GOVERNMENT OF PAKISTAN

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

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C2DM P-07/26

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National Disaster Management Authority
Prime Minister's Office
Government of Pakistan

About CoE-C2DM Course

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 P-07/26 (6^{th} July – 24^{th} July 2026) participants.

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STUDENT RESEARCH PAPER

Germany Flood (2021) Regional Hazard Profile, Vulnerability Assessment and Early Warning System Reform

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Certificate Course in Disaster Management
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Center of Excellence – Climate Change & Disaster Management

National Disaster Management Authority

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Executive Summary

Western Germany was struck in the second week of July 2021 by a slow-moving storm system that stalled over the Ahr and Erft river catchments, releasing rainfall equal to a full month's average within roughly twenty-four hours. Between 184 and 196 people lost their lives across the country, with 134 of those deaths concentrated in the Ahr valley of Rhineland-Palatinate alone, a single-event toll greater than the sum of every inland flood fatality recorded in Germany over the preceding forty years.

This report examines the disaster through a structured disaster-risk lens covering the regional hazard profile, vulnerability and resilience factors, scientific and institutional gaps, and the performance of the early warning chain. The central finding is that the flood was forecast competently: European and national meteorological authorities issued warnings three to four days ahead of the peak flooding. What failed was not detection but the pathway between an accurate forecast and a household that knew to act on it, a breakdown rooted in fragmented institutional responsibility, single points of failure in warning delivery, and messages that did not convey real urgency.

Key Recommendations:

- Establish a fixed protocol that automatically converts a national or European flood forecast into a defined local evacuation action, rather than leaving the decision to separate district-level judgement calls.
- Diversify warning delivery through cell-broadcast SMS, repaired and expanded siren networks with backup power, and updated hazard maps that include low-probability, high-consequence scenarios.
- Redesign warning messages around clarity and actionability, using plain language, maps and short action steps rather than technical severity codes alone.
- Recognise and formally integrate community-led response networks, neighbours, voluntary organisations and local associations, into official disaster management structures rather than treating them as auxiliary.
- Invest in AI and ML-based hydrological forecasting to close data and lead-time gaps, while pairing these tools with clear institutional ownership so technical gains are not lost in the handover to local authorities.

1. Regional Context & Hazard Profile

1.1 Key Terms and Analytical Framework

Four terms recur throughout disaster-risk literature and are used here in their standard technical sense. Hazard is the physical event itself, its magnitude, timing and probability. Exposure is the population, buildings and infrastructure situated within reach of the hazard. Vulnerability is the reduced capacity of a person or system to withstand that hazard, including whether a warning can actually reach and be understood by them. Risk is the outcome that results when hazard, exposure and vulnerability combine.

Read through this lens, the German case is unusual: the hazard was forecast competently, and exposure was already well documented on paper. What failed was the vulnerability side of the equation, specifically, the pathway between a correct forecast and a household that knew to act on it.

1.2 Sequence of the Weather Event

The European Flood Awareness System (EFAS) flagged the approaching low-pressure system by 9–10 July 2021, several days before flooding began, and Germany's national weather service (DWD) issued corroborating severe-weather warnings from 12 July onward. Some catchments in North Rhine-Westphalia and Rhineland-Palatinate recorded 100 to 150 millimetres of rain within 48 hours, a total DWD described as the heaviest in over a century, and in places possibly the heaviest in a thousand years. Later scientific attribution work concluded that rainfall of this intensity was made substantially more likely by human-driven climate change, meaning the July 2021 event should be read as a preview of future risk rather than a freak occurrence.

1.3 Historical Trends and Regional Vulnerability

The Ahr valley has long combined a narrow, steep-sided river catchment with dense settlement along the valley floor, a pattern that concentrates exposure in exactly the terrain most prone to flash flooding. Research teams studying the region note that public attention prior to 2021 had focused mainly on technical flood-proofing rather than on the social and administrative dimensions of resilience, leaving a gap between physical infrastructure and the human systems needed to act on a warning, an imbalance that projects such as the SOZIAHR initiative on social, economic and administrative dimensions of climate resilience were subsequently formed to address.

1.4 Scale of Loss

Table 1 summarises the main categories of loss recorded across the affected German states, distinguishing immediate impacts from those that followed in subsequent weeks and months.

Area of Loss	Immediate Impact	Subsequent Impact
People	184–196 deaths and over 700 injuries nationwide; 134 deaths in the Ahr valley alone.	Extended demand for grief and trauma counselling; support helplines established for survivors.
Infrastructure	20 of 35 bridges on the Ahr river destroyed; over 80 rail stations shut down; roads and utilities badly damaged.	Reconstruction expected to take several years; emergency access remained difficult for weeks.
Economic	Around EUR 33 billion in total German economic loss; EