psychological outcomes. This represents an important research and policy gap.

4. Community Resilience Factors

Community participation is essential because an official warning is useful only when people receive it, understand it and can act on it. Local organizations, volunteers,

community leaders and health workers can provide the connection between government systems and vulnerable households.

Pakistan's anticipatory response already involves organizations such as the Pakistan Red Crescent Society, Edhi Foundation, NGOs and community groups. Their activities include first aid, ambulance services, awareness, water distribution, cooling support and community mobilization.

The 2025 activation demonstrates the importance of trained local networks. In Sindh, 544 heatstroke camps were established, 809 patients were treated, 100 frontline workers were trained and more than 200 volunteers were trained.

Local and indigenous knowledge can strengthen these systems. Communities understand local water sources, neighbourhood conditions, work patterns and vulnerable households. Combining this knowledge with scientific forecasts can make anticipatory action more practical and effective.

5. Scientific & Institutional Gaps

Pakistan has developed an important anticipatory framework, but several gaps limit its effectiveness. First, heat-related illness and mortality data are not yet sufficiently standardized or timely. A national heat-health database is needed to support evidence-based decisions.

Second, warnings may not reach all vulnerable people, particularly in rural communities and areas with limited digital access. Third, permanent cooling centres remain limited, while temporary heatstroke camps are more common. Fourth, outdoor workers require stronger protection through adjusted working hours, rest periods, water and heat-risk thresholds.

Electricity outages also threaten the effectiveness of cooling interventions. Hospitals and designated cooling centres should receive priority power during extreme heat. Finally, Pakistan needs stronger evaluation. Current reporting emphasizes numbers reached, camps established and services delivered, but future evaluations should also measure reductions in illness, hospital admissions and deaths.

Technology can support these improvements through integrated databases, geographic risk mapping and, where appropriate, AI/ML-assisted analysis. Such tools should complement rather than replace local institutions and community networks.

6. Mitigation Strategies & Best Practices

Pakistan's anticipatory-action chain provides a practical foundation. PMD forecasts extreme heat approximately 3–10 days in advance. A predefined temperature threshold activates an alert, pre-committed financing is released, and actions such as water

distribution, cooling camps, public awareness and hospital preparedness begin before peak heat.

Start Ready financing has expanded substantially. Funding increased from approximately £128,039 in 2022 to £291,171 in 2023 and £419,763 in 2025, representing approximately a 3.3-fold increase across the activation cycles.

International experience provides further lessons. Ahmedabad's Heat Action Plan was introduced after the severe 2010 heatwave. Research found that at 47°C, the mortality risk ratio decreased from 2.34 before the plan to 1.25 after implementation, with approximately 1,190 deaths estimated to have been avoided annually.

Pakistan should build on its existing provincial experience while adapting successful international practices to local conditions.

7. Risk Communication & Early Warning

Early warning should be people-centred, simple and actionable. Pakistan should use multiple communication channels, including SMS, WhatsApp, television, radio, schools, community organizations and local government networks. Messages should be provided in relevant local languages and explain practical actions such as drinking sufficient water, avoiding peak heat, checking vulnerable family members and seeking medical help when severe symptoms appear.

Communication should also consider gender, disability, literacy and digital-access differences. Community volunteers can support last-mile communication by visiting or contacting vulnerable households during high-level heat alerts.

A vulnerable-person registry could further strengthen protection. France provides an example of a system in which vulnerable elderly people can be identified and checked during heat alerts. A locally adapted registry could prioritize isolated elderly people, children and other high-risk households in Pakistan.

8. Policy Recommendations

Based on the evidence reviewed, the following measures are recommended:

1. Expand anticipatory action nationwide by extending effective provincial approaches to all high-risk districts, particularly rural Sindh, southern Punjab and Balochistan.

2. Establish a national heat-health database linking PMD forecasts with hospital admissions, heat-related illness and mortality records.

3. Develop permanent community cooling centres in high-risk urban and rural locations, supported by reliable water and electricity.

4. Protect outdoor workers through heat-risk thresholds, modified working hours, rest breaks, shade and access to drinking water.

5. Strengthen last-mile communication using SMS, WhatsApp, radio, local languages, schools and trained community volunteers.

6. Develop a vulnerable-person registry to allow direct assistance to high-risk individuals during extreme heat.

7. Ensure electricity and water continuity for hospitals and cooling centres during heatwave periods.

8. Improve evaluation systems by measuring illnesses, hospital admissions and deaths prevented rather than relying only on reach and activity indicators.

9. Include mental health in heatwave planning by monitoring psychological distress, sleep disruption, irritability and cognitive effects among vulnerable populations.

10. Strengthen inter-agency coordination among PMD, NDMA, PDMAs, health departments, district administrations, NGOs and private-sector service providers.

9. Conclusion

Pakistan has made a significant shift from responding to heatwaves after they occur towards taking action before extreme heat reaches its peak. The development of the Karachi Heatwave Management Plan, forecast-based financing, provincial SOPs and the NDMA Heatwave Guidelines 2024 shows that an anticipatory architecture is now developing at national and provincial levels.

The 2025 Start Ready activation further demonstrates that forecasts can be converted into practical action through pre-positioned finance, heatstroke camps, water distribution, awareness activities and trained frontline personnel. However, important challenges remain. Coverage is still uneven, permanent cooling infrastructure is limited, health data require improvement, outdoor workers remain highly exposed, and the psychological consequences of extreme heat are insufficiently measured.

International evidence, particularly from Ahmedabad, demonstrates that coordinated heat-health planning can save lives. Pakistan should therefore move towards a system that combines scientific forecasting, pre-arranged finance, community participation, local knowledge, strong health systems and technology.

The next stage should focus not simply on responding to heatwaves but on preventing their consequences. Most importantly, success should be measured by the illnesses and deaths prevented, the vulnerable people reached, and the resilience created before the next extreme heat event occurs.

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PARTICIPANT RESEARCH PAPER

The 2023 Türkiye and Syria Earthquakes: Risk, Resilience, Response and Lessons for Crisis Management

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Abstract

The 6 February 2023 earthquake sequence in southern Türkiye and northern Syria exposed the interaction between extreme seismic hazard, vulnerable construction, disrupted infrastructure, social inequality and institutional capacity. A moment magnitude 7.8 mainshock was followed about nine hours later by a magnitude 7.5 event, producing widespread collapse across a transboundary region already carrying major humanitarian burdens. This paper analyzes the disaster through an integrated risk perspective, using the attached presentation as its organizing foundation and corroborating it with assessments from the U.S. Geological Survey, the Government of Türkiye, the World Bank, the World Health Organization and United Nations agencies. It evaluates regional hazard, physical and social vulnerability, community resilience, scientific and institutional gaps, mitigation, early warning and policy priorities. The central finding is that earthquake losses were not determined by ground motion alone. They were amplified by weaknesses in the building stock, inconsistent enforcement, cascading lifeline failures, winter conditions, displacement and constrained humanitarian access in Syria. Effective resilience therefore requires risk-informed land use, independently verified construction quality, retrofitting of critical facilities, interoperable command arrangements, inclusive community preparedness and transparent recovery governance. The event demonstrates that plans create value only when they are exercised, resourced and translated into accountable implementation before impact.

Keywords: Earthquake risk; Türkiye; Syria; community resilience; disaster governance; build back better

Introduction

The 2023 Türkiye and Syria earthquakes constitute a defining modern crisis-management case because a severe natural hazard intersected with dense urban exposure, vulnerable buildings and a complex humanitarian environment. The attached presentation emphasizes response, recovery and lessons learned, including early international assistance, multi-agency coordination, critical-infrastructure restoration, volunteer engagement and the Türkiye Earthquakes Recovery and Reconstruction Assessment (TERRA). It also identifies recurring operational pressures: incomplete information, time constraints, heightened tempo, uncertainty, anxiety and the need for timely decisions (Zohaib Asghar, 2026). These observations provide a practical basis for examining why impacts became catastrophic and how future systems can reduce risk.

This paper applies the disaster-risk relationship in which hazard, exposure and vulnerability combine, while capacity and resilience moderate consequences. It does not treat the earthquake as a purely geophysical event. Instead, it considers the built environment, governance, health systems, displacement, public communication and recovery choices. The analysis is especially relevant to crisis-management engineers because it connects scientific evidence with command-center functions, operational coordination and long-term risk reduction.

Regional Context and Hazard Profile

Türkiye lies within a highly active tectonic setting shaped by the interaction of the Anatolian, Arabian and African plates. The 6 February rupture occurred near the East Anatolian Fault system and involved shallow strike-slip faulting. The U.S. Geological Survey recorded a magnitude 7.8 earthquake at 01:17 UTC, followed roughly nine hours later by a magnitude 7.5 earthquake about 90 kilometres to the north (USGS, 2023a; USGS, 2023b). The sequence ruptured a large fault area and was followed by extensive aftershock activity, sustaining danger to survivors, responders and already damaged buildings.

The affected geography extended across eleven provinces in southern and southeastern Türkiye and into northern Syria. The disaster crossed administrative and national boundaries, damaging housing, hospitals, schools, roads, airports, power systems, water networks and communications. Winter weather and the early-morning timing increased exposure during the initial hours. The World Bank estimated direct physical damage in Türkiye at US$34.2 billion, with residential buildings representing the largest share, while TERRA estimated total damages and losses and recovery needs at US$103.6 billion, equivalent to 9 percent of Türkiye’s forecast 2023 GDP (World Bank, 2023a; Government

of Türkiye, 2023). These figures distinguish direct asset damage from the broader resources required for recovery and resilience.

Northern Syria faced the same seismic shock under markedly different baseline conditions. Years of conflict had weakened services, displaced communities and fragmented access and governance. The World Bank's Syria assessment relied substantially on remote evidence because of access constraints, illustrating how data limitations can become part of disaster risk itself (World Bank, 2023b). Consequently, a common hazard produced differentiated consequences across localities.

Risk and Vulnerability Assessment

Physical vulnerability was concentrated in the building stock. Collapse risk depends on structural system, material quality, detailing, age, maintenance, site conditions and compliance throughout design and construction. The scale of residential damage indicates that code publication alone was insufficient. The presentation highlights construction amnesties and inconsistent implementation as governance concerns (Zohaib Asghar, 2026). Where non-compliant buildings remain occupied, regulatory exceptions can convert known seismic hazard into accumulated systemic risk.

Critical infrastructure created cascading vulnerabilities. Damage to hospitals reduced trauma capacity precisely when demand surged. Disrupted transport and airport access slowed rescue and relief, while failures in electricity, water and telecommunications constrained health care, shelter management and situational awareness. WHO reported damage to health facilities and prioritized trauma care, essential medicines, disease surveillance, mental-health support and continuity of services for vulnerable groups (WHO, 2023a). These interdependencies show why lifeline resilience must be assessed as a network rather than facility by facility.

Social vulnerability further shaped outcomes. Poverty, disability, age, gender-related needs, insecure tenure, language barriers and displacement influence warning access, evacuation choices, shelter suitability and recovery resources. In Türkiye, the affected provinces hosted a substantial refugee population; in northwest Syria, millions already depended on humanitarian assistance before the earthquakes (United Nations, 2023; World Bank, 2023a). Risk assessment must therefore map populations and service dependencies, not merely buildings. It should also protect personal data and avoid stigmatizing vulnerable groups.

Community Resilience Factors

Community resilience was visible in neighbour-to-neighbour rescue, volunteer mobilization, donations, local knowledge and the rapid activation of national and

international assistance. The presentation identifies mukhtars, provincial centers, the national disaster center, security services and international partners as elements of the response network (Zohaib Asghar, 2026). Such relationships can accelerate needs identification and resource distribution when formal systems are overloaded.

However, spontaneous capacity requires structure. Volunteers need safe tasking, registration, protective equipment, supervision and clear handover arrangements. Trusted local leaders can validate information, identify isolated households and support culturally appropriate communication. Resilience also depends on social infrastructure: schools, clinics, community organizations, local businesses and faith-neutral humanitarian networks. Recovery that involves affected residents in housing, livelihood and service decisions is more likely to retain trust and address actual priorities. TERRA's principles stress participation, inclusion, disaster-risk reduction, sustainability and building back better (UNDP, 2023).

Scientific and Institutional Gaps

A key scientific gap is the conversion of hazard knowledge into building-level action. Seismic maps and fault studies identify regional danger, but decision makers also need current exposure inventories, structural vulnerability data, micro zonation, rapid damage indicators and accessible aftershock guidance. USGS emphasizes that aftershock forecasts describe likely scenarios rather than predict the exact time, place and magnitude of an individual event (USGS, 2023a). Risk communication must preserve this distinction to avoid false certainty.

Institutional gaps included uneven enforcement, difficult coordination across jurisdictions, information fragmentation and limited visibility of needs in inaccessible areas. Multiple agencies may collect incompatible datasets or use different operating pictures. Under severe time pressure, unclear authority and unverified information can delay priorities. The solution is not a single database alone, but agreed data standards, common operating procedures, interoperable communications, trained liaison officers and recurring multi-agency exercises. Independent review is also necessary so that lessons identified become funded corrective actions rather than archived reports.

Mitigation Strategies and Best Practices

The first priority is to prevent collapse. Authorities should maintain risk-based inventories, inspect high-occupancy and essential facilities, retrofit deficient structures and enforce codes through independent design review, site inspection and material testing. Schools, hospitals, emergency operations centers, bridges, water facilities and communications hubs should meet enhanced performance objectives. Land-use planning should account

for fault rupture, liquefaction, landslide and access constraints, while utilities should incorporate redundancy, sectional isolation and backup power.

Preparedness must remain actionable. Scenario-based exercises should test nighttime staffing, winter conditions, mass-casualty flows, damaged communications, cross-border assistance and sustained aftershocks. Urban search and rescue arrangements need pre-identified staging areas, logistics routes and international reception procedures. Community programs should include household safety, safe evacuation, reunification planning and first aid. Recovery should follow build-back-better principles without creating unsafe speed incentives. Damage and needs assessments such as GRADE and TERRA provide baselines for prioritization, but projects should be tracked through transparent milestones, engineering assurance and public reporting (World Bank, 2023a; Government of Türkiye, 2023).

Risk Communication and Early Warning

Earthquake early warning cannot predict an earthquake; it can detect an event after rupture begins and potentially provide short notice before strong shaking reaches more distant locations. Its value increases when alerts trigger predefined actions such as stopping trains, opening fire-station doors, isolating hazardous processes and prompting people to drop, cover and hold on. Because available warning may be only seconds and may be absent near the epicentre, structural safety and preparedness remain primary.

Crisis communication should be fast, authoritative, multilingual, accessible and consistent across government, media, telecom operators and community channels. Messages should state what is known, what remains uncertain, what action is required and when the next update will occur. Aftershock messages must discourage entry into damaged buildings and provide clear inspection pathways. Rumour monitoring should support correction without suppressing legitimate concerns. Command centers should publish verified geospatial information, shelter and health-service availability, road status and missing-person processes while safeguarding sensitive data. Redundant channels, including cell broadcast, radio, satellite links, sirens and local messengers, are essential when power or networks fail.

Policy Recommendations

1. Establish independently audited seismic-safety programs that link occupancy permits to verified design, construction and inspection records, and prohibit regularization mechanisms that bypass life-safety requirements.
2. Create prioritized, funded retrofit portfolios for hospitals, schools, emergency facilities and lifeline networks, using transparent risk criteria and completion dashboards.

3. Develop interoperable national and provincial common operating pictures with standardized damage, needs, resource and casualty data, supported by resilient communications.
4. Institutionalize recurring multi-agency exercises and corrective-action programs, assigning each lesson an owner, budget, deadline and verification method.
5. Expand inclusive community preparedness through municipalities and trusted local leaders, with multilingual and accessible materials for refugees, older people and persons with disabilities.
6. Integrate early warning with automated protective actions and public education, while clearly communicating its limitations.
7. Apply build-back-better, green debris management, livelihood restoration and community participation to recovery, with independent engineering and financial oversight.
8. Strengthen regional scientific cooperation on fault monitoring, microzonation, building performance and open risk data, including mechanisms for evidence collection in access-constrained areas.

Conclusion

The Türkiye-Syria earthquake sequence demonstrates that catastrophic loss emerges when severe shaking meets vulnerable structures, fragile lifelines and unequal social conditions. The response mobilized substantial national, local, volunteer and international capacity, yet the scale of collapse and disruption exceeded normal systems and exposed coordination, information and implementation gaps. Syria’s pre-existing humanitarian emergency intensified those constraints.

The principal lesson for crisis management is that resilience is an implementation discipline. Codes must be enforced, infrastructure must perform, command arrangements must be exercised, information must be interoperable and communities must be included before disaster. Early warning and communication can reduce selected consequences but cannot compensate for unsafe buildings. Recovery offers an opportunity to reduce future risk only when speed is balanced with engineering assurance, transparency and participation. Continuous organizational learning should therefore connect after-action findings to accountable investment, ensuring that the lessons of 2023 become measurable improvements rather than recommendations alone.

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PARTICIPANT RESEARCH PAPER

RIVERINE FLOODING ALONG THE INDUS

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Abstract

Riverine flooding along the Indus is a major disaster risk for Pakistan, with Sindh particularly exposed because it lies at the bottom of the Indus basin on almost flat, low-lying terrain. The river flows on a ridge above the surrounding plain, so when protective embankments breach, floodwater can spread across the floodplain and may not readily drain back into the river. The 2022 floods provide a critical case study. The event followed unusually heavy monsoon rainfall from mid-June through October; the presentation reports rainfall roughly 4.5 times normal across Sindh and Balochistan and about 726% above average in Sindh during August. Glacial and snowmelt further compounded pressure on the Indus system. Sindh recorded 12,356,860 people affected, 1,003 lives lost, 8,422 injuries, 2,087,186 houses damaged, 436,435 livestock lost and 7,383,023 people displaced. This paper examines the geographic and physical mechanisms of riverine flooding, the 2022 Sindh experience, root causes, vulnerability, community resilience, scientific and institutional gaps, mitigation, early warning and policy options. It argues for integrated flood-risk management combining stronger embankments, improved drainage, better early warning, risk-informed floodplain land use, community participation and climate adaptation.

Keywords: Climate Change; Disaster Risk Reduction; Early Warning; Indus River; Riverine Flooding

1. Introduction

The Indus River system is fundamental to Pakistan's geography, agriculture, water management and settlement patterns. At the same time, the river creates a substantial flood hazard for communities living on and around its floodplain. The presentation identifies the Indus basin as draining approximately 970,000 km² and highlights Sindh's 1,400 miles of flood-protection embankments and three major barrages—Guddu, Sukkur and Kotri—as important components of the regional flood-risk system. Sindh's downstream position, nearly flat terrain and the elevation of the river above parts of the surrounding plain make the province particularly exposed.

Riverine flooding occurs when river discharge exceeds the capacity of the channel and associated protection systems, allowing water to overtop or breach embankments and spread onto surrounding land. Along the Indus, the process can be intensified by heavy monsoon rainfall, glacial and snowmelt, barrage and levee pressure, hill torrents, weak drainage and settlement within the active floodplain. The 2022 floods demonstrate how these factors can interact rather than operate independently.

The purpose of this research is to analyze riverine flooding along the Indus using the 2022 floods in Sindh as a case study. The objectives are to explain the hazard mechanism and geographic context; assess social, economic and physical vulnerability; examine community resilience and institutional response; identify scientific, technological and governance gaps; and propose mitigation, early-warning and policy measures.

2. Regional Context & Hazard Profile

The Indus system is shaped by monsoon rainfall as well as snow and glacier melt from the Himalayan and wider mountain catchment. The presentation notes that Pakistan's 7,200+ glaciers feed the Indus and identifies warming as a factor that can accelerate melt. Heavy and sustained rainfall over the upland catchment raises inflow, while extreme rainfall directly over Sindh and Balochistan can add further water to an already stressed landscape. Hill torrents from Balochistan can also add pressure before the Indus reaches the Arabian Sea.

Rising discharge is funnelled through Guddu, Sukkur and Kotri barrages, where backwater effects can raise river levels upstream. Under high flood pressure, protective embankments can breach, releasing water onto the floodplain. Because Sindh has an extremely low gradient and the river flows on a ridge above the surrounding plain, floodwater can spread widely and remain for weeks or months when drainage is inadequate.

The 2022 event began with unusually heavy monsoon rainfall from mid-June through October. The presentation identifies atmospheric rivers as contributing additional moisture and reports rainfall roughly 4.5 times normal across Sindh and Balochistan, with Sindh receiving approximately 726% more rainfall than average in August 2022. Rain fell on already saturated soil after a wet July, while glacial melt added further volume. The presentation timeline places flooding from 14 June 2022, peak rainfall in August, widespread inundation by late August, national recession beginning in October, and standing water persisting in parts of Sindh into March 2023 and beyond.

Source: PDMA Sindh Risk Matrix

Simplified Flood Risk Matrix

Risk Driver	Exposure	Potential Impact	DRR Priority
Heavy monsoon rainfall	Settlements and farmland	Inundation and displacement	Forecasting and evacuation
Glacial/snow melt + high flow	Indus floodplain	High river levels	River monitoring and coordination
Barrage/backwater effects	Areas near control points	Concentrated pressure	Hydrological monitoring
Embankment breach	Floodplain communities	Sudden inundation	Inspection and reinforcement
Flat terrain + weak drainage	Low-lying areas	Long-duration waterlogging	Drainage rehabilitation
Informal floodplain settlement	Households and infrastructure	High exposure	Risk-informed land use

3. Risk & Vulnerability Assessment

The scale of the 2022 Sindh disaster demonstrates the province's high exposure. The presentation records 12,356,860 people affected, 1,003 lives lost, 8,422 injuries, 2,087,186 houses damaged, 436,435 livestock perished and 7,383,023 people displaced.

These figures show that flood risk extends beyond temporary inundation to housing, mobility, livelihoods, household assets and community stability.

Agriculture and livestock are particularly vulnerable because rural livelihoods depend heavily on land, animals, irrigation and market access. Flooding can remove both immediate income and the productive assets required for recovery. Prolonged standing water can delay cultivation and restrict access to markets, while damaged roads and drainage systems prolong disruption.

The presentation identifies weak drainage infrastructure as a major reason floodwater remains for extended periods, increasing disease and livelihood risks. Embankment and levee failures can cause severe impacts because they rapidly release water into settlements and agricultural areas. Barrage backwater effects can further concentrate pressure at vulnerable points. Informal settlement and cultivation within active floodplains increase the population and assets exposed.

Gender and social vulnerability must also be considered. Women, children, older people and persons with disabilities may face additional barriers in receiving warnings, evacuating and accessing relief. Gender-responsive preparedness should include women's participation in local planning, accessible warnings, safe shelters, protection measures and livelihood recovery.

4. Community Resilience Factors

Communities living along the Indus possess practical knowledge of seasonal water behaviour, local flood routes, embankment conditions and safe locations. This knowledge can complement technical forecasts. Social networks can support evacuation, food and water sharing, identification of vulnerable households and information dissemination when formal systems are disrupted.

Community participation is especially important because conditions vary between districts and settlements. Local volunteers and focal persons can translate technical warnings into practical actions. Participatory mapping can identify evacuation routes, shelters, critical facilities and households needing additional support. However, prolonged inundation and loss of livelihoods can overwhelm local coping capacity. Community resilience should therefore be strengthened alongside, not instead of, government preparedness and response systems.

5. Scientific & Institutional Gaps

Effective Indus flood management requires reliable rainfall, river-flow, embankment, elevation, exposure and infrastructure data. The presentation highlights PMD early warning, pre-positioning, embankment inspection, daily situation reports, evacuation

coordination, damage assessment and reconstruction as parts of the response architecture. Connecting these components is essential because a forecast is valuable only when it leads to timely action.

GIS, satellite-based monitoring, hydrological and hydraulic modelling can improve inundation mapping and forecasting. Artificial intelligence and machine learning may assist forecasting and rapid damage assessment where quality-controlled data exist, but these technologies should complement hydrological expertise and field verification. Stronger coordination among NDMA, PDMA Sindh, forecasting agencies, irrigation departments, district administrations and communities can reduce delays and improve preparedness.

6. Mitigation Strategies & Best Practices

Structural mitigation should begin with systematic inspection and reinforcement of embankments at historically weak points before each monsoon season. Drainage is another major priority: rehabilitation of irrigation and drainage networks can shorten inundation periods. These measures should be supported by regular maintenance rather than emergency repair alone.

Non-structural measures should include floodplain land-use management, preparedness training, evacuation planning, risk communication and community awareness. The presentation specifically recommends regulating settlement and cultivation within the active floodplain. Risk-informed planning is essential because reducing exposure can prevent losses that engineering measures alone cannot eliminate.

Climate adaptation should be integrated into infrastructure and recovery programmes. Future planning should account for the possibility of changing rainfall and hydrological extremes and should apply Build Back Better principles so that reconstruction reduces future risk.

7. Risk Communication & Early Warning

The presentation identifies PMD early warning as a key pre-flood action and recommends stronger integration with district-level situation reports. A people-centred warning system should move from forecast to action: communities need to know what is happening, where the danger is, when it may occur and what they should do.

Warnings should use multiple channels because electricity, internet and mobile connectivity can fail. SMS and mobile alerts can be combined with radio, local volunteers, mosque announcements, community leaders and district officials. Messages should be clear, localised and action-oriented. Last-mile communication is essential in rural Sindh,

and warning plans should identify focal persons, evacuation routes, transport arrangements and shelters before the monsoon.

8. Policy Recommendations

1. Strengthen embankment inspection, maintenance and reinforcement before every monsoon, prioritizing historically weak points.
2. Rehabilitate drainage and irrigation networks to reduce the duration of standing water.
3. Integrate PMD forecasts with district-level situation reports, evacuation triggers and community warning networks.
4. Manage settlement and cultivation within active floodplains through risk-informed land-use planning.
5. Establish integrated Indus-basin data systems linking rainfall, river levels, inundation maps and exposed populations.
6. Expand GIS, remote sensing and validated modelling for forecasting, mapping and damage assessment.
7. Develop responsible AI/ML applications where data quality permits, with human oversight.
8. Institutionalize community participation through drills, local flood mapping and volunteer networks.
9. Make flood preparedness and recovery gender-responsive, including safe shelters and women's participation.
10. Apply Build Back Better principles to reconstruction so that repaired infrastructure reduces future flood risk.

9. Conclusion

Riverine flooding along the Indus is a structural disaster risk shaped by extreme rainfall, snow and glacier melt, river discharge, barrage pressure, embankment performance, flat terrain, drainage limitations and human settlement. The 2022 Sindh floods demonstrate the scale that this risk can reach when multiple drivers occur together. The presentation's evidence shows millions affected and displaced, extensive housing damage, livestock losses and prolonged inundation.

The central lesson is that flood risk cannot be managed through emergency relief alone. Stronger embankments and drainage are necessary, but they must be combined with floodplain land-use management, reliable scientific information, people-centred early warning, institutional coordination and community participation. Climate adaptation

should be integrated into this system so that future investments are resilient to changing extremes.

Building resilience along the Indus requires a continuous disaster-risk-management cycle: understand the hazard, reduce exposure, lower vulnerability, prepare communities, act on warnings, respond effectively and recover in ways that reduce future risk.

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PARTICIPANT RESEARCH PAPER

Urban Flooding in Karachi: Causes, Governance Gaps, and a Framework for Sustainable Resilience

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Abstract

Karachi, Pakistan's largest city and principal economic hub, faces recurring and increasingly severe urban flooding driven by intensifying monsoon rainfall, an aging and undersized drainage network, unplanned urbanization, and chronic solid waste mismanagement. This paper examines the structural, environmental, and institutional drivers of flood risk in Karachi through the lens of the disaster management cycle and the Sendai Framework for Disaster Risk Reduction 2015–2030, situating the analysis within Pakistan's National DRR Policy 2025–2030. Drawing on the record-breaking 223.5mm single-day rainfall of August 2020 and the catastrophic 2022 floods that affected Sindh province nationally, the paper argues that fragmented governance rather than rainfall intensity alone is the principal root cause of Karachi's flood vulnerability. It assesses socio-economic and public health impacts, community resilience capacities, and scientific and institutional gaps, before proposing a layered mitigation framework spanning grey infrastructure, nature-based solutions, waste management, and governance reform. The paper concludes with evidence-based policy recommendations, including the establishment of a unified metropolitan flood authority, mandatory pre-monsoon desilting with public reporting, and expanded community-based early-warning systems, to support the transition from reactive emergency response toward sustained, institutionally anchored flood resilience.

Keywords: Climate Change Adaptation; Disaster Risk Reduction; Governance Fragmentation; Sendai Framework; Urban Flooding.

1. Introduction

Karachi is home to more than 20 million people and generates approximately one-fifth of Pakistan's Gross Domestic Product, making it the country's single most economically consequential urban centre (Pakistan Bureau of Statistics, n.d.). Over recent decades, rapid and largely unplanned urban expansion has outpaced the capacity of the city's drainage infrastructure, much of which was designed decades ago for a far smaller population. At the same time, the monsoon has grown more erratic, delivering intense rainfall in short bursts rather than sustained spells, most visibly during the record-setting 223.5mm downpour of 28 August 2020. The convergence of these pressures has transformed seasonal rainfall into a recurring disaster with severe human, economic, and public health consequences.

The problem this paper addresses is not simply meteorological: it is the interaction between climatic hazard, urban vulnerability, and institutional capacity. The purpose of this research is to critically examine the causes and consequences of urban flooding in Karachi and to identify evidence-based, institutionally grounded solutions relevant to disaster risk management. Its objectives are threefold: to characterize the hazard, vulnerability, and capacity dimensions of flood risk; to diagnose the governance gaps that perpetuate recurring flood losses; and to propose short- and long-term mitigation and policy measures. The scope is confined to urban flooding within Karachi, with the 2022 Sindh floods used as a comparative case to illustrate recurring structural drivers.

2. Regional Context and Hazard Profile

Karachi is a low-lying coastal megacity on the Arabian Sea, exposed to both monsoonal rainfall and coastal hazards such as sea-level rise and storm surge in its low-lying wards. In disaster risk terminology, hazard refers to a potentially damaging physical event, such as intense rainfall; exposure denotes the people, property, and systems situated in hazard-prone locations; vulnerability describes the conditions that increase susceptibility to harm; and risk is the resulting potential for loss, understood as a function of hazard, exposure, and vulnerability interacting with the capacity to cope and adapt.

Historically, Karachi's flood profile has escalated in severity. The August 2020 event, in which the city recorded 223.5mm of rainfall within 24 hours surpassing the previous 1967 record caused over 40 deaths and weeks of standing water in low-lying wards. Two years later, the 2022 Pakistan floods affected 33 million people nationwide, with Sindh province bearing roughly 70 percent of national damages and losses, national damages estimated

at USD 14.9 billion, and an estimated GDP contraction of about 2.2 percent (Government of Pakistan, Asian Development Bank, European Union, UNDP, & World Bank, 2022). Taken together, these events indicate an intensifying trend consistent with broader regional climate projections for South Asia's monsoon variability.

3. Risk and Vulnerability Assessment

Karachi's flood risk is best understood as the product of hazard, vulnerability, and capacity acting together, rather than rainfall intensity alone. On the hazard side, erratic and intensifying monsoon rainfall, record-breaking single-day totals, and sea-level rise in coastal wards combine to produce increasingly severe flood triggers. Vulnerability is concentrated among informal settlements (katchi abadis) built directly along storm water channels, high-density and low-lying wards with limited natural absorption, and populations lacking secure tenure or infrastructure. Capacity, meanwhile, remains thin: drainage systems designed decades ago for a much smaller population, chronically under-resourced desilting programs, and only emerging community-based early-warning pilots partially offset by Pakistan Meteorological Department (PMD) forecasting and NDMA's National Emergency Operations Centre.

The socio-economic consequences of this risk profile are wide-ranging. Economically, flooding damages property, industry, and transport networks, disrupting supply chains and port operations in a city that anchors roughly one-fifth of national GDP. Livelihoods are disrupted through business interruption and the destruction of informal-sector assets, disproportionately affecting low-income households. Public health impacts include waterborne disease outbreaks, mosquito-borne illness, and disrupted access to healthcare facilities in the aftermath of flooding. Infrastructure damage extends to collapsed roads, power outages from waterlogged substations, and damaged public transit. Socially, flooding drives displacement of low-income households, school closures, and disproportionate impact on residents of informal settlements, who typically have the least capacity to relocate or recover. Gender dimensions compound these vulnerabilities: women and girls in displaced or flood-affected households often face heightened risks related to safety, healthcare access, and loss of livelihood activities conducted from the home, underscoring the need for gender-sensitive response and early-warning design.

4. Community Resilience Factors

Despite thin institutional capacity, community-level resilience factors offer a foundation to build upon. Social capital and community networks in Karachi's neighborhoods often provide the first line of response during flood events, including informal mutual aid, shared transport, and information exchange well before formal agencies mobilize.

Emerging community-based early-warning pilots, which disseminate alerts through local networks and mobile messaging, demonstrate the potential of grassroots participation to complement formal forecasting systems. Indigenous and locally accumulated knowledge of flood-prone areas, seasonal rainfall patterns, and effective short-term coping mechanisms such as elevating household assets or coordinating localized drainage clearance further strengthens community capacity. However, these resilience assets remain informal, unevenly distributed, and disconnected from municipal planning, meaning their impact is currently limited to localized coping rather than systemic risk reduction.

5. Scientific and Institutional Gaps

The most significant obstacle to reducing Karachi's flood risk is institutional fragmentation. Responsibility for drainage and storm water management is dispersed across at least six agencies including NDMA at the federal level, the Provincial Disaster Management Authority (PDMA) Sindh, the Karachi Metropolitan Corporation (KMC), District Municipal Corporations (DMCs), the Karachi Water and Sewerage Corporation (KWSC), and the Sindh Irrigation Department with no single body holding end-to-end accountability from planning through early warning to response. Post-flood assessments repeatedly identify this fragmentation, rather than rainfall alone, as a recurring root cause of flood losses.

Compounding this governance gap are scientific and data-related shortfalls: annual desilting is often budgeted but rarely completed before monsoon onset, and no public reporting mechanism exists to track progress or hold agencies accountable. Zoning enforcement along waterways remains weak, allowing encroachments to persist once informal settlements take hold. Adoption of modern technologies such as AI/ML-based flood forecasting and hazard modelling remains nascent relative to the scale of exposure, and inter-agency data-sharing on drainage capacity, encroachment mapping, and real-time rainfall is limited. These combined gaps constrain evidence-based planning and undermine the effectiveness of otherwise sound engineering and policy interventions.

6. Mitigation Strategies and Best Practices

Addressing Karachi's flood risk requires a layered approach combining structural and non-structural measures. Grey infrastructure interventions include upgrading and desilting storm water drains, enforcing rights-of-way along waterways, and installing modern pumping stations at chronic flood spots. Nature-based solutions restoring wetlands, expanding urban green cover, and reinstating permeable surfaces can absorb peak runoff and reduce reliance on engineered drainage alone. Waste and sanitation

measures, including reliable solid waste collection and enforcement against dumping in nullahs (storm water channels), directly reduce blockages that exacerbate flooding during peak rainfall. Governance and policy measures, including a unified flood-risk authority, updated building codes, and functioning early-warning systems, provide the institutional backbone without which structural investments underperform.

A short-term versus long-term framing helps sequence these measures. In the short term (0–2 years), priorities include pre-monsoon desilting of major and secondary nullahs, rapid-response pumping stations for chronic flood spots, community-based early-warning alerts via SMS and local networks, and temporary relocation and relief planning for high-risk informal settlements. In the long term (3–10+ years), priorities shift to a master drainage plan redesigned for current and projected rainfall intensity, legal protection and restoration of natural waterways and wetlands, an empowered unified metropolitan flood authority, and climate-resilient building codes with incentives for permeable urban design. International and national best practices in integrated urban drainage management and nature-based flood defense, documented in post-disaster needs assessments and DRR policy literature, support the feasibility of this layered approach when institutional commitment is sustained.

7. Risk Communication and Early Warning

Effective risk communication and early warning are essential to reducing loss of life and enabling timely response. Currently, PMD forecasting and NDMA's National Emergency Operations Centre provide the formal backbone of flood forecasting, but last-mile communication to high-risk, often informal, settlements remains inconsistent. People-centred and gender-sensitive early-warning systems which account for differences in access to mobile technology, literacy, and mobility among women, children, and marginalized groups are needed to ensure warnings translate into effective protective action. Community engagement in the design and dissemination of alerts, including through trusted local networks rather than solely top-down channels, increases the likelihood that warnings are understood, trusted, and acted upon. Expanding SMS-based and community-network alert systems, building on existing pilot programs, represents a cost-effective near-term step toward closing this last-mile gap.

8. Policy Recommendations

Building on the diagnosis above, four priority policy actions are recommended, drawing on the demonstrated need for integrated governance, evidence-based measures, and technology integration:

- Institutionalize a single, empowered metropolitan flood authority under the Government of Sindh and KMC within one to two years, with a legal mandate and dedicated budget line, to close the end-to-end accountability gap identified in the governance diagnosis.
- Mandate annual pre-monsoon desilting, led by PDMA Sindh, KMC, and DMCs, with public reporting of the percentage of nullahs desilted before each monsoon, to create transparency and accountability currently absent from the system.
- Integrate nature-based buffers restored wetlands and green corridors into the metropolitan master plan over a three-to-five-year horizon, led by the Sindh Planning and Development Department and KMC, measured by hectares of habitat restored.
- Expand community-level early-warning systems in high-risk informal settlements within one to two years, coordinated by NDMA, PDMA Sindh, and NGO partners, tracked by the number of settlements covered by SMS or alert networks.

These recommendations are deliberately structured around clear responsible authorities, timeframes, and measurable success indicators, consistent with the Sendai Framework's emphasis on strengthening disaster risk governance and investing in disaster risk reduction for resilience.

9. Conclusion

Urban flooding in Karachi is not a single meteorological event but the cumulative outcome of intensifying climatic hazard, concentrated vulnerability, and fragmented institutional capacity. The evidence from the 2020 and 2022 flood events demonstrates that the same structural drivers undersized drainage, encroachment on waterways, and weak inter-agency coordination recur regardless of whether the trigger is a single extreme-rainfall day or a season-long monsoon. Addressing this challenge sustainably requires combining immediate engineering fixes with long-term ecological restoration, community resilience building, and institutional reform, anchored in the Sendai Framework and Pakistan's National DRR Policy 2025–2030. Ultimately, coordination not rainfall alone determines whether Karachi floods, and it is coordination that must be the focus of sustained policy commitment going forward.

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PARTICIPANT RESEARCH PAPER

Climate Change and Emerging Public Health Risks in Pakistan: Disaster Management Perspectives

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Abstract

The public health challenges resulting from climate change are becoming more pronounced in Pakistan through increased heat waves, flooding, changes in vector-borne disease distribution, air pollution, and climate-induced displacements. This paper will explore the topic through the lens of disaster risk reduction such as: 2022 floods that affected 33 million people, caused at least 1,000 deaths, destroyed 888 health facilities, and saw a rise in malaria by fivefold to 2.6 million; 2015 Karachi heatwave where people were subjected to seventeen times the normal risk of dying from heat; the spread of dengue infection in areas where transmission was not feasible earlier due to rising temperatures; Lahore smog that has led to a significant increase in cases of asthma, bronchitis, and COPD; and the psychological distress experienced after the floods, where a study in Khyber Pakhtunkhwa found 96% of those surveyed suffered from PTSD. The research results indicated that there has been reactive disaster management and health systems in Pakistan as opposed to anticipatory, characterized by incomplete data, inadequate health integration in early warning systems and weak coordination between NDMA, PDMA and the health sector. Recommendations of the paper include the incorporation of health monitoring in early warning systems, better preparation for heat-health and vector control, water and sanitation preparedness, and the inclusion of mental health services in disaster response and adaptation efforts.

Keywords: Climate Change; Disaster Risk Reduction; Pakistan; Preparedness; Public Health

1. Introduction

The phenomenon of climate change is no longer restricted to ecological damage but is itself directly responsible for creating public health crises in vulnerable nations like Pakistan. Higher temperatures, unpredictable monsoons, frequent floods, and poor air quality have begun to influence the pattern of disease experienced by people in Pakistan, putting immense pressure on their already scarce health facilities. Heat-related illnesses, malaria, dengue, post-flood waterborne disease, respiratory and heart disease from smog, and post-disaster stress are all becoming more and more common outcomes.

The problem that this paper attempts to tackle is the existence of a structural misalignment whereby Pakistan's disaster management infrastructure is well developed for physical hazards and has always considered public health, specifically mental health, as a supplementary issue after the occurrence of a hazard event and not as an integral aspect of preventive measures for risks. In both the 2015 Karachi heat wave and 2022 flood events, it has been observed that the health centers become non-operational during the period of peak demand. This study's rationale is based on the fact that in order to fill this gap, it is necessary to bring all the relevant evidence from the literature from different areas such as meteorology, disaster management, and public health together to conduct a comprehensive analysis.

The purpose of this research is to understand how climate change is increasing the public health vulnerabilities of Pakistan and how their disaster management system is designed in anticipation of these threats instead of reacting after they occur.

Objectives

- To identify the major climate-related hazards affecting public health in Pakistan.
- To examine the documented health impacts of these climate-related hazards.
- To assess gaps in Pakistan's preparedness and disaster management for climate-related health risks.
- To recommend measures to strengthen health preparedness and disaster risk reduction in Pakistan.

The scope of the study includes national-level climate-health trends in Pakistan between the years 2015 and 2024, specifically examining floods, heatwaves, vector-borne

disease, air pollution, and the effects on mental health resulting from these phenomena, using academic literature and official reports from WHO and governments.

2. Regional Context & Hazard Profile

The geographical layout of Pakistan, with glaciated northern mountains, the plains of the Indus Basin, and the arid south, leaves the country's populace vulnerable to climate-related diseases. Riverine and flash floods lead to waterborne and vector-borne disease outbreaks; heat waves in Sindh and southern Punjab cause heat stroke and cardiac arrest cases; and wintertime inversions result in smog due to pollutants trapped above Lahore and other cities in Punjab. Climate projections used in modeling have shown that the suitability for vector-borne disease is changing: the dengue disease spots in Karachi, Lahore, and Peshawar will continue to be suitable in the future, while new areas like Kotli, Muzaffarabad, and Drosh that have not seen dengue disease previously will see it emerge in the 2020s, while Quetta, Zhob, and Garhi Dopatta are predicted to become suitable in the 2050s (Saeed et al., 2022).

This paper adopts the World Health Organization's long-standing definition of health, which extends beyond the mere absence of disease to encompass complete physical, mental, and social well-being (WHO, 1946). It is on this premise that the inclusion of psychological risks, such as post-traumatic stress disorder, anxiety, and depression, among physical diseases will be discussed in this risk assessment. To understand climate-health risk, however, the concepts of hazard, exposure, vulnerability, and risk must be differentiated. A hazard refers to the occurrence of any climate-related event which is likely to cause harm to the health of individuals, including events like heat wave, flooding, or pollution events. Exposure is defined as the presence of individuals, especially outdoor workers, the elderly, children, and the sick, in locations exposed to hazards. Vulnerability in Pakistan varies across geography; Sindh and southern Punjab have high mortality risk due to heat stress, the Indus Valley floodplains have high morbidity risk after disasters, and the urban centers in Punjab are vulnerable to risks related to air pollution. Climate-related risk is defined by the relationship between hazard, exposure, and vulnerability, as exemplified by the heatwave that struck in 2015 and floods in 2022 in Pakistan. The increasing burden of dengue in Pakistan is also associated with climate change (Abid & Abid, 2022; Saeed et al., 2022).

3. Risk & Vulnerability Assessment

Climate risks give rise to compound health emergencies, and the floods of 2022 serve as a case in point. The regional office of the World Health Organization (WHO) reports that the floods affected 33 million people spread over 116 districts with 66 worst-hit; 1,000

fatalities, 1,500 injuries, and 161,000 displacements into relief camps were reported (WHO, 2022a). In the post-floods analysis, it was found that about 13% of the total health infrastructure had been either damaged or destroyed, and about 15% of the population lost their access to primary and secondary healthcare while malaria infections soared to almost five times to reach 2.6 million patients (Akhtar & Reid, 2024). In another cross-sectional study in Khyber Pakhtunkhwa flood-affected districts, 83.4 percent reported that they had experienced illness or disability due to floods against 16.4 percent previously while 92.8 percent perceived that floods had impacted their health and sanitation conditions (Khan et al., 2024).Widely reported waterborne and vector borne diseases like cholera, diarrhea, leptospirosis, and hepatitis, as well as others were seen because of the collapse in the sanitation infrastructure due to the floods (Manzoor & Adesola, 2022). In fact, disease surveillance was weak before the floods, since there were reports of 4,531 cases of measles and 15 cases of poliovirus infection in Pakistan, prior to the floods (WHO, 2022a).

Heatwaves are a recurrent acute danger. According to an epidemiological investigation of death certificate data from hospitals and clinics during the 2015 Karachi heat wave event, residents experienced about seventeen times the typical likelihood of dying from heat than the same period in the previous year (Ghumman & Horney, 2016), and with maximum risks being higher among less affluent and uneducated populations. There is a geographical expansion of vector-borne disease; according to a geographical study that uses downscaled projections, existing dengue disease hotspots, like Karachi, Lahore, and Peshawar, will remain while new high-altitude districts will become suitable (Saeed et al., 2022). Further, air pollution exacerbates these threats. For instance, according to a recent study of the 2024 smog season in Lahore, there was a dramatic increase in the number of people diagnosed with asthma at hospitals, from 12.5 percent to 28.7 percent; bronchitis increased from 10.1 percent to 22.3 percent; COPD cases went up from 4.9 percent to 12.1 percent, while PM2.5 levels rose by almost three times, from 60.5 $\mu g/m^3$ to 180.3 $\mu g/m^3$ (Malik et al., 2024).Outdoor workers, women, children, elderly people, and informal settlement dwellers always suffer the greatest exposures to hazards and weakest resilience capacities.

The impact of disasters on vulnerable groups is further exacerbated by livelihoods and gender aspects. In the context of the 2022 floods in the country, WHO has highlighted that pregnancy-related challenges among women in displacement camps were mainly due to the unavailability of adequate delivery services and safe drinking water (WHO, 2022a). In addition, shocks to livelihoods and food security are also common: the Khyber

Pakhtunkhwa flood impact assessment has shown that 48.7 percent of the respondents lost their income sources due to floods, 22.6 percent experienced difficulty in accessing food, and almost 40 percent had become homeless (Khan et al., 2024). Loss of health infrastructure and long-term hospitalisation have also added to poverty due to catastrophic expenditures on healthcare. Such consequences of disasters are not gender-neutral; one can refer to a national study which shows that people affected by 2010 floods in Pakistan demonstrated post-traumatic stress symptoms even after almost three years, with the prevalence being significantly higher for females and unemployed individuals (Aslam & Kamal, 2016).

Natural disasters also impose a heavy burden of mental disorders which has been largely overlooked. Research among survivors of floods in Pakistan has found high instances of posttraumatic stress, anxiety, and depression, where a study conducted among 270 flood survivors in the province of Khyber Pakhtunkhwa found 96 percent of the participants to exhibit signs of PTSD, with no gender differences found (Iqbal & Sial, 2023). This is in line with an earlier observation regarding higher PTSD prevalence after floods in the national sample (Aslam & Kamal, 2016). The situation is made worse by the lack of capacity, as Pakistan currently only has a few thousand practicing psychiatrists compared to its population of over 230 million, making it difficult for those displaced by floods and heatwaves to access any professional psychological services. A disaster management plan that focuses exclusively on the physical safety of the people concerned is thus missing out on caring for an important health outcome of the disaster.

4. Community Resilience Factors

Resilience at the community level will always come first in defending against climate and health hazards, especially in cases where the health infrastructure is not well established. Social networks, mosques announcements, and non-government organizations like the Edhi Foundation constantly bridged the gap in the case of the 2015 heatwave through body recovery and emergency transportation. The provincial response, including the prohibition on taking leaves for health personnel by Sindh, heatstroke wards, and SOPs for Upper, Central, and Lower Sindh by PDMA Sindh considering the different thermal regions of the region, reveals a new but partial form of institutionalized preparedness model (PDMA Sindh, 2024). Coping strategies by indingenous groups, such as flexible working hours, do not often align with scientific advice. Moreover, community involvement in local health emergencies is also very limited.

Table 1. Community Resilience Factors for Climate-Related Health Risks in Pakistan

Resilience Factor	Current Situation	Recommended Improvement
Social capital and charitable networks	Active but informal (e.g., Edhi Foundation, mosque networks)	Formalize in district-level emergency health response plans
Heatstroke/emergency wards	Established reactively during alerts (Sindh, Punjab)	Have permanent heat-health teams stationed seasonally
Indigenous coping knowledge	Present but undocumented	Coordinate with PMD/NDMA heat-health alerts
Community health committees	Limited or absent at village level	Set up Village Health and Disaster Committees associated with DDMAs
Public awareness campaigns	Ad hoc, hazard-specific	Create routine, year-round multi-hazard health messaging

5. Scientific & Institutional Gaps

However, there are significant challenges that Pakistan faces in integrating climate and health data for disaster preparedness. The monitoring and forecasting of climate, disease, disasters, and health services take place within separate organizations which include the Pakistan Meteorological Department, National Institute of Health, NDMA, and provincial health departments among others. This lack of integration could result in inadequate translation of climatic and hazards warnings into health sector disaster preparedness and responses. Moreover, there is a lack of localized modeling and forecasting of climate and health risks, especially heat related mortalities and effects of pollution. The application of technology like GIS, remote sensing, and predictive modeling for early detection of climate related health risks still needs to be improved at provincial and district levels (Saeed et al., 2022).

6. Mitigation Strategies and Best Practices

To minimize climate-induced health risk factors, the use of both structural and non-structural measures alongside capacity building and health risk awareness campaigns is essential. Examples of structural measures include the creation of heat stroke season clinics and measures to be taken in cases of hazardous smog conditions, like closing

schools temporarily (National Disaster Management Authority, 2024). Among the examples of non-structural measures are vector control by larviciding and elimination of stagnant water in areas that have suffered flooding, especially due to an observed increased number of malaria cases in these regions (Akhtar & Reid, 2024). Psychosocial assistance and proper referral of people having psychological problems should also be included into disaster preparedness and response. Equally important is capacity building and training of health workers to prevent and treat vector-borne diseases and heat disorders. Health risk awareness campaigns should be carried out in advance before the high-risk periods begin.

The Ahmedabad Heat Action Plan in India, which started in 2013 after the country experienced its worst heat wave in 2010 causing approximately 1,344 additional deaths, is a pertinent best practice in anticipatory heat action plans (Azhar et al., 2014). An evaluation of the plan revealed that it led to the prevention of an estimated 1,190 additional deaths per year through measures such as threshold-based heat alerts, cooperation among agencies, and training of health workers (Hess et al., 2018). The success of the Ahmedabad Heat Action Plan is indicative of the importance of early warning systems, coordination between institutions, and readiness of the health sector in dealing with heat problems. Such models can be replicated in vulnerable regions of Pakistan like Sindh and Punjab based on their respective climatic, health care infrastructure, and human resources requirements.

7. Risk Communication & Early Warning Systems

Pakistan's early warning system is well developed for weather-related risks but loosely linked with health sector responses, and hardly gender-sensitive in terms of last mile delivery. Heatwave warnings from NDMA, such as those for May 2024 predicting three consecutive waves in Punjab and Sindh, are issued days before hand directing the relevant departments to open up heatstroke centers and awareness campaigns (National Disaster Management Authority, 2024). The delivery of information in far flung and illiterate areas largely depends upon television and social media which might neglect women who have comparatively lesser access to cellular phones and radios in rural areas and outdoor workers in case of smog warnings. A truly people-centric and gender-sensitive early warning system would deliver messages through the women community health workers and women associations rather than through mosques.

8. Policy Recommendations

- NDMA should establish a national platform that connects PMD forecast, NIH surveillance system, and hospital data for health-specific early warnings and preparedness prior to any climate hazard occurrence.
- The health authorities should develop plans for seasonal heat-health and vector-borne disease preparedness which include positioning of essential medicines and establishing dedicated heatstroke treatment facilities prior to each high-risk season.
- PDMAs should enhance and expand their heat-wave SOPs, taking into account specific temperatures, disease patterns, and health-care systems in different provinces.
- Ministry of Climate Change, in collaboration with provincial environmental departments, should strengthen its efforts on controlling smog and air pollution, especially in Punjab.
- DDMAs should establish community health and disaster committees at the local level for communication, dissemination of early warnings, and health surveillance during climate-induced disasters.
- Universities and other research institutions, such as GCISC, should develop climate-health modeling beyond dengue to include mortality from heat as well as health effects due to pollution.
- Funding for disaster management and public health should provide funds for health preparedness, prevention, and emergency response related to climate change in order to continue preparations between major disasters.
- Disaster management protocols should involve not only physical aid but also psychosocial first aid and mental health support, especially among flood-hit populations.

9. Conclusion

The impacts of climate change are changing the health risks in Pakistan, with seasonal health threats becoming recurrent emergencies. In this regard, floods in 2022, the 2015 heat wave, growing threats of malaria and dengue, Lahore smog, and post-disaster stress provide evidence that climate disasters are impacting the physical and psychological well-being of people in the country. While NDMA, provincial administrations, and health officials have devised response plans for addressing these challenges, there are still shortcomings in terms of coordination and anticipation.

It is necessary for Pakistan to develop effective early warning systems that consider physical and mental health indicators; localized research and data collection; and psychosocial considerations within disaster response mechanisms. Proper investment in

disaster preparedness and prevention will enable the country to move from response to disaster risk reduction.

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PARTICIPANT RESEARCH PAPER

Satellite-Based Earth Observation for Disaster Monitoring and Damage Assessment: Techniques, Tools and Applications for Pakistan

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Abstract

Satellite-based Earth Observation (EO) has become an indispensable component of disaster management in Pakistan, offering rapid, wide-area and objective information before, during and after hazard events. This paper reviews the principal EO techniques — optical, synthetic aperture radar (SAR) and thermal/wide-area sensing — and the tools, including ArcGIS, Google Earth Engine and QGIS, that convert raw imagery into actionable products such as flood-extent maps and building-level damage grades. Drawing on the 2022 Pakistan floods, in which satellite mapping supported response and recovery for an estimated 33 million affected people and underpinned a US$30 billion Post-Disaster Needs Assessment, the paper demonstrates EO's value across the full disaster management cycle, from mitigation and preparedness to response and recovery. It further identifies critical gaps: monsoon cloud cover that limits optical sensors precisely when floods peak, outdated exposure baselines, a shortage of trained analysts within disaster-management authorities, and weak last-mile translation of technical products into community-level warnings. The paper concludes that the principal barrier to wider EO adoption in Pakistan is institutional rather than technological, and recommends embedding satellite products into standard operating procedures, building in-house geospatial capacity, and investing in national exposure datasets.

Keywords: ArcGIS; Damage Assessment; Disaster Risk Reduction; Earth Observation; Remote Sensing

1. Introduction

Pakistan is among the countries most exposed to hydrometeorological and geophysical hazards, including riverine and flash flooding, glacial lake outburst floods (GLOFs), drought and earthquakes. When roads are cut and ground teams cannot reach affected areas, satellites still can. Earth Observation gives disaster managers rapid, repeatable, wide-area and objective information at a scale and speed that ground survey cannot match — a single Sentinel-2 scene images a swath roughly 290 km wide.

The 2022 floods, which inundated approximately one-third of the country at peak and affected more than 33 million people across Sindh, Balochistan, Khyber Pakhtunkhwa and Punjab, demonstrated both the value and the limits of this technology. Satellite-derived flood-extent layers guided relief routing and shaped the sectors of the Post-Disaster Needs Assessment, which estimated damages and losses of approximately US$30 billion. At the same time, the event exposed gaps in exposure data, technical capacity and last-mile communication that continue to constrain Pakistan's disaster-management authorities.

This paper examines the principal EO techniques and tools used for disaster monitoring and damage assessment, their application across the disaster management cycle, and their relevance to climate change adaptation and disaster risk reduction (DRR) in Pakistan. It reviews the scientific and institutional gaps that limit the country's use of satellite data, and proposes policy measures to institutionalize EO within national disaster-management practice.

2. Regional Context & Hazard Profile

A hazard refers to a potentially damaging physical event, such as a flood, earthquake or heatwave. Exposure refers to people, infrastructure, crops and livelihoods located in areas that could be affected. Vulnerability refers to the social, economic and physical conditions that increase the likelihood of harm, while risk results from the interaction of hazard, exposure and vulnerability. Satellite EO principally strengthens the hazard and exposure sides of this equation by providing consistent, repeatable measurement over time.

Pakistan's disaster history illustrates the recurring need for such capability. The 2005 Kashmir earthquake and the 2010 and 2022 floods each required rapid, large-area damage assessment beyond the reach of ground teams; the 2023 Turkiye–Syria earthquakes later demonstrated comparable satellite-based building-damage grading internationally. Riverine flooding along the Indus, flash flooding in hill torrents, GLOF risk in the northern glaciated basins, and periodic drought in Sindh and Balochistan together

form a hazard profile for which wide-area, frequently revisited satellite observation is particularly well suited.

Three sensor types underpin this observation. Optical sensors (e.g., Sentinel-2, Landsat 8/9, and Pakistan's own PRSS-1) capture visible and infrared bands used for vegetation and water indices, but are blocked by cloud. SAR sensors (e.g., Sentinel-1, RADARSAT, ICEYE) transmit and read back microwave pulses, and so can see through cloud, smoke and darkness — a decisive advantage during monsoon flooding. Thermal and wide-area sensors (MODIS, VIIRS, INSAT) provide coarser-resolution but daily coverage for fire and heat anomalies. Every mission trades spatial detail against revisit frequency and spectral richness, and disaster managers must select instruments accordingly. Encouragingly, the core data sources — Sentinel, Landsat, MODIS and VIIRS — are free and openly licensed; the binding constraint on their use in Pakistan is analytical skill rather than data cost.

3. Risk & Vulnerability Assessment

Satellite EO contributes most directly to risk assessment by mapping exposure and tracking how a hazard evolves over an affected population. During the 2022 floods, flood-extent layers identified cut-off settlements and damaged roads, informing search, rescue and relief logistics, while damage-grading products fed compensation surveys and the PDNA's socio-economic loss estimates. Very-high-resolution commercial imagery (0.3–3 m, from providers such as Planet and Maxar, typically tasked through the International Charter "Space and Major Disasters") enables building-level damage classification — no damage, possible, damaged, or destroyed — that underlies compensation and reconstruction planning.

However, imagery alone cannot establish socio-economic vulnerability. Exposure layers describing building footprints, population distribution and cropland in Pakistan are frequently outdated or fragmented, which weakens the translation of a flood-extent map into a reliable estimate of livelihood disruption, food-security impact or housing loss. Vulnerable groups — including women, outdoor and informal-sector workers, and residents of unplanned settlements — are especially likely to be under-represented in existing exposure datasets, since such settlements are often absent from formal land-use records even though they are visible in satellite imagery. Gender dimensions compound this gap: women's restricted mobility and unequal access to information can mean that satellite-derived warnings and relief information reach households unevenly unless deliberately paired with community-level dissemination.

Addressing this requires pairing physical hazard mapping with regularly updated exposure baselines and disaggregated socio-economic data, so that satellite-derived hazard information can be converted into a genuine measure of who is at risk and by how much.

4. Community Resilience Factors

Earth Observation products are only as useful as their translation into local action, and community participation is essential to that translation. Local knowledge of drainage patterns, historical flood lines and vulnerable households can validate and refine satellite-derived flood-extent maps, particularly in areas where cloud cover or coarse resolution limits confidence in the imagery alone.

Field-verification tools such as Esri's Survey123 illustrate how ground-truth data can be fed back into the geospatial pipeline, closing the loop between remote analysis and local reality and allowing communities to contribute to, rather than only receive, disaster-management products. Community networks, local government and volunteers similarly play a decisive role in interpreting technical flood or damage maps for households who may lack digital access.

Combining satellite-derived hazard information with indigenous knowledge and community coping mechanisms — such as locally understood evacuation routes and historical settlement patterns that avoid known flood paths — can make EO-informed early warning and response more practical, trusted and effective than either source alone.

5. Scientific & Institutional Gaps

Despite Pakistan's growing reliance on satellite EO, four categories of gap constrain its effectiveness. First, physical limits: monsoon cloud cover blocks optical sensors precisely when floods peak, and while SAR can see through cloud, its interpretation requires specialist skills that remain scarce; revisit gaps between satellite passes can also miss fast-moving flash floods.

Second, data and integration gaps: imagery itself is abundant, but exposure data — buildings, population and crops — is often outdated or fragmented, and inter-agency data-sharing protocols between SUPARCO, NDMA, PDMAs and line departments remain limited. Third, capacity gaps: disaster-management authorities employ few trained remote-sensing and GIS analysts, leaving Pakistan dependent on externally produced rapid-mapping products (from UNOSAT, Copernicus EMS and similar mechanisms) with limited local validation. Adoption of AI and machine-learning methods for automated flood and damage classification is similarly nascent.

Fourth, a last-mile gap: a flood map produced in Islamabad is not, by itself, a warning received in a village in Dadu or Jacobabad. Technical geospatial products must be actively translated into district-level, actionable, people-centred information before they can reduce loss of life or livelihood.

6. Mitigation Strategies & Best Practices

Several structural and non-structural measures can reduce these gaps. On the technical side, InSAR-based ground-deformation monitoring can identify unstable slopes before landslides occur, floodplain delineation using optical and SAR change detection can inform land-use planning, and drought and glacial-lake indices can support seasonal preparedness. Pakistan's national capability, anchored in SUPARCO's PRSS-1 satellite and flood-monitoring cell, provides a domestic platform that can be strengthened rather than built from scratch.

On the institutional side, capacity building in SAR-based flood mapping and in tools such as ArcGIS Pro, ArcGIS Image Analyst, QGIS and Google Earth Engine would allow disaster-management cadres to process imagery in-house rather than relying solely on external rapid-mapping activations. International best practice offers a useful model: mechanisms such as the International Charter "Space and Major Disasters", Copernicus Emergency Management Service, UNOSAT/UNITAR and Sentinel Asia provide free rapid-mapping support on activation, and have already supported Pakistan during the 2022 floods and, internationally, the 2023 Turkiye–Syria earthquakes.

Awareness and training programmes for provincial and district disaster-management staff, alongside dedicated geospatial cells within NDMA and the PDMAs, would help retain the skills gained through such activations rather than losing them once an event has passed.

7. Risk Communication & Early Warning

Converting satellite intelligence into effective early warning requires a people-centred, gender-sensitive communication chain. Pakistan's National Emergency Operations Centre (NEOC) already integrates satellite products with Pakistan Meteorological Department forecasts and PDMA reports into a common operating picture; extending this picture through ArcGIS Online dashboards and StoryMaps can give provincial and district authorities near-real-time visibility of evolving hazards such as rain and snow-cover accumulation, GLOF risk and flood extent.

However, a dashboard alone does not constitute a warning. Last-mile communication should draw on multiple channels — SMS, community radio, local government networks and trained volunteers — and should be delivered in local languages with clear,

actionable guidance, taking account of gender, disability and digital-access differences that can otherwise leave the most vulnerable households uninformed.

District-level products distilled from satellite analysis, rather than raw imagery or technical maps, are what ultimately allow communities to act — for example, by evacuating settlements identified as cut off or by pre-positioning relief before a mapped flood peak arrives.

8. Policy Recommendations

Based on the evidence reviewed, the following measures are recommended:

1. Institutionalize EO in standard operating procedures by making satellite-based flood-extent and damage products a mandated, standard input to NEOC and PDMA decision cycles, rather than an ad-hoc request.
2. Build in-house geospatial capacity by training disaster-management cadres in SAR-based flood mapping, ArcGIS/QGIS and Google Earth Engine, and by retaining these skills through dedicated geospatial cells.
3. Invest in national exposure baselines — regularly updated building-footprint, cropland and population layers — as the multiplier that converts satellite imagery into reliable impact and compensation estimates.
4. Automate and localize analysis through pre-agreed AI-assisted flood and damage-detection pipelines for Pakistan's major river basins, paired with district-level dashboards in local languages.
5. Strengthen inter-agency data-sharing protocols between SUPARCO, NDMA, PDMAs, PMD and line departments to reduce duplication and fragmentation of exposure data.
6. Expand use of international rapid-mapping mechanisms — the International Charter, Copernicus EMS, UNOSAT and Sentinel Asia — while building the local validation capacity to make full use of their products.
7. Strengthen last-mile communication through SMS, radio, community volunteers and local-language dashboards so that technical products reach vulnerable households, not only emergency operations centres.
8. Mainstream gender- and vulnerability-sensitive exposure mapping so that informal settlements, outdoor workers and women-headed households are adequately represented in satellite-informed risk assessments.
9. Support continued investment in national satellite capability, including SUPARCO's PRSS-1 programme, as a long-term complement to free international missions such as Sentinel and Landsat.

9. Conclusion

Satellite-based Earth Observation has helped shift disaster management in Pakistan from reaction towards anticipation, delivering rapid, wide-area and objective intelligence across the full disaster management cycle, from mitigation to recovery. The core data — Sentinel and Landsat imagery — is free, and mature tools such as ArcGIS and cloud-based platforms like Google Earth Engine have put these techniques within reach of every disaster-management authority.

The 2022 floods demonstrated both this potential and its limits: satellite mapping guided relief and underpinned a US$30 billion damage assessment, yet the response also exposed persistent gaps in exposure data, technical skills and last-mile delivery. These findings suggest that the principal frontier for Pakistan is institutional rather than technological — embedding EO into standard operating procedures, people and budgets, rather than waiting for new sensors or software.

Strengthening exposure baselines, building in-house geospatial capacity, and translating technical products into people-centred, last-mile warnings would allow Pakistan to convert its already strong satellite data access into consistently better outcomes for the communities most exposed to climate-related hazards.

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PARTICIPANT RESEARCH PAPER

Satellite-Based Earth Observation for Disaster Monitoring and Damage Assessment: A Multi-Sensor Framework for Rapid and Resilient Disaster Management in Pakistan

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Abstract

Satellite-based Earth Observation (EO) has become a critical source of actionable information for disaster risk reduction (DRR), emergency response and post-disaster recovery. This paper examines how a multi-sensor EO framework—combining Synthetic Aperture Radar (SAR), multispectral optical imagery, digital elevation models and geospatial exposure data—can strengthen disaster monitoring and damage assessment in Pakistan. The analysis is based on the operational concepts presented in the author's NDMA course presentation and is expanded through recent institutional and scientific literature. The paper argues that SAR is particularly valuable during monsoon floods because it can acquire imagery independent of daylight and most cloud conditions, while optical systems provide complementary visual and spectral information for detailed damage verification and environmental assessment. EO products become operationally meaningful when linked with population, infrastructure and vulnerability layers and delivered through institutional workflows to decision-makers and field responders. Pakistan's hazard profile makes rapid geospatial intelligence especially important, but technical capacity, data interoperability, validation and last-mile communication remain major constraints. The paper recommends automated SAR processing, a unified spatial data infrastructure, multi-sensor damage assessment protocols, targeted capacity development and people-centred risk communication to improve the use of EO across the disaster-management cycle.

Keywords: Climate change; damage assessment; disaster risk reduction; Earth Observation; remote sensing

1. Introduction

Climate change, rapid urbanization, population growth and environmental degradation are increasing the complexity and consequences of disasters. Pakistan is exposed to multiple hazards, including riverine and flash floods, droughts, earthquakes, landslides, glacial hazards, heatwaves and coastal storms. These hazards often affect areas where exposure and vulnerability are already high. Consequently, disaster management requires information that is spatially explicit, timely, repeatable and capable of supporting decisions before, during and after an emergency.

Satellite-based EO meets many of these requirements by providing repeated observations across large areas. The value of EO, however, does not lie in imagery alone. Its operational importance emerges when observations are transformed into products such as flood extent maps, deformation maps, damage indicators and exposure estimates and then integrated into institutional decision processes. The presentation on “Satellite-Based Earth Observation for Disaster Monitoring & Damage Assessment” frames this transition as a shift from reactive emergency management toward precision-guided DRR.

The purpose of this paper is to examine the contribution of multi-sensor EO to disaster monitoring and damage assessment and to identify practical measures for strengthening its use within Pakistan’s disaster-management system. The study focuses on three objectives: first, to explain the complementary roles of SAR and optical satellite systems; second, to assess EO-based approaches for risk, vulnerability and damage analysis; and third, to propose institutional, technical and policy recommendations relevant to NDMA and associated disaster-management organizations.

2. Regional Context & Hazard Profile

Disaster risk is produced through the interaction of hazard, exposure and vulnerability. A hazard is a potentially damaging physical event or process; exposure refers to people, infrastructure, livelihoods and assets located in areas that may be affected; vulnerability describes the conditions that increase susceptibility to harm; and risk represents the potential for adverse consequences arising from their interaction. EO contributes to all four dimensions by mapping hazard processes and combining them with spatial information on settlements, population and critical assets.

Pakistan's geographic diversity creates a broad hazard profile. Monsoon rainfall and river systems create recurrent flood risk across major plains, while mountainous northern and north-western areas are exposed to landslides, earthquakes and cryosphere-related hazards. Dense urban development and critical infrastructure increase exposure, while poverty, limited mobility, weak housing and unequal access to information can increase vulnerability. Climate change can further intensify hydrometeorological extremes and compound existing risks.

The 2022 Pakistan floods demonstrated the scale at which satellite information can support crisis monitoring. The International Charter reported that the floods affected approximately 33 million people, highlighting the need for wide-area observations that cannot be obtained rapidly through ground surveys alone. In such conditions, satellite systems provide a common geographic picture that can support situation awareness, prioritization and recovery planning.

3. Risk & Vulnerability Assessment

A central strength of EO is the ability to connect hazard observations with exposure and vulnerability information. For floods, SAR imagery can be processed to delineate likely inundated areas because smooth water surfaces commonly produce low radar backscatter under suitable viewing and environmental conditions. The resulting flood layer can be overlaid with population grids, settlement footprints, land use, roads, hospitals, schools and other critical assets. This changes a flood map from a descriptive product into a decision-support tool capable of identifying potentially affected communities and infrastructure.

Optical multispectral imagery complements SAR by supporting land-cover classification, vegetation and crop impact assessment, sediment and burn-scar mapping, and visual confirmation of selected damage. Very-high-resolution commercial imagery may provide detailed evidence of damaged roofs, roads and other structures, although cloud cover and tasking constraints can limit availability during an active event. A multi-sensor approach is therefore more robust than dependence on a single platform.

Risk assessment must also consider social and economic dimensions. The same flood depth or earthquake intensity can have very different consequences depending on housing quality, livelihood dependence, income, access to transport, disability, age and gender. Women, children, older persons, persons with disabilities and socially marginalized groups may face additional barriers to evacuation, shelter, information and recovery. EO cannot directly measure all these factors, but it can provide the spatial framework through which demographic and socio-economic data can be analyzed.

Damage assessment similarly requires caution. Satellite-derived damage products are often proxies rather than direct measurements of loss. A change detected in imagery may indicate structural damage, debris, flooding or land-surface disturbance, but interpretation depends on sensor characteristics, acquisition geometry, land cover and validation data. Interferometric SAR (InSAR) and coherence-change analysis can reveal ground deformation and surface changes associated with earthquakes, landslides and other events. These techniques are powerful, but their results should be combined with engineering assessment, field verification and contextual information before they are used for official loss estimation or post-disaster needs assessment.

4. Community Resilience Factors

Community resilience depends not only on technology but also on social capital, local knowledge and institutional relationships. Community networks can help identify isolated households, validate mapped conditions and disseminate warnings. Indigenous and locally developed coping practices may provide valuable information about historical flood routes, safe locations, seasonal patterns and evacuation behavior.

EO should therefore strengthen—not replace—community knowledge. Participatory mapping, local validation and feedback mechanisms can improve the accuracy and legitimacy of geospatial products. A map produced at national scale may show the location of inundation, but local communities can explain which bridge remains usable, which settlement has vulnerable residents or which route is inaccessible. Combining satellite intelligence with local knowledge creates a more complete operational picture and supports a people-centred approach to DRR.

5. Scientific & Institutional Gaps

Despite its potential, EO adoption faces scientific and institutional constraints. Data availability does not automatically produce usable intelligence. Satellite products may have limitations related to spatial resolution, revisit frequency, cloud contamination, radar speckle, terrain effects and classification uncertainty. Automated and AI/ML-based methods can accelerate processing, but models require representative training data, transparent validation and periodic review to avoid systematic errors.

Institutionally, fragmented datasets, inconsistent coordinate systems, delayed data sharing and unclear product standards can reduce the value of rapid mapping. Capacity gaps may also exist in SAR processing, InSAR, cloud-based analysis, coding and interpretation of uncertainty. A technically sophisticated product that is not delivered in a usable format or linked to a clear operational decision may have limited practical impact. These challenges indicate that investment should focus on the full information chain—from acquisition and processing to validation, dissemination and use—rather than on software or imagery alone.

6. Mitigation Strategies & Best Practices

Best practice is to establish EO as a routine component of preparedness rather than a capability activated only after disaster. Pre-disaster baseline datasets should include elevation, drainage, land use, settlement extent, population distribution, critical infrastructure and historical hazard footprints. Standard operating procedures should define sensor selection, processing steps, validation thresholds, map formats and responsibilities.

For flood monitoring, automated SAR workflows can produce rapid preliminary inundation layers, followed by quality checks and integration with optical imagery where available. For earthquakes and landslides, InSAR and coherence-based products can identify deformation or surface change and help prioritize field inspection. International mechanisms, including the International Charter “Space and Major Disasters,” Copernicus Emergency Management Service, Sentinel Asia and UN-SPIDER, demonstrate the value of coordinated access, rapid mapping and technical support. Pakistan can benefit further by ensuring that national workflows are interoperable with

these mechanisms and that national and provincial users are trained to request, interpret and operationalize products.

7. Risk Communication & Early Warning

The final value of geospatial intelligence is determined by whether it reaches the people who need to act. Risk communication should translate technical outputs into clear, timely and actionable messages. A complex radar classification map may be useful for analysts but may not be suitable for district authorities or communities. Decision products should therefore be tailored to users: strategic summaries for senior leadership, operational maps for responders and accessible warnings for communities.

People-centred and gender-sensitive early warning requires attention to the last mile. Warnings should be disseminated through multiple channels and designed for people with different literacy levels, languages, mobility constraints and access to technology. Community organizations, local governments, media and emergency services should be integrated into the communication chain. EO can improve situational awareness, but warnings and response decisions must remain connected to human networks and local action.

8. Policy Recommendations

Based on the analysis, five policy directions are recommended. First, NDMA and partner institutions should institutionalize automated, documented multi-sensor EO workflows within emergency operations, with clear service-level targets for product generation and dissemination. Second, a unified spatial data infrastructure should enable standardized sharing of authoritative hazard, exposure and response layers among NDMA, PDMAs, district authorities and technical agencies.

Third, sustained capacity development is required in SAR, InSAR, cloud-based geospatial analysis, AI/ML validation and uncertainty communication. Fourth, satellite derived damage assessment should follow a tiered protocol that distinguishes rapid screening products from validated estimates used for official assessment. Fifth, community participation should be incorporated into product validation and risk communication so that technology supports locally grounded decisions.

These recommendations align with the broader direction of Pakistan's disaster management planning, which emphasizes proactive preparedness, capacity enhancement and coordinated risk reduction. EO should therefore be treated as an institutional capability embedded across preparedness, response and recovery rather than as an isolated GIS activity.

9. Conclusion

Satellite-based Earth Observation can substantially strengthen disaster management by providing timely, repeatable and geographically extensive evidence. SAR is particularly important during cloud-covered emergencies, while optical imagery provides complementary environmental and structural information. When these observations are integrated with elevation, population, infrastructure and vulnerability data, they support more informed prioritization of response and recovery.

However, technology alone does not create resilience. Reliable disaster intelligence requires validated methods, trained analysts, interoperable institutions, community knowledge and effective last-mile communication. The strongest model for Pakistan is therefore an integrated multi-sensor and multi-level approach in which EO supports science-based planning while communities and institutions remain central to decision making. By developing automated processing pipelines, shared spatial infrastructure, technical capacity and people-centred communication, NDMA and its partners can move further toward proactive, precision-guided and resilient disaster risk management.

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PARTICIPANT RESEARCH PAPER

The Sendai Framework for Disaster Risk Reduction: Global Policy and Implementation

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Abstract

The Sendai Framework for Disaster Risk Reduction (SFDRR) 2015–2030 is a global United Nations agreement signed by 187 countries to shift disaster management from reactive response to proactive, risk-informed governance. While the framework has successfully reduced global disaster mortality rates and increased the number of countries adopting local and national disaster risk reduction (DRR) strategies, overall progress remains highly uneven. Globally, the number of people affected by disasters has increased, economic losses have increased, critical infrastructure damage remains high, and international financial assistance to developing countries is limited.

Countries are still focusing on reactive measures rather than emphasising preparedness and mitigation; as a result, disaster financing continues to be a major hurdle for successful implementation of SFDRR.

Developed nations like the United States struggle with a lack of localized data collection, fragmented reporting across federal agencies, and security-related data gaps, while countries like Poland continue to prioritize emergency response over preparedness.

Despite contributing minimally to global carbon footprints, Pakistan ranks as the 8th most climate-vulnerable country globally, facing threats such as flooding, extreme heatwaves, droughts, GLOF's, heavy monsoon rains, earthquakes, and more. To implement SFDRR successfully, Pakistan has established a decentralized disaster management network spanning national, provincial, and district levels to manage risk prevention according to regional geographies and their requirements. Most recently, Pakistan launched the National Disaster Risk Reduction Strategy (NDRRS) 2025–2030, aligned with the Paris Agreement and Sustainable Development Goals. This strategy relies on six core pillars—ranging from AI-driven early warning systems to sustainable financing—to transition the state into a proactive, resilient framework.

Key words: Disaster Risk Reduction, Early Warning Systems, Policy Implementation, Sustainable Development Goals, United Nations

1. Introduction

1.1 Background and Rationale

The Sendai Framework for Disaster Risk Reduction (SFDRR), launched in 2015—to be achieved by 2030—by the United Nations (UN) is the first major global agreement to work on disaster risk reduction through the implementation of integrated and inclusive economic, structural, legal, social, health, cultural, educational, environmental, technological, political, and institutional measures to prevent and reduce hazard exposure and vulnerability to disaster, increase preparedness for response and recovery, and thus strengthen resilience (UNDRR). SFDRR aims to achieve 7 targets: substantially reduce disaster mortality rate, number of affected people, economic loss, and damage to critical infrastructure, and substantially increase countries with local and national Disaster Risk Reduction (DRR) strategies, international cooperation for aiding developing countries, and availability and access to early warning systems and DRR information. It was adopted by 187 countries and is being actively self-reported to the United Nations Office for Disaster Risk Reduction (UNDRR) on the global targets; 81 countries have reported on all seven targets and 107 countries have reported on all SDG-related targets (UNDRR Sendai Monitoring).

1.2 Problem Statement

The Sendai Framework aims to reduce disaster risk and losses in lives, livelihoods, and health and in the economic, physical, social, cultural, and environmental assets of persons, businesses, communities, and countries. UN wishes to ensure that all stakeholders are prepared for multi-hazards by preventing and reducing hazard exposure and vulnerabilities to disaster and, subsequently, making communities more resilient for managing and responding to disasters (NDRMF). Climate change is occurring at a rapid speed, and the hazards and risks are increasing with it; thus, it is imperative to ensure that all nations have preparedness at the core of their Disaster Management (DM) Policies. However, despite the Sendai Framework, many countries are still focusing on reactive response rather than being proactive, as intended by SFDRR.

1.3 Purpose and Objectives

The study aims to understand the practical implementation of SFDRR and analyse how the it has changed national policies from being reactive to proactive. Moreover, the study will specifically focus on the key challenges faced worldwide in the implementation of the framework.

1.4 Scope

The study aims to objectively analyse the implementation of SFDRR across the globe; how successful it has been so far and what are the key challenges that nations need to overcome.

2. Policy Implementation and Gaps

As reported in the UN General Assembly, the midpoint of the implementation of SFDRR has been uneven; some targets have been achieved globally, while some have seen no improvement. Progress is uneven across geographies, scales, and income levels. For example, countries have enhanced disaster risk assessments; however, at the same time, the implementation at the local level remains inadequate. Similarly, financing for disaster remains reactive rather than focusing on preparedness; in fact, countries are still trying to ensure that guilt-free funding is set aside to ensure that agencies and governments can prepare adequately for disasters without having to carry the burden of spending it for “no reason” in case the disaster does not occur.

SFDRR has had varied results; the global disaster mortality rate has reduced from 1.60 in the period 2005–2014 to 1.15 in the period 2013–2022. Countries with DRR strategies have increased from 55 in 2025 to 126 in 2022, with 102 countries having DRR strategies at a local level as well and 101 countries utilising multi-hazard early warning systems. However, people affected by disasters have increased from 1,092 during the period 2005–2014 to 2,034 in the period 2013–2022. Direct economic losses in 2022 amounted to 0.83 per cent of the total gross domestic product (GDP) of the reporting countries, which was significantly higher than the average of 0.37 per cent reported during the period 2015–2022 and is still estimated to be significantly underreported and undervalued. The average annual number of critical infrastructure units and facilities destroyed or damaged by disasters (global target D) was 102,628 during the period

2015–2022. Lastly, developing countries have reported that international cooperation remains limited, with only $304 million officially provided for assistance in disasters.

Similarly, studies have corroborated the findings regarding the uneven response in implementation of SFDRR; in Poland, the government remains focused on responding to emergencies rather than preparedness, as well as not having a risk management plan at a national level accounting for the available resources, and organisational and administrative capacity of responding to a disaster (Goniewicz, Burkle, F.M. 2019).

One of the key factors in implementation and monitoring of SFDRR—in the USA—lies in 1) the lack of a national focal point and Federal mandates for disaster loss reporting, 2) the lack of consistent and systematic data collection and reporting across Federal agencies, 3) the lack of strong incentives for local, county, and state entities to report disaster loss statistics to the Federal government, and 4) the lack of reporting on particular disaster losses due to security concerns (Wilkins, A. et al. 2021).

3. Regional Context

According to the United Nations Development Programme, Pakistan continues to rank as the 8th most vulnerable country to the impacts of climate change despite not contributing to the carbon footprint in any substantial manner. Moreover, with increasing temperatures and climate change, Pakistan remains at risk in the future and, thus, must integrate DRR practices in every sector to ensure minimal impact in case of a disaster. (UNDP)

Following SFDRR, Pakistan has ensured implementation of DRR strategies by having a decentralised mechanism for DM: the National Disaster Management Council (NDMC), headed by the Prime Minister, is the main governing body at the national and federal level, followed by the National Disaster Management Authority, the body responsible for execution and implementation of policies. A similar structure is employed for provinces: the Provincial Disaster Management Committee, headed by the Chief Minister, is the highest policy-making body at the provincial level, followed by Provincial Disaster Management Authorities and District Disaster Management Authorities. The decentralised system ensure that each province can have policies for preparedness for multi-hazards according to the geography of their own province, for example, the

province of Punjab would prepare their resources and focus their resilience for facing floods, whereas province of Sindh will prepare for heatwaves and droughts.

One of the key components of Pakistan's DRR strategy is to ensure that groups most affected, i.e., women, children, disabled, elderly, and transgenders, are included in DM policies and their requirements are met in case of a disaster. Their department, the Gender & Community Cell (GCC), works on developing key policies and providing resources such as proper dignity kits for women when a disaster occurs. Moreover, NDMA has Revised National Policy Guidelines for Vulnerable Groups (with UN Women & ADB) to strengthen national guidance on inclusive planning, data, services, and protection for marginalized groups (NDMA, 2025).

Currently, Pakistan has launched the National Disaster Risk Reduction Strategy (NDRRS) 2025–2030, serving as Pakistan's primary strategic roadmap for transitioning from a reactive, response-centric model to a proactive, risk-informed governance framework. The strategy is made with reference to the Paris Agreement and Sustainable Development Goals, with a focus on Pakistan's vulnerabilities such as flooding and extreme heatwaves to ensure that policies are made in accordance with the practical needs of the country. The strategy aims to prioritise six core pillars: enhancing multi-hazard risk understanding, strengthening decentralized disaster governance, investing in structural and ecosystem-based resilience, modernizing early warning systems through AI and satellite technology, ensuring sustainable financing, and embedding social inclusion.

Pakistan has also simultaneously published a National Disaster Response Plan for 2026 to prepare for, respond to, and recover from disasters in the climate-vulnerable future. It has recognised for multi-hazards such as intensifying floods, earthquakes and Glacial Lake Outburst Floods (GLOFs) to heatwaves, cyclones and drought. This plan sets forth a coordinated, multilevel, proactive approach that employs DRR techniques and plans to strengthen institutional capacity, integrate risk financing, and leverage community resilience to prepare them to respond accordingly to disasters, such as going to a safe zone in case of flooding.

4. Conclusion

The review of SFDRR 2015–2030 showcases the struggle of practically implementing a global policy; while it is easy to adopt an agreement, it takes a lot of resources and systematic changes to ensure that it is implemented with according to its true purpose. On a national level, countries have successfully implemented SFDRR to a certain level—such as lowering overall disaster mortality rates and increasing the adoption of national DRR strategies—but the overall implementation is uneven and requires more work.

The key hurdle in SFDRR is that DRR practices are still rooted in being reactive in nature instead of focusing on preparedness and mitigation. Both developed and developing nations continue to struggle with systemic inefficiencies, ranging from fragmented data collection and a lack of centralized federal mandates in the United States to an overriding institutional focus on emergency response rather than long-term preparedness in Poland. Furthermore, the lack of international cooperation and the restricted availability of proactive, "guilt-free" preparedness financing leave developing nations to bear the burden of climate change.

For Pakistan, which ranks as the eighth most climate-vulnerable nation globally despite its negligible contribution to the global carbon footprint, transitioning from a reactive to a proactive governance model is imperative. Moreover, due to being climate-vulnerable, Pakistan requires more substantial assistance from countries contributing substantially towards the emissions and ensure that Pakistan can equip itself to deal with disasters accordingly.

In conclusion, the successful realization of the Sendai Framework targets by 2030 relies on shifting from reactive crisis response to proactive, risk-informed governance. By securing sustainable financing for climate-vulnerable countries like Pakistan, and utilising advanced early warning technologies effectively, Pakistan can continue to improve its current strategies and aim for more resilient communities, and in turn, a resilient nation.

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PARTICIPANT RESEARCH PAPER

Smog Effects in Lahore District, Pakistan

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Abstract

Smog is one of the most serious environmental and public-health challenges facing Lahore District, Pakistan, particularly during the winter season. Rapid urbanization, increasing vehicular traffic, industrial emissions, brick kilns, agricultural residue burning, waste burning, construction activities, and unfavorable meteorological conditions contribute to high concentrations of particulate matter and other pollutants. Among these, fine particulate matter ($PM_{2.5}$) is especially hazardous because it can penetrate deeply into the respiratory system and contribute to cardiovascular and respiratory diseases. This paper examines the effects of smog in Lahore District through a risk and vulnerability framework. It discusses the regional context and hazard profile, identifies vulnerable populations and communities, examines resilience factors, and highlights scientific and institutional gaps. The paper also evaluates mitigation strategies, risk communication, early-warning mechanisms, and existing policy responses in Punjab. Evidence suggests that Lahore requires an integrated, long-term approach involving cleaner transportation, industrial and brick-kiln regulation, agricultural alternatives, improved air-quality monitoring, health preparedness, community participation, and effective early warning. Stronger institutional coordination and evidence-based enforcement are essential for reducing exposure and improving resilience.

Keywords: Lahore, smog, $PM_{2.5}$, air pollution, vulnerability, public health

1. Introduction

Air pollution has become a major environmental and health concern in rapidly growing cities throughout South Asia. Lahore District is particularly vulnerable because of its large population, rapid urban expansion, extensive transportation network, industrial activities, and proximity to agricultural areas. During the autumn and winter months, these emission sources combine low wind speeds, atmospheric inversion, high humidity, and limited vertical mixing, producing persistent episodes of smog.

Fine particulate matter ($PM_{2.5}$) is one of the most important pollutants associated with Lahore's smog. According to the World Health Organization (WHO, 2021), the recommended annual mean concentration for $PM_{2.5}$ is only 5 μg/m³, while the 24-hour guideline is 15 μg/m³. These guideline values reflect substantial evidence linking particulate pollution to premature mortality and cardiovascular, respiratory, and other health problems. The scale of Lahore's problem is substantial. World Bank assessments indicate annual average $PM_{2.5}$ concentrations of approximately 110–130 μg/m³ in central Lahore and about 87 μg/m³ across Lahore Division, demonstrating exposure far above health-based guidelines (World Bank, 2025).

Smog should therefore be considered not simply an environmental problem but a multidimensional disaster-risk issue. Its effects include increased illness, reduced visibility, disruption of education and transportation, reduced labor productivity, economic losses, and disproportionate impacts on socially and economically vulnerable populations.

2. Regional Context and Hazard Profile

Lahore is in northeastern Pakistan within the broader Indo-Gangetic atmospheric region. Air pollution in this region is not confined to individual administrative boundaries. Pollutants can travel considerable distances through regional atmospheric circulation. The World Bank (2025) estimates that a substantial share of Punjab's $PM_{2.5}$ originates within Punjab itself, while additional pollution comes from other Pakistani provinces and international sources.

Consequently, Lahore's smog should be addressed as an airshed-level problem rather than exclusively as a municipal problem.

Several sources contribute to Lahore's pollution. These include vehicular emissions, industrial combustion, brick kilns, agricultural residue burning, construction dust, road dust, open waste burning, and household or commercial fuel combustion. Source apportionment research has identified motor vehicles as a major contributor to primary organic carbon, while biomass burning and fuel combustion also contribute significantly (Stone et al., 2010).

Brick kilns are another important source. Lahore's brick-making sector traditionally relies on combustion technologies and fuels that can generate substantial particulate emissions. Research has found extremely high $PM_{2.5}$ concentrations in environments influenced by brick kilns and major roads, demonstrating the importance of combustion sources in local exposure.

Meteorological conditions intensify these emissions during winter. Low wind speeds, temperature inversions, high humidity, and shallow atmospheric mixing layers prevent pollutants from dispersing effectively. Secondary pollutants can also form through atmospheric chemical reactions. Historical research in Lahore found winter $PM_{2.5}$ concentrations substantially higher than those during warmer and wetter seasons, with soil and road dust, industrial emissions, vehicular emissions, and secondary aerosols identified as important contributors.

3. Risk and Vulnerability Assessment

The risk associated with smog results from the interaction of the hazard, population exposure, vulnerability, and capacity to respond. In Lahore, exposure varies significantly according to occupation, location, socioeconomic status, mobility, and access to protective resources.

Health vulnerability

$PM_{2.5}$ is particularly dangerous because its small size allows it to penetrate deeply into the lungs and, in some cases, enter the bloodstream. The WHO (2021) identifies particulate pollution as a major risk factor for cardiovascular disease, stroke, chronic obstructive pulmonary disease, respiratory infections, and cancer (World Health Organization).

Children, older adults, pregnant women, and individuals with asthma, chronic respiratory conditions, and cardiovascular diseases are especially vulnerable. Outdoor workers

such as traffic police, street vendors, construction workers, sanitation workers, and motorcycle riders may experience prolonged exposure.

Socioeconomic vulnerability

Smog also creates an environmentally-justice issue. Wealthier households may have greater access to air purifiers, private vehicles, high-quality masks, healthcare, and the ability to work indoors. In contrast, low-income households may depend on outdoor employment and public or motorcycle transportation and may live closer to industrial or highly polluted areas.

Therefore, the ability to respond to smog is strongly influenced by economic resources. Policies that rely entirely on individual protective behavior can unintentionally increase inequality because not everyone has equal capacity to reduce exposure.

Educational and economic impacts

Severe smog can interfere with schooling when authorities restrict outdoor activities or temporarily close educational institutions. For example, Punjab authorities have previously imposed restrictions on educational institutions during severe pollution episodes. Punjab EPD

Smog can also reduce productivity through illness, absenteeism, transportation delays, and reduced outdoor economic activity. These effects demonstrate that air pollution is both a public-health and economic-development concern.

4. Community Resilience Factors

Community resilience refers to the ability of communities to anticipate, prepare for, cope with, and recover from hazardous conditions. Several factors influence Lahore's resilience to smog.

First, **public awareness** is essential. Communities need accessible information about the health consequences of $PM_{2.5}$, protective behavior, and the meaning of air-quality indicators. Public awareness surveys in Lahore have demonstrated the importance of understanding smog and adopting preventive measures.

Second, access to **reliable information** strengthens resilience. Residents are more likely to modify behavior when information is timely, understandable, and trusted. Government agencies, schools, healthcare providers, media organizations, and community groups should therefore provide consistent messages.

Third, **healthcare access** is critical. Hospitals and primary healthcare centers should prepare for seasonal increases in respiratory and cardiovascular complaints. Health surveillance systems can help authorities identify periods when pollution is generating increased health impacts.

Fourth, **social networks** can support vulnerable people. Families, neighborhood organizations, schools, and community leaders can help disseminate warnings and identify individuals who need assistance.

Finally, **economic capacity** affects household resilience. Public policies should therefore provide community-level protection rather than placing the entire responsibility on individual residents.

5. Scientific and Institutional Gaps

Despite increasing research on Lahore's air pollution, important scientific gaps remain.

One major limitation is the **insufficient spatial coverage of air-quality monitoring**. Lahore is a large and diverse district, but monitoring stations cannot fully represent pollution levels in all neighborhoods, industrial areas, roads, and peri-urban communities.

A second gap involves **source attribution**. Although research has identified transportation, industry, brick kilns, dust, biomass burning, and secondary aerosols as important sources, continuous source-apportionment studies are required to identify seasonal and neighborhood-level contributions. Another gap concerns **health surveillance**. Lahore needs stronger systems linking air-quality measurements with hospital admissions, emergency visits, respiratory diseases, cardiovascular events, mortality, and school absenteeism.

Institutional fragmentation is another challenge. Environment, transport, agriculture, industry, health, education, and local-government agencies all have responsibilities related to air pollution. Weak coordination can result in fragmented policies.Punjab has nevertheless established important regulatory instruments. The Punjab Environmental Protection (Smog Prevention and Control) Rules, 2023 establish requirements for sectors such as brick kilns and industrial units and address practices including stubble and open waste burning (Government of Punjab, 2023a). Punjab EPD+1

6. Mitigation Strategies and Best Practices

Effective mitigation requires reducing emissions at their sources rather than relying primarily on emergency responses.

Transportation

Transportation should be a major priority. Measures should include stricter vehicleemission testing, retirement of highly polluting vehicles, cleaner fuels, improved public transportation, and gradual electrification of buses and other high-use vehicles.

Investment in public transport is particularly important because it can simultaneously reduce emissions and provide affordable mobility to lower-income residents.

Industry and brick kilns

Industrial facilities should comply with emission standards through regular inspections and monitoring. Brick kilns should transition toward cleaner technologies and fuels. Financial and technical assistance can help small operators comply without creating excessive economic hardship.

Agricultural burning

Agricultural residue burning should be reduced by providing farmers with economically viable alternatives, including mechanical residue management, collection, biomass utilization, and incentives for non-burning practices.

Waste management

Open burning of municipal waste should be eliminated through improved waste collection, recycling, composting, and enforcement. Public education should explain the contribution of waste burning to particulate pollution.

Integrated clean-air planning

Punjab's Clean Air Policy provides a broader policy framework for addressing air pollution across sectors (Government of Punjab, 2023b). Punjab EPD

In 2025, the World Bank approved $300 million in financing to support Punjab's Clean Air Program and Smog Mitigation Action Plan. The program targets major sectors including transport, agriculture, industry, energy, and municipal services and aims to reduce $PM_{2.5}$ levels by 35% over the next decade (World Bank, 2025).

7. Risk Communication and Early Warning

A reliable early-warning system is essential because smog episodes can develop rapidly and persist for several days.

Lahore should develop an integrated system combining real-time $PM_{2.5}$ monitoring, meteorological forecasting, satellite observations, and air-quality modeling. Alerts should be issued before pollution reaches extremely hazardous levels.

Risk communication should be simple and action-oriented. Instead of merely announcing an AQI value, authorities should explain what residents should do. For example, during hazardous conditions, vulnerable individuals should minimize outdoor exposure, schools should restrict outdoor activities, and healthcare facilities should prepare for increased respiratory cases.

Communication should use television, radio, SMS, social media, mobile applications, schools, mosques, community organizations, and local government channels. Messages should be available in Urdu, Punjabi, and English.

Importantly, early warnings must be trusted. Contradictory information from different agencies can reduce public compliance. A centralized communication protocol should therefore be developed.

8. Policy Recommendations

The following recommendations are proposed for Lahore District:

1. Develop an integrated Lahore airshed management system involving environment, transport, agriculture, industry, health, education, and municipal authorities.
2. Expand $PM_{2.5}$ monitoring to cover residential, industrial, roadside, peri-urban, and brick-kiln areas.
3. Strengthen vehicle-emission enforcement through transparent digital inspection and certification.
4. Accelerate clean public transportation, particularly electric buses and other low emission systems.
5. Modernize brick kilns through mandatory cleaner technologies accompanied by financial and technical support.

6. Provide farmers with alternatives to crop-residue burning rather than relying only on punitive enforcement.
7. Eliminate open waste burning through better municipal waste collection and enforcement.
8. Establish an air-pollution health surveillance system connecting pollution data with hospital and mortality records.
9. Develop a Lahore smog early-warning platform that provides forecasts and health recommendations several days in advance.
10. Prioritize vulnerable populations by providing targeted protection for children, older adults, outdoor workers, low-income households, and people with chronic diseases.
11. Improve public access to air-quality data through transparent online dashboards and mobile applications.
12. Strengthen regional cooperation, because air pollution crosses district, provincial, and national boundaries.

These recommendations are consistent with the direction of Punjab's existing clean-air initiatives and the World Bank-supported Punjab Clean Air Program.

9. Conclusion

Smog in Lahore District is a serious and multidimensional environmental hazard with consequences for public health, economic productivity, education, transportation, and social well-being. $PM_{2.5}$ represents the most important health concern because of its ability to penetrate deep into the respiratory system and contribute to cardiovascular and respiratory disease. Lahore's pollution problem is generated by multiple sources, including vehicles, industries, brick kilns, agricultural burning, waste combustion, dust, and regional pollution. The vulnerability of Lahore's population is unequal. Low-income households and outdoor workers may experience greater exposure while possessing fewer resources for protection. Strengthening community resilience therefore requires not only public awareness but also improved healthcare, reliable information, social support, and equitable environmental policies.

Punjab has established important regulatory and policy mechanisms, including the 2023 Smog Prevention and Control Rules and the Clean Air Policy. However, stronger

enforcement, monitoring, institutional coordination, and health surveillance are necessary. The World Bank-supported Punjab Clean Air Program provides an important opportunity to shift from temporary seasonal responses toward long-term emission reduction.

Ultimately, Lahore needs to treat smog as a persistent environmental and public-health risk rather than an annual emergency. A combination of clean transportation, industrial regulation, cleaner brick-kiln technology, agricultural alternatives, improved waste management, community engagement, scientific monitoring, and effective early warning can substantially reduce exposure. Long-term success will depend on sustained political commitment, transparent implementation, scientific evidence, and cooperation across administrative and regional boundaries.

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PARTICIPANT RESEARCH PAPER

Urban Flood Risk in Gujranwala District: Effects of Urban Expansion, Drainage Constraints, and Extreme Rainfall

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Abstract

The fourth largest urban centre of the country, Gujranwala is a strong industrial hub, which is getting more vulnerable to urban flooding due to the mix of unplanned urban expansion, old and insufficient drainage system and heavy monsoon rains. The population of the district increased to 5.96 million in 2023 from 3.40 million in 1998, whereas the Water and Sanitation Agency (WASA) drainage system has never been able to meet demand as urban development has always outpaced its expansion. In recent years, extreme rainfall events have consistently caused flooding in the Palkhu Nullah, Dek Diversion Channel, and municipal storm drains, inundating markets, households, roads, and resulting in the loss of life. The flooding has happened repeatedly in recent years in Palkhu Nullah, in the Dek Diversion Channel, in municipal storm drain systems, all due to extreme rainfall events which have flooded markets, inundated households, roads, and taken lives. In this paper, the hazard profile, drivers of vulnerability, institutional and scientific gaps, and mitigation options of the district are compiled and a policy pathway towards shifting the process of urban floods from reactive relief to anticipatory climate-resilient governance in Gujranwala is presented that can be followed by the framework of the National Disaster Management Authority (NDMA) and Provincial Disaster Management Authority (PDMA) Punjab.

Keywords: Climate Change Adaptation, Disaster Risk Reduction, Drainage Infrastructure, Palkhu Nullah, Urban Flooding.

1. Introduction

Urban flooding (flooding of urban built-up areas when the amount of rainfall exceeds the capacity of the natural and engineered drainage system) has emerged as one of the most frequent and expensive hazards in Pakistan and has been impacting cities like Lahore, Karachi, Peshawar, Rawalpindi, and increasingly secondary industrial cities like Gujranwala. Gujranwala, the “City of Wrestlers”, has been growing rapidly in the last 30 years without considering natural drainage lines that were established to carry the monsoon run-off towards the Palkhu Nullah and eventually to the Chenab River, which is estimated to contribute 5–9 per cent to the country's GDP due to the abundance of light-engineering, ceramics and hardware industries in the area. The lack of an incremental extension of the sewerage and drainage infrastructure is further complicated by informal and formal development encroaching on floodplains, natural waterways and colonial era culverts. The present research paper has explored the issue of urban flood risk in Gujranwala district with an analysis of three interacting drivers; namely urban expansion, drainage constraints, extreme rainfall and how their combined impact can be mitigated by concerted evidence-based action by the institutions. The goals are to:

1. Describe the flood hazard and historical flood events in the district;
2. understand the socio-economic vulnerability of populations exposed to floods;
3. Identify gaps in flood management science, technology and institutionalization; and
4. Recommend structural, non-structural, and policy interventions, in keeping with national Disaster Risk Reduction (DRR) and Climate Change Adaptation (CCA) agendas.

The scope includes all of Gujranwala district and emphasizing Gujranwala City Tehsil and Wazirabad along the Palkhu Nullah where the recent floods have been most intense.

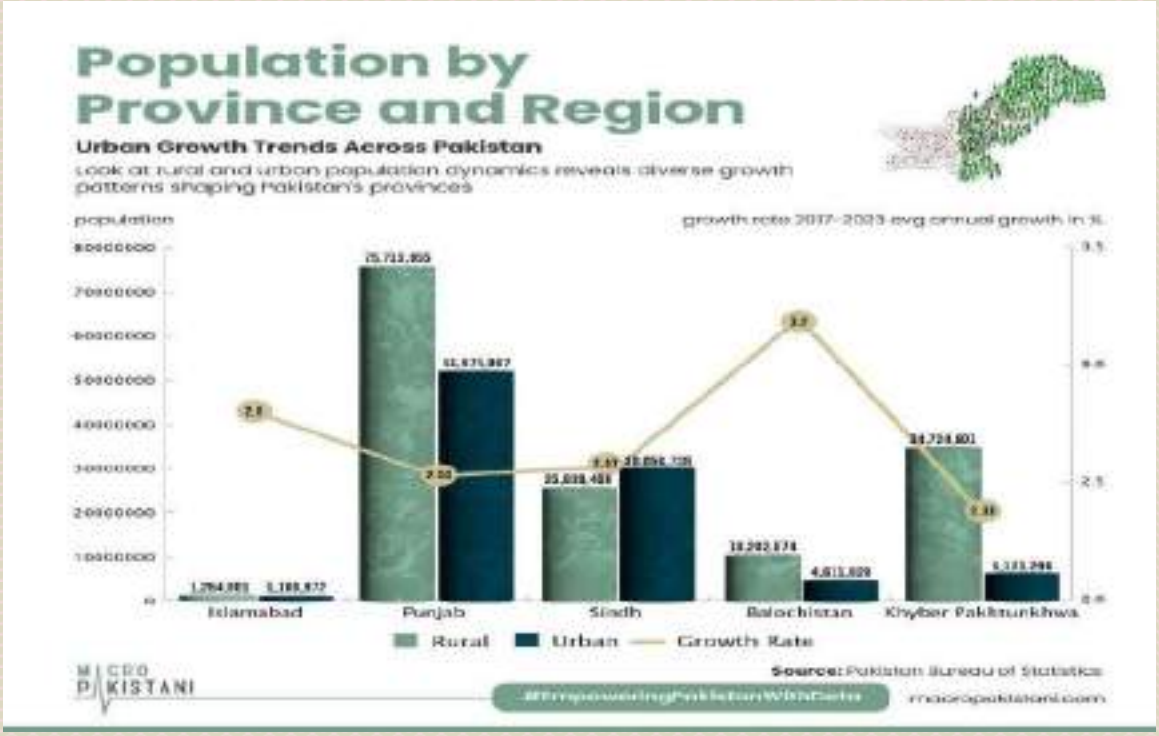
2. Regional Context & Hazard Profiling

Gujranwala district is situated in the elevation of the Chenab river system and is spread over about 3,622 km², with the Palkhu, Aik and Dek nullahs being the major seasonal hill torrent-fed streams that transport monsoon flow from the elevation of Sialkot–Narowal towards the Chenab. Its discharge is now flowing through, or next to, the developed

areas of Gujranwala City and Wazirabad and a surge in water level of the nullah results in a significant rise of water level in the urban areas without passing through open countryside, as it used to do several decades ago. The recent literature on monsoon changes in Pakistan shows a clear intensification trend, with observational and climate-model analyses suggesting that part of the observed increase in extreme rainfall over the region is due to anthropogenic warming, and independent trend analysis of daily monsoon extremes indicating a statistically significant increase in precipitation indices across Pakistan.

Table 1. Hazard, Exposure, Vulnerability, and Risk in the Gujranwala Context.

Concept	Application to Gujranwala
Hazard	Intense, often short duration monsoon rainfall (upto 250 mm in 2 hours) combined with high discharge flows in the palkhu nullah and Dek Diversion Channel exceeding design capacity.
Exposure	Residential mohallas, wholesale markets, industrial units, roads, schools, and health facilities situated in low-lying areas and along nullah embankments across Gujranwala city, Wazirabad, and Kamoke tehsils.
Vulnerability	Undersized 198-era drainage network, incomplete WASA works, floodplain encroachment, blocked colonial-era culverts, and limited household capacity to absorb repeated losses.
Risk	The probability of human, economic, and infrastructure loss arising from the interaction of hazard, exposure, and vulnerability, manifested in recurrent market and household inundation and periodic fatalities.



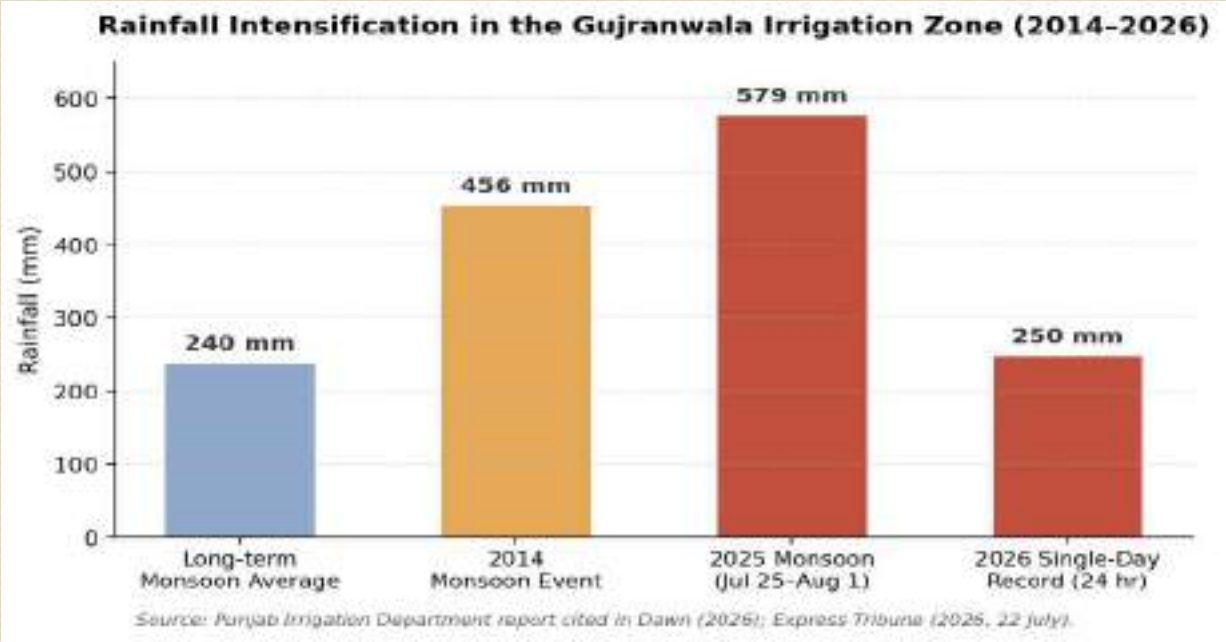
3. Risk & Vulnerability Assessment

The historical record of fluvial flooding events in urban areas during the Gujranwala irrigation zone during the last 12 years shows a progressive trend of increasing fluvial flooding risk in urban areas, which is summarized in Table 2 and shown in Figure 2. The average rainfall on the zone has been exceeded many a times and in 2025, it was over 240 mm, more than double the long-term average, with single day totals breaking records at Gujranwala city itself.

Table 2. Recorded Extreme Rainfall and Urban Flood Events Affecting Gujranwala

Year	Rainfall Recorded	Key Impacts
2014	456mm (isolated locations, Gujranwala irrigation zone)	Benchmark historic flood event in the irrigation zone prior to the 2025 season; widespread nullah overtopping.
2025	579 mm average, 25 Jul-1 Aug (irrigation zone)	Dek Diversion Channel peak discharge of 50,350 cusecs against a 35,200-cusec design capacity; 99 drains

		overflowed at 11 vulnerable points across Lahore and Gujranwala divisions.
2025	Forecast accumulation>350mm (late Aug-Sep)	PDMA ‘significant flood warning’ for Lahore, Gujranwala, and Gujrat divisions, over 150,000 people and 500,000 livestock relocated province-wide.
2026	250mm in 24 hours (Gujranwala city-record)	At least five deaths, including two children; homes, shops, and markets submerged; incomplete WASA works blamed for prolonged inundation.
2026	5000 cusecs discharge, palkhu Nullah, Wazirabad	“High flood” alert issued to Irrigation Department, PDMA, and district administration; rising water levels through Wazirabad.



In addition to inundation, flood water has been found to be contaminated with sewage, which also increases the risk of waterborne and vector borne diseases, as seen in other cities of Punjab. Gujranwala's daily-wage earners and small traders in the markets are already reported to be flood-affected for 2026 and they are losing income for every day of closure, and for industrial units, whose reliance is on ground floor storage, they are facing damage to their stocks. Women, children, older people and persons with disabilities were particularly affected in terms of evacuation of narrow, waterlogged streets as well as access to safe sanitary facilities, consistent with observations of Pakistan's monsoon season of 2025, where more than half of all fatalities nationally resulted from house collapse disproportionately affecting low-income and informally constructed housing.

4. Community Resilience Factors

The people of Gujranwala have shown their informal resilience time and time again despite the shortcomings in the institutions. As was observed in other urban locations across Punjab, self-help was observed in Wazirabad when households were seen clearing their homes during the July 2026 floods, while WASA and the district administration mobilised the drainage operations. The long settled mohallah communities usually have accurate and practical knowledge of which streets, culverts or drains it is expected to flood first, which is not always recorded systematically by the municipal authorities. This resilience needs to be enhanced by establishing formal disaster management committees in the community, involving traders' associations (due to the commercial nature of the impact of flood in the wholesale markets) and school-based preparedness measures and civil-society organisations in the pre-monsoon drain-clearing drives and preparedness of household, and making it a formal, recognized part of the district's DRR system.

5. Scientific & Institutional Gaps

The responsibility of the flood related infrastructure in Gujranwala is divided into the WASA Gujranwala (water supply, sewerage and drainage), Gujranwala Development Authority (land-use planning and approvals), Punjab Irrigation Department (nullahs and diversion channels), Metropolitan/Municipal Corporation (solid-waste management), and PDMA Punjab and NDMA (disaster coordination). This division of mandate is fairly

widespread across the globe, and it's a problem that was cited in the 2025-2026 flooding in Lahore and Gujranwala divisions, when an assessment by the internal Irrigation Department of Punjab mentioned that many of the culverts constructed during the colonial era to enable natural drainage had been blocked by subsequent structures, creating coordination gaps.

Table 3. WASA Gujranwala Infrastructure snapshot.

Indicator	Status
Year Established	1997, under the Gujranwala Development Authority
Service Area	73 urban union councils, approximately 160km2
Water Supply Coverage	37% of service area
Sewerage/drainage coverage	71% of service area
Core Sewer network age	Dating 1968, extended in four subsequent phases
Disposal Infrastructure	40 disposal stations discharging to the Mir Shikaran seepage Drain and Ado Rain Drain

No published, regularly updated hydraulic or hydrological model (like those developed for other South Asian cities using models like HEC-HMS coupled with GIS) exists that quantifies the stormwater runoff generated by Gujranwala's present urban development against present drainage capacity, as opposed to planning for urban development in advance of the stormwater runoff generated. The existing academic studies on urbanization of Gujranwala have focused on the Urban Heat Island effect (UHI), in one such study based on Landsat data, the surface temperatures had increased by 8°C from 2003 to 2018 due to built-up expansion, whereas relatively fewer studies in the peer-reviewed literature have focused specifically on pluvial flood risk, creating an identified gap in the literature that this paper aims to address through an integrated hazard–drainage–governance framework.

6. Mitigation Strategies & Best Practices

Structural Measures

- Upgrade and desilt trunk and lateral sewers that were designed prior to 1968 to meet current impervious surface area standards.
- Widening and desilting of Palkhu Nullah and also of Dek Diversion Channel before monsoons and put conveyance of at least design discharge (35200 cusecs and above for Dek channel).
- Identify, reopen and protect closed colonial era culverts through legal means.
- Implement Sponge City style green infrastructure in new green development for housing (GDA) schemes, including permeable pavements, retention basins and rain gardens.
- Build localized embankments and elevate critical infrastructure at locations that will be flooded regularly like Awan Chowk.

Non-Structural Measures

- Impose a policy of no construction on floodplains, natural waterways and drainage rights-of-way using GDA zoning.
- Improve municipal solid waste disposal service to reduce the blockage of drains and culverts.
- Establish pre-monsoon desilting audit and make it public reporting and ensure completion of audit.
- Strengthen technical capacity in WASA and the Municipal Corporation, in the areas of GIS based Flood Hazard Mapping and Hydraulic Modelling.

7. Risk Communication & Early Warning

The early warning infrastructure already exists at the basin level for Gujranwala: PMD Flood Forecasting Division provides flood warnings for the flows of Palkhu, Aik and Dek Diversion nullah and the Punjab Flood Warning Centre reports real-time discharge measurement (in 5,000 cusecs) for Gujranwala's Palkhu Nullah during high flood conditions. What needs to be built is the final link between the warnings, at the river and nullah level, and the local level action, in urban areas. The 24-hour WASA Control room and more than 200 monitoring cameras installed throughout the city of Lahore in the year 2026 is a replicable model for Lahore. For Gujranwala, this needs to be

complemented with SMS and mobile-app alerts, community-loudspeaker announcements, and simple, multilingual messaging that is accessible to residents of informal settlements, women, older persons, and persons with disabilities, and community-based early-warning volunteers who are directly connected to the district administration structure of PDMA Punjab.

8. Institution Wise Policy Recommendation

Table 4. Institution-wise policy recommendations

Institution	Recommended Actions
NDMA	Develop a national urban flood risk management framework that formally incorporates secondary industrial cities such as Gujranwala, promote GIS, and AI based flood forecasting as standard practice across PDMAs.
PDMA Punjab	Strengthen district-level preparedness plans for Gujranwala division, conduct annual flood simulation exercises, ensure timely dissemination of Flood Forecasting Division advisories to district administration.
Gujranwala Development Authority (GDA)	Enforce floodplain and drainage right-of-way zoning, require stormwater retention infrastructure in new housing-scheme approvals.
WASA Gujranwala	Expand sewerage/drainage coverage beyond current levels, commission a citywide hydraulic drainage model, complete pending drainage works. before each monsoon season.
Punjab Irrigation Department	Restore and maintain design discharge capacity of the Palkhu Nullah and Dek Diversion Channel, audit and reopen blocked culverts along nullah corridors.
Pakistan Meteorological Department (PMD)	Expand radar coverage and real-time rainfall forecasting for the Gujranwala-Sialkot corridor,

	strengthen last-mile flood warning dissemination.

9. Conclusion

Urban flood risk in Gujranwala is not just a result of extreme rainfall, but of extreme rainfall being imposed upon a drainage network originally designed for a much smaller and less built-up city, and an urban footprint which has repeatedly intruded into the watercourses that would otherwise run off the city. As the district's population and built-up area keeps growing, the hazard is getting worse as seen in the recorded escalation of a 240 mm long term average monsoon to 579 mm in 2025 and 250 mm in 2026. This compound risk can only be mitigated by coordinated investments in modernized drainage and nullah infrastructure, the effective implementation of floodplain zoning, the incorporation of GIS and AI based forecasting tools already available at the basin scale and the formal recognition of the coping capacity of the community. Addressing urban flood resilience requires a multi-sectoral approach that includes science-based planning, institutional coordination and social resilience.

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PARTICIPANT RESEARCH PAPER

Urban Resilience Planning Under Rapid Urbanization and Climate Change: An Empirical Study of Institutional and Infrastructure Readiness in Metropolitan Pakistan

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Abstract

Rapid, unguided urbanization and intensifying climate change are converging to create severe structural, social, and institutional risks in Pakistan's metropolitan centers. This empirical study examines the operational readiness of urban planning and disaster management authorities in the Islamabad Capital Territory and the adjoining Rawalpindi metropolitan corridor. Using a mixed-methods design, the study developed and validated two instruments the Urban Infrastructure Vulnerability Scale (UIVS; α = .89) and the Institutional Disaster Preparedness and Adaptation Scale (IDPAS; α = .92) administered to 340 urban planners, disaster management officials, engineers, and community stakeholders. Regression analysis showed that infrastructure vulnerability (β = .42, p < .001) and weak institutional preparedness (β = -.38, p < .001) together explained 58% of the variance in perceived urban disaster severity. Findings indicate that while national policies such as the National Adaptation Plan 2023 align well with global standards, execution is undermined by institutional fragmentation, outdated hydraulic infrastructure, and socio-spatial inequity in informal settlements. The paper concludes with targeted recommendations for the National Disaster Management Authority to strengthen integrated, evidence-based urban resilience governance.

Keywords: Climate Change Adaptation; Disaster Risk Reduction (DRR); Institutional Preparedness; Pakistan; Urban Resilience

1. Introduction

Global climate projections confirm that extreme weather events are increasing in frequency and severity, creating unprecedented operational challenges for urban systems (Abdul & Yu, 2020). Cities across the global South are expanding rapidly, but this growth is largely driven by unplanned spatial expansion, informal housing proliferation, and degradation of natural ecological buffers (United Nations Human Settlements Programme [UN-Habitat], 2023). Pakistan illustrates this dual crisis acutely: as the world's fifth most populous nation, it is experiencing annual urban population growth above 3.0%, with more than 54% of its urban population concentrated in a handful of major metropolises (Ministry of Planning, Development & Special Initiatives, 2024).

The convergence of unguided urban growth and climate volatility has turned cities into high-risk environments. The 2022 monsoon floods affected over 33 million people nationwide, recurring monsoon inundation now regularly disrupts low-lying sectors and nullahs of Islamabad, and lethal urban heatwaves have become common. Drainage systems designed for historic rainfall patterns are routinely overwhelmed by shortduration, high-intensity cloudbursts, while encroachment on natural drainage channels restricts stormwater discharge and converts heavy rainfall into flash flooding.

National frameworks including the National Disaster Risk Reduction Policy, the National Adaptation Plan (NAP) 2023, and the Pakistan Green Building Code 2023 exist, but a persistent gap separates high-level policy formulation from municipal execution. Urban planning authorities, such as the Capital Development Authority (CDA) and provincial development bodies, often operate in isolation from the disaster management architecture overseen by NDMA and the Provincial Disaster Management Authorities (PDMAs).

This study addresses that gap empirically. Its objectives are to: (1) assess the physical, environmental, and spatial vulnerabilities of urban infrastructure under rapid growth and extreme weather; (2) measure the organizational readiness, inter-agency coordination, and policy implementation capacity of relevant authorities; (3) validate two purpose-built assessment scales UIVS and IDPAS for disaster management research in South Asia; and (4) deliver evidence-based recommendations to NDMA for building climate-resilient

urban governance. The scope of the study is limited to the Islamabad Capital Territory (ICT) and the Rawalpindi metropolitan corridor.

2. Regional Context & Hazard Profile

Urban resilience is defined as the capacity of an urban system including its population and underlying ecological and socio-technical networks to absorb, adapt to, and recover from chronic stresses and acute shocks without losing core functions (Asian Development Bank [ADB], 2014; Latif & Yu, 2020). Traditional planning relied on hard, engineered protection such as embankments and concrete storm channels; contemporary DRR discourse instead emphasizes ecological and adaptive resilience, incorporating bluegreen infrastructure and dynamic land-use governance.

Urbanization in Pakistan has outpaced municipal service provision and regulatory enforcement. UN-Habitat (2023) reports that approximately 40.1% of urban residents in major Pakistani cities live in informal settlements (Katchi Abadis), many sited-on floodplains, riverine zones, and active drainage channels. Conversion of permeable land to impermeable concrete accelerates surface runoff, intensifies urban heat island (UHI) effects, and degrades groundwater recharge (Himalayan Water Project, 2024).

For clarity, this study adopts standard DRR terminology: a hazard is a potentially damaging physical event or phenomenon (e.g., a cloudburst or heatwave); exposure refers to people, assets, or systems located in hazard-prone areas; vulnerability is the set of physical, social, economic, and institutional conditions that increase susceptibility to harm; and risk is the probable loss arising from the interaction of hazard, exposure, and vulnerability.

Within this framework, the ICT Rawalpindi corridor faces two dominant hazard streams. Hydro-meteorological hazards include localized monsoon cloudbursts that overwhelm sectors designed without adequate hydraulic capacity, illustrated by recurring inundation in Sector E-11 and adjoining nullahs. Thermal hazards stem from rising ambient summer temperatures, high structural density, and loss of green canopy. Both are compounded by governance and regulatory deficits: weak enforcement of master plans, unapproved land conversion, poor solid-waste management that blocks drains, and fragmented jurisdiction among municipal, federal, and military land authorities.

3. Risk & Vulnerability Assessment

To quantify these vulnerabilities, the study combined psychometric scale administration with structured institutional evaluation in a cross-sectional, mixed-methods design (N = 340). Participants were sampled through multi-stage stratified random sampling across three sectors: disaster management institutions (NDMA, PDMA, Rescue 1122, Civil Defense; n = 110); urban planning and development authorities (CDA, RDA, municipal corporations, Planning Commission; n = 130); and civil society, academic experts, and community representatives (n = 100).

Two instruments were developed and validated: the ten-item Urban Infrastructure Vulnerability Scale (UIVS; M = 38.42, SD = 6.18, α = .89) and the ten-item Institutional Disaster Preparedness and Adaptation Scale (IDPAS; M = 24.15, SD = 7.34, α = .92), both exceeding the standard α ≥ .80 reliability threshold (Table 1).

Instrument	No. of Items	Mean (M)	SD	Cronbach's α
Urban Infrastructure Vulnerability Scale (UIVS)	10	38.42	6.18	.89
Institutional Preparedness & Adaptation Scale (IDPAS)	10	24.15	7.34	.92

Note. N = 340.

Pearson correlations showed that institutional preparedness was strongly and negatively associated with infrastructure vulnerability (r = -.61, p < .001) and with historical disaster impact (r = -.54, p < .001), while infrastructure vulnerability was strongly and positively associated with historical disaster impact (r = .68, p < .001) (Table 2).

Variables	1 (UIVS)	2 (IDPAS)	3 (HDI)
1. Urban Infrastructure Vulnerability (UIVS)	1.00	-.61**	.68**

2. Institutional Preparedness (IDPAS)	-.61**	1.00	-.54**
3. Historical Disaster Impact (HDI)	.68**	-.54**	1.00

*Note. ** p < .001.*

A multiple linear regression predicting perceived urban disaster severity confirmed that infrastructure vulnerability (β = .42, p < .001) and institutional preparedness (β = -.38, p < .001) were both significant predictors, jointly explaining 58% of the variance (R^2 = .58, F(2, 337) = 232.41, p < .001) (Table 3).

Model Predictors	Unstd. B	Std. β	t	p
(Constant)	12.45	—	6.84	< .001
Infrastructure Vulnerability (UIVS)	0.46	.42	9.20	< .001
Institutional Preparedness (IDPAS)	-0.39	-.38	-8.11	< .001

Note. R = .76, R^2 = .58, Adjusted R^2 = .57.

Beyond the aggregate scores, the assessment surfaced concrete socio-economic dimensions of risk. Informal settlements (Katchi Abadis) bear disproportionate exposure: located on ecologically vulnerable, low-lying land and lacking municipal stormwater networks, these communities suffer greater asset loss, livelihood disruption, and health risk from sewage contamination during monsoon flooding, with knock-on effects for household food security when access routes and local markets are cut off. Within these communities, women, children, older residents, and persons with disabilities face compounded susceptibility women and children are disproportionately involved in unpaid water, sanitation, and care work that intensifies during and after flood events, while limited mobility raises risk for older and disabled residents during evacuation. These

patterns indicate that exposure and susceptibility in Pakistan's metropolitan areas are shaped as much by socio-spatial inequity as by physical hazard intensity.

4. Community Resilience Factors

Despite weak formal systems, informal social capital provides an important, underleveraged buffer against urban shocks. Neighborhood and mohalla-level networks routinely undertake ad hoc drain clearance, mutual aid during flooding, and informal early warning by word of mouth ahead of forecast heavy rain. Long-settled residents of flood prone sectors often carry indigenous knowledge of local drainage behavior and seasonal risk patterns that is rarely captured in formal hazard mapping but could usefully inform it. Community participation in formal urban planning and disaster preparedness processes nonetheless remains minimal: residents are typically informed of decisions rather than consulted in them, and community-based organizations are rarely integrated into municipal drainage or zoning decisions.

Where community resilience capacities have been mobilized for example, through Rescue 1122's community engagement activities response times and hazard awareness have measurably improved. This suggests that formalizing and resourcing existing community networks, rather than building parallel structures, is likely to be the most cost-effective path to strengthening grassroots resilience.

5. Scientific & Institutional Gaps

The empirical findings point to several structural gaps. Inter-agency coordination emerged as one of the weakest measured dimensions (IDPAS Item 2: M = 2.12, SD = 0.81), confirming a persistent operational silo between urban development agencies responsible for zoning and master-plan execution and disaster management bodies responsible for emergency response; disaster management therefore remains largely reactive rather than integrated into spatial planning.

Data availability and quality are similarly limited: no shared, real-time geospatial platform for hazard monitoring or vulnerability mapping exists across CDA, RDA, and NDMA/PDMA systems, constraining evidence-based decisions. Adoption of AI/ML and predictive modeling for hydraulic forecasting, heat-risk mapping, and early warning also remains minimal compared to regional peers, representing an unrealized opportunity for low-cost forecasting gains. Municipal technical staff often lack training in climate-

adjusted hydraulic design, GIS-based planning, and risk communication. Finally, while strategies such as the Pakistan Green Building Code 2023 and NAP 2023 are conceptually strong, municipal-level enforcement is compromised by political pressure, competing land development priorities, and budget constraints.

6. Mitigation Strategies & Best Practices

Addressing these gaps requires both structural and non-structural measures. On the structural side, municipal engineering standards should shift from exclusive reliance on concrete channels toward nature-based solutions: permeable paving, urban retention ponds, restored wetlands, and expanded urban forest canopy (Urban Green Belts) to increase infiltration, control runoff, and reduce urban heat island effects. Hydraulic design baselines also need revision, with stormwater infrastructure standardized to withstand 50to-100-year return-period precipitation events rather than the historic 10-to-20-year baselines currently in use.

On the non-structural side, capacity building for municipal engineers and planners in climate-adjusted design and GIS-based risk mapping, public awareness campaigns on flood and heat safety, and regular multi-agency preparedness drills would strengthen readiness without requiring major capital investment. Regional best practices, such as blue-green infrastructure programs adopted in other South and Southeast Asian cities, offer transferable models for retrofitting Pakistani urban drainage systems at comparatively low cost.

7. Risk Communication & Early Warning

Effective risk communication is central to reducing urban disaster impact, particularly for informal settlements that are both highest-risk and least-served by formal systems. Localized, people-centred early warning systems covering flash flooding and extreme heat should be established at the sector and neighborhood level, using SMS alerts, mosque loudspeakers, and community volunteer networks to close the “last mile” gap that formal meteorological warnings typically fail to reach. These systems should be explicitly gender-sensitive, ensuring that warning content and channels reach women and other groups who may have less access to public information spaces.

Partnering with Rescue 1122 to form trained neighborhood volunteer teams, combined with improved micro-drainage and sanitation in Katchi Abadis, would materially reduce

flash-flood casualties and displacement. Engaging communities in designing these systems, rather than simply informing them, is essential to ensure warnings are trusted and acted upon.

8. Policy Recommendations

Based on the empirical findings, this paper submits the following recommendations to NDMA, in collaboration with provincial disaster management authorities and municipal development bodies:

- Mandate Integrated Risk Assessment and Zoning: Require compulsory Climate and Disaster Risk Assessments (CDRA) for all urban development, housing, and commercial projects prior to master-plan approval, with strict zoning buffers along floodplains and natural drainage paths, backed by meaningful legal and financial penalties for encroachment.
- Operationalize Institutional Coordination: Establish an Urban Climate Resilience Taskforce (UCRTF) jointly led by NDMA, the Ministry of Climate Change and Environmental Coordination, and provincial urban development authorities (CDA, RDA, LDA, KDA), supported by a shared GIS-based vulnerability-mapping platform for real-time hazard monitoring and joint operational planning.
- Strengthen Institutional Capacity and Evidence Use: Invest in training municipal staff in climate-adjusted hydraulic design and GIS-based planning, and institutionalize the use of empirical instruments such as UIVS and IDPAS for periodic, evidence-based monitoring of urban resilience across metropolitan Pakistan.

Together, these measures would help close the gap between Pakistan's well-developed national policy frameworks and their inconsistent execution at the municipal level.

9. Conclusion

This study demonstrates empirically that urban disaster severity in metropolitan Pakistan is driven less by hazard intensity alone than by the interaction of physical infrastructure vulnerability and institutional preparedness gaps, which together explained 58% of the variance in perceived disaster severity. While national policy frameworks are conceptually well-aligned with global standards, municipal execution remains hampered by institutional fragmentation, outdated hydraulic infrastructure, and socio-spatial

inequity affecting informal settlements. Building genuine urban resilience will require an integrated approach that combines science-based infrastructure planning, mobilization of existing social capital and indigenous community knowledge, wider adoption of geospatial and predictive technologies, and sustained inter-agency coordination. The recommendations offered here provide NDMA and its partner agencies with a concrete, evidence-based starting point for that integration.

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PARTICIPANT RESEARCH PAPER

Integrated Flood Risk Assessment in Dera Ghazi Khan: Hill Torrents, Riverine Flooding and Climate Resilient Infrastructure

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Abstract

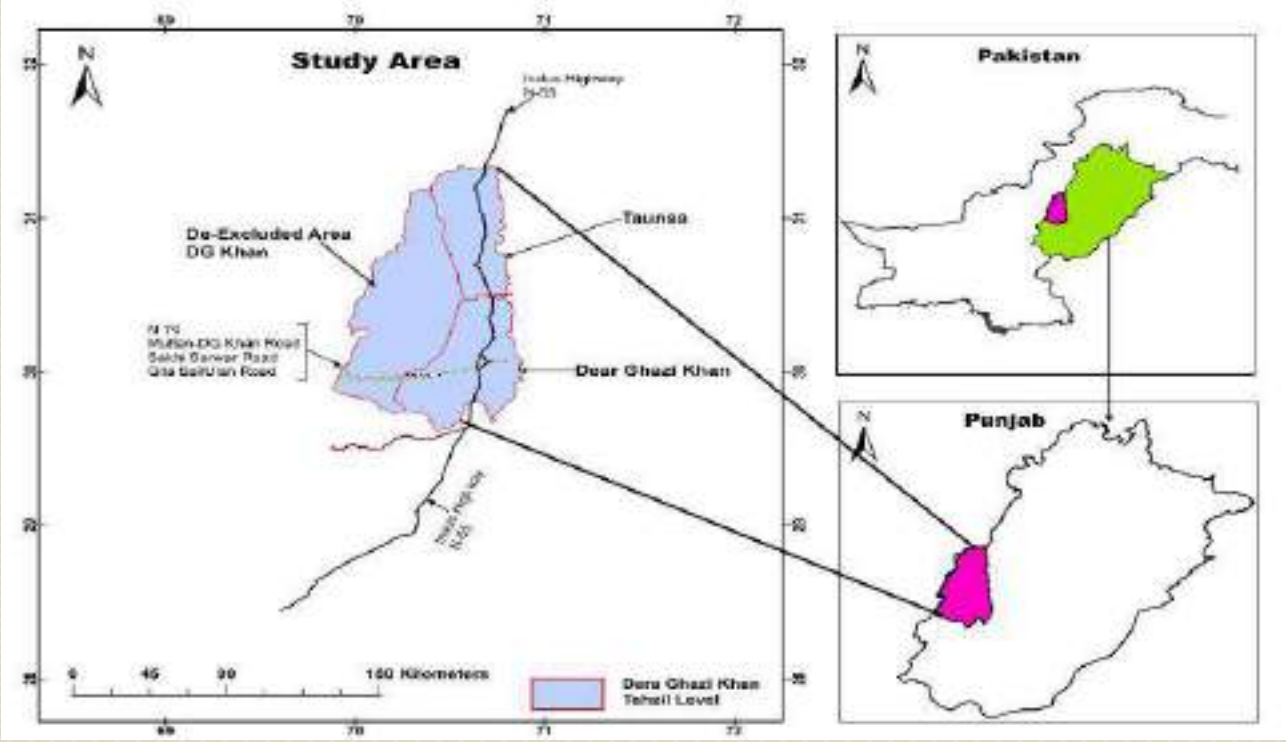
Dera Ghazi Khan lies between the Koh-e-Suleman range and the Indus River. It is a narrow plain exposed to two hydrologically distinct flood hazards that are managed as one. The western catchment's hill torrents arrive as sediment-laden flash floods with lead times of under an hour, while the Indus riverine floods develop over days and remain on the land for weeks. This research paper integrates findings from published hydrological simulations, census and post-disaster assessments, government audit findings and the event record for 2010, 2012 and 2022. It finds that risk in this domain is additive rather than compounded. The same populations, croplands and lifeline infrastructure are exposed to both hazards, yet the forecasting and warning systems are primarily calibrated for the river. It also demonstrates that the three statutory tiers created by the National Disaster Management Act 2010 are sound in concept but inconsistently implemented, leaving the district-level plan yet to be sufficiently prepared and executed. Recommendations are aimed at management and storage rather than exclusion and include catchment gauging, delay-action storage, elevated critical facilities, impact-based early warning and statutory district planning.

Keywords: Climate Resilient Infrastructure; Dera Ghazi Khan; Disaster Risk Reduction; Hill Torrent; Riverine Flooding.

1. Introduction

Background

District Dera Ghazi Khan is located as the most southern district of Punjab during the colonial era of Sub-continent. Before this it was a part of Derajat under Sikh rule. The Town of Dera Ghazi Khan was formed by a Mirani Baloch Sardar Haji Khan in 1476 near the west bank of Indus. The region enjoyed important status during the last five centuries due to its geo strategic position. Its boundary is not only linked with all provinces but it is an important military and trade route for Sindh and Balochistan. The region has variety of geographical surface as hilly area with plain and Kacha near as riverine. The mountain range is also rich with mineral but the harsh climatic impacts has affected the life and culture in the region. Many areas of Dera Ghazi Khan are densely populated with barren areas but overall, the geo-strategic position of Dera Ghazi Khan plays a vital role in the political geography.



Mountain Region

The mountain region of Dera Ghazi Khan is known as Sulaiman most of which is situated in Balochistan Province. The average height of mountain is about 1000 feet,

/305 meters but at several places it exceeds 7000 feet/213 meters. In Dera Ghazi Khan District the highest Peak is Ek-Bai / Yak-Bai (One More) which is 7,462 feet. /227meters high. Next to it is Fort Manroo 6,470 feet/1972 meters high with the exception of some high points, the mountains is mostly rugged and bare of any vegetation and foliage. The Mountain are formed of sandstone with occasion outcrops of limestone. Lack of vegetation makes these mountains susceptible water action during rainy reason which have created fantastic landscapes. However, at high altitudes wild trees like Olive, acacia, peesh and other shrubs and hedge grow abundantly. The wood of olive and acacia trees is used as fuel. These mountains have rich deposits of many useful and valuable minerals including gypsum, coal and uranium. Transhumance lifestyle is very common in this region people typically move lowlands in winter and highlands in summer.

Hill Torrents

From Suleiman Range many hill torrents flow eastwards through narrow gorges and finally discharge their water in the Indus. Three of them are quite Big and originated at a very high levels and brings with them huge boulders. In the monsoon seasons these torrents flow at full speeds. The numbers of these books also increases manifolds. They inundate many villages in the plains and cause heavy damage to crops and roads. However, these torrents are not without blessings. In final analysis these prove beneficial from agricultural point of view because they brings with them silt from them mountain and deposits it in the plains. This Layer of silt increase the fertility of land. The flood water of hills torrents is also stored by erecting mall embankments and then used for consumption by men and animals as well as for irrigation. The famous hill torrents of the region are Bathi, Kanwan and Manoi in tehsil Taunsa Sharif. Soi, Vador, Sakhi Sarwar and Mithwan are in tehsil Dera Ghazi Khan.

River Indus

The majestic Indus has played a pivotal role in the evolution of traditions and cultures of not only these districts but the entire Indus Basin. Between 1900-1500 B.C. when the Aryans arrived in the sub-continent, they also admired and acknowledged the greatness and importance of this river. In the sacred Hindu book Rig Vedas, the river has been highly praised and declared superior to all other rivers. This river flows from north to

south along the entire border of 210 mile/ 337 kilometers of the division. The width of the river, at some places, is between 10 to 13 miles /15 to 20 kilometers. The water level rises during the month of May and remains high till the end of August. Due to increase, in the level and velocity of river water, the nearby settlements are inundated and remain submerged for about three months. Due to the agricultural and economic importance of this river, the Hindus gave it the title of Jhanda Peer while the Muslims called this river as Khawaja Khizar and Dill Darya. In 1958 a barrage was constructed on it near Taunsa Sharif. From this barrage a canal namely Dera Ghazi Khan Canal was drawn which irrigates a vast area of the district. In 1984, at a place named Ghazi Ghat, a bridge was constructed over the river which reduced the distance between Multan and Dera Ghazi Khan to 60 Miles 100 kilometers. Near the bridge still stands marooned the Queen of Indus steam ship that used to take passengers across the River.

Figure 1: Ghazi Ghaat

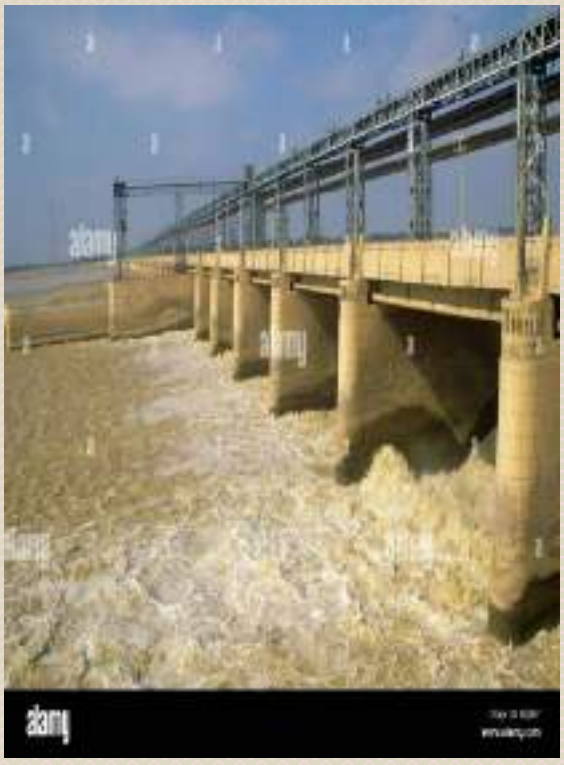


Figure 2: Taunsa Barrage

Climate

The district is some 457 miles /736 kilometers away from the sea with average height of about 1000 feet/305 meters above sea level. However, at places in the Suleiman Range the height as more than 7000 feet/2133 meters. The climate of the two districts varies as one move from plains to the mountain heights. In general weather of the entire region is humid and hot. The winters and summers remain dry. The duration of winter season is very short. Only December and January are the cold months. During extreme cold, night temperature falls below freezing point. Chilly winds blow, with sporadic rains for a few days during January while weather remains pleasant during the months of November and January. After 15th March the temperature begins to rise. The moths of June, July and August are the hottest. After 15th April hot winds start blowing, which cause scorching heat during the month of May. Such hot wind is locally called too. During the months of May and June windstorms blow in afternoons. During June the mercury shoots up to 50 degrees centigrade bringing ordinary activities to a standstill during mid-day. There is an insignificant rain fall in the end of July and August, but very often monsoons pass away without any rain. On the other hand, climate of the mountainous region is mostly cold. It is mildly hot in summer. In the moths of May and June, nights at Fort Munro are bracing and night temperature falls below 34 degrees Centigrade. Gentle breeze blows throughout the day. There is also a good deal of rain which causes hill torrents to flow and makes the weather cold. Weather is very cold from the month of October to March and people from such areas migrate to plains to save themselves from cold and also to protect their animals from starvation as grass goes dry in the pastures. There is occasionally some snowfall on the high hills especially at Fort Munro.

Flood

Flood risk in Pakistan is most often described in terms of the Indus and its tributaries. The framing is incomplete for Dera Ghazi Khan, a narrow strip of land between the Koh-e-Suleman range and the Indus, served by water from both directions on two separate clocks, and the same population is expected to absorb it. Riverine floods can be forecasted at barrage level, offering days of lead time Hill torrents can develop in ungauged catchments, over half of which are in Balochistan and can occur within an

hour of the rainfall that no gage records (Saleem et al., 2023). But the combined risk is treated as if it were a single hazard.

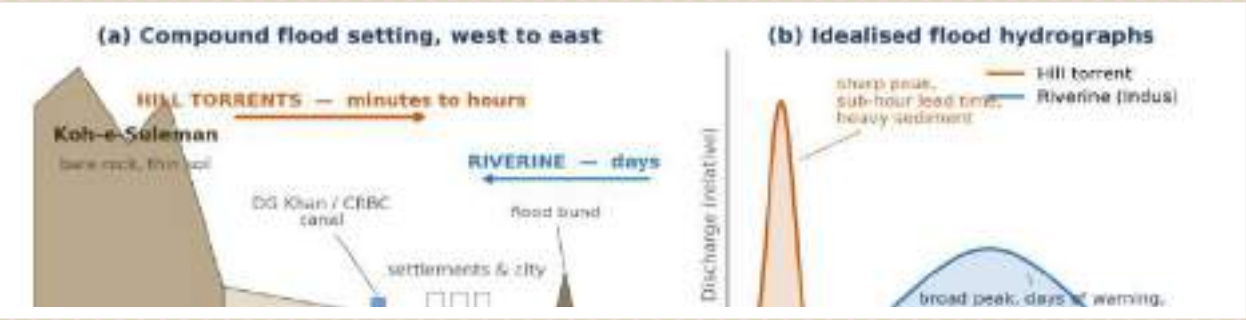
In the present research, the two hazards are differentiated by their physical characteristics but are treated together in terms of their effects. Its aims to assess:

- Socio-economic impact
- Vulnerability to hazards
- To rank climate-resilient measures
- to review the institutional architecture
- Identify governance gaps
- Characterize hazards and their exposure. The methodology is a systematic review of secondary evidence, including peer-reviewed modeling, census statistics, audit reports, event records and post-disaster needs assessment findings.

2. Regional Context and Hazard Profile

The 2023 census reported a population of 3.39 million in Dera Ghazi Khan with almost 75% of the total population residing in rural areas (PBS, 2023). The literacy rate was around 44%. The climate is arid to semi-arid with irregular distribution of rainfall of 125 to 375 mm per annum (Rashid, 2016). The district is one of the poorest in the country, something that affects how much of each flood is carried over into the next. Traditionally, risk is a function of hazard, exposure and vulnerability, and can be reduced by influencing any of these three factors (UNDRR, 2015). The Suleman Range is blessed with more than 200 hill torrents which emerge from the hills and flow eastward into Dera Ghazi Khan and Rajanpur. Of these, 13 torrents have large catchments and the capacity for major floods (Rashid, 2016). The primary districts impacted are Sanghar, Vehowa, Sori Lund, Vidore, Sakhi Sarwar and Mithawan. The two districts contain about 45% of the total catchment, with the rest in Balochistan, so the rainfall that results in a flood in Punjab often falls under different administration.

Compound flood setting: (a) west-to-east cross-section; (b) idealised hydrographs.



Author's schematic, after Rashid (2016) and Saleem et al. (2023).

The two differ in almost every operationally relevant respect (Table 1). Treating them as one is a category error: the measures suited to a slow, forecastable flood are largely the opposite of those needed against a fast, sediment-laden surge.

Table 1. Comparative characteristics of the two flood hazards.

Characteristic	Hill torrent (west)	Riverine flood (east)
Trigger	Convective rain over Suleman catchments	Monsoon accumulation, upper Indus basin
Lead time	Minutes to hours; often under one hour	Days; trackable between barrages
Duration	Hours	Days to weeks of standing water
Sediment	Very high; channels shift between seasons	Moderate; silt on the floodplain
Main defense	Storage, dispersion, cross-drainage works	Flood bunds, with sudden failure on breach
Dominant loss	Housing, livestock, road and canal crossings	Standing crops, housing, displacement

3. Risk and Vulnerability Assessment

Exposure

The peak discharges and the catchment areas modeled range over two orders of magnitude. Sanghar has a drainage area of 4786 km2 and can produce a modeled 100-year peak of around 226,000 cusecs. Sakhi Sarwar has a catchment forty-five times smaller but due to its high runoff coefficient and steep slopes still generates about 16,500 cusecs (Saleem et al., 2023). So, a small catchment does not replace a small hazard. The estimated total contribution of these torrents to the Indus is 0.5 to 0.8 million

acre-feet with return periods of 25 to 200 years. This volume is sufficient to raise the stage of the river downstream.

Event Record

The latest record covers the full range of the hazard from disaster only driven by torrents to a joint season where both mechanisms are active simultaneously.

Table 2. Recorded flood events and their dominant mechanism.

Year	Mechanism	Recorded impact
2010	Torrent-led, then riverine	Torrent flows also raised Indus levels; 1,778 villages affected in 11 districts (Hashmi et al., 2012).
2012	Hill torrent only	Three torrents plus a canal breach affected some 300 villages (Dawn, 2012).
2022	Compound	342 villages damaged, 699,502 people affected; Indus Highway submerged (Saleem et al., 2023).

Socio-economic impact

Losses are concentrated in three asset classes that poor households cannot self-insure: mud-brick housing, standing crops, and livestock. The national assessment of 2022 estimated that, in the absence of decisive recovery support, between 8.4 and 9.1 million people could be pushed below the poverty line and the worst affected sectors were housing, agriculture and livestock and transport (Ministry of Planning, Development and Special Initiatives, 2022). However, when livestock and stored grain are your working capital, one event can turn a functioning farm economy into a multi-year cycle of debt.

Vulnerable groups and gender

Vulnerability is unevenly distributed. Women are more likely to be at home when a daytime torrent arrives, less likely to be reached by warnings issued through male-dominated public channels, and face acute privacy and health constraints during evacuation. Livestock losses fall heaviest on them, since they manage the animals. In the 2026 rescue at Shero Dasti, boats evacuated people, livestock and wheat stocks together, which is how households themselves rank what must be saved (Express

Tribune, 2026a). Rod kohi or spate irrigation is an age-old system where torrent water is deliberately diverted over the Pachad plain, deposits fertile silt and supports sorghum, millets, oilseeds and pulses on land with no canal supply. Distribution proceeds by the usual rules of successive upstream to downstream rights (Saleem et al., 2023). If managed well, this water improves income, yields and living standards measurably (Kamran, 2014). The policy implication is telling: the hazard is also the livelihood and any measure that would simply block torrent water would destroy the asset base it is meant to protect. Communities have also operational knowledge that is not captured in any instrument: which crossings fail, how long it takes for a torrent to arrive. While the system should not be romanticized, small embankments fail in high flows and local storage is inadequate.

4. Scientific and Institutional Gap

The catchments are not gaged. Their contribution to Indus flows is not reliably measured. Modeling uses satellite topography, soil grids and a few distant rain gages, with Barkhan often being the only representative station (Saleem et al., 2023). Trends analysis shows mean rainfall decreasing with increasing extremes, the most difficult pattern to design for. Sediment transport analysis is repeatedly missing and machine-learning nowcasting from existing satellite inputs has not been operationalized here. The most consequential gap is institutional. The Auditor General's report for 2024-25 linked weak pre-disaster planning to over Rs 7.17 billion spent rehabilitating canals damaged in the 2022 and 2023 floods (Express Tribune, 2026b; Pakistan Today, 2026). Reactive expenditure on that scale measures the cost of the planning gap.

Institutional Roles

Responsibility for flood risk in Dera Ghazi Khan sits with the three statutory tiers created by the National Disaster Management Act 2010 (Government of Pakistan, 2010). The National Disaster Management Authority is the federal implementing, coordinating and monitoring body: it lays down guidelines and standards, approves the national plan and holds the working relationship with the Pakistan Meteorological Department on forecasting. The Provincial Disaster Management Authority, Punjab, converts that framework into provincial and monsoon contingency planning, holds the relief budget and directs the Irrigation Department on bunds and torrent works. The District Disaster

Management Authority, chaired by the Deputy Commissioner, is the district planning, coordinating and implementing body, and is the tier that must issue the local warning, order evacuation and coordinate line departments and Rescue 1122.

Table 3. Statutory tiers under the NDM Act 2010 and their bearing on flood risk in the district.

Tier	Mandate relevant to this district	Where it is not being exercised
NDMA (Federal)	Guidelines and standards; national plan; coordination; forecasting link with PMD	No standard for sub-hour flash-flood warning; catchments outside the PMD gauge network
PDMA Punjab (Provincial)	Provincial and monsoon contingency planning; relief budget; direction to Irrigation on torrent works	Statutory DRR plan not prepared; planning remains reactive
DDMA Dera Ghazi Khan (District)	District plan and response plan; local warning and evacuation; coordination of Rescue 1122	No torrent-specific contingency annex; half the catchment lies outside its jurisdiction

The structure is sound on paper; the weakness lies in the lower tiers, where planning has stayed reactive and the statutory district plan is still unprepared. No single tier, moreover, has jurisdiction over the whole hazard, since roughly half the torrent catchment lies in Balochistan. Torrent risk in Punjab therefore needs an NDMA-brokered inter-provincial arrangement on catchment gauging and data sharing.

5. Mitigation Strategies and Best Practices

Structural measures should be sized for two purposes at once, flood attenuation and spate supply, because here they are the same water. Modelling indicates retention potential of 0.14, 1.14 and 1.13 million acre-feet on Kaha, Vehowa and Sanghar respectively (Saleem et al., 2023). Delay-action dams, dispersion structures across the Pachad and adequately sized cross-drainage works on the district's canals are the

established interventions, each requiring sediment management designed in from the start. Non-structural measures carry equal weight. Elevating and flood-proofing health units, schools, feeder roads and water points protects service continuity at modest cost when built in at design stage, and land-use rules keeping construction out of active torrent paths are low-capital and high-return. The Asian Development Bank's Punjab Hill Torrents Management Project, cleared at concept stage in 2025, is framed around nature-based solutions for both flood protection and agricultural productivity (ADB, 2025).

6. Risk Communication and Early Warning

Where lead time is under an hour, the outcome is decided by warning design community trust and pre-agreed response rather than by forecasting alone. Detection requires automatic weather stations and telemetered level gauges in the upper catchments, publishing in real time so that officials and communities see the same information at once. Dissemination requires a short, colour-coded, impact-based message stating what will happen and what to do, pushed simultaneously through mosque loudspeakers, cell broadcast, Rescue 1122 and union council focal points.

The last mile is where most systems fail. Warnings must reach women directly, through women volunteers and household channels rather than only by announcement in male public spaces and should be in the local language. Because households must decide within minutes whether to move livestock and grain, evacuation routes and animal holding areas should be agreed and rehearsed before the season, since unexplained false alarms erode compliance faster than any technical failure.

7. Policy Recommendation

The measures below follow from the gaps identified above, sequenced so that low-cost actions which save lives come first while capital works proceed on a longer horizon.

Table 4. Prioritized recommendations, lead institutions and horizon.

Recommended measure	Lead institution	Horizon
Telemetered rain and level gauges on the 13 major catchments, published in	Punjab Irrigation Department; PMD	Short, 0-2 years

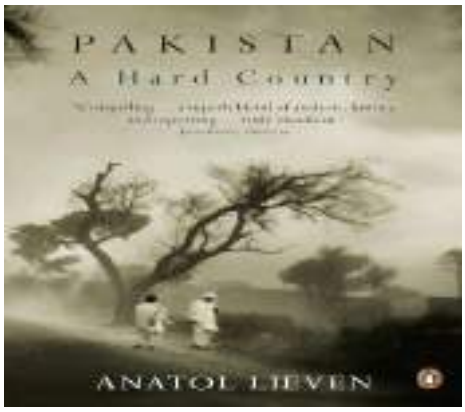
Recommended measure	Lead institution	Horizon
real time		
National flash-flood warning standard; inter-provincial catchment data arrangement	NDMA; PMD	Short, 0-2 years
Statutory district DRR plan with torrent-specific contingency annexes	DDMA Dera Ghazi Khan; PDMA Punjab	Short, 0-2 years
Impact-based, gender-sensitive last-mile warning protocol with drills	DDMA; Rescue 1122; union councils	Short, 0-2 years
Elevate and flood-proof critical facilities, feeder roads and water points	C&W; Health; Education Departments	Medium, 2-5 years
Delay-action storage and dispersion structures sized for attenuation and spate supply	Irrigation Department; Small Dams Organisation	Medium to long
Codify rod kohi water rights alongside new storage	Irrigation and Revenue Departments; communities	Medium, 2-5 years

Conclusion

There are three major findings to keep in view in Dera Ghazi khan context. First, the district faces two hazards and one population i.e., flash torrents from the west and slow riverine flooding from the east differ in onset, duration, path and damage and cannot be managed by a single system. Second, the torrent is also the livelihood, so the objective must be management and storage rather than blockage. Third, where lead time is under an hour, flood risk is a human and institutional problem before it is a technical one.

The institutional architecture needed to act already exists in law; what is missing is its exercise at provincial and district level.

- A prepared district plan
- A torrent-specific contingency annex
- An inter-provincial arrangement that NDMA is uniquely placed to broker.



The cost of not doing so is already being paid, in reactive expenditure and in losses borne by those least able to absorb them. Anatol Lieven wrote in the book “Pakistan A Hard Country” that “if floods and other ecological disasters on this scale become regular events as a result of climate change, Pakistan will be destroyed as a state and an organized society but so too will many other countries around the world.”

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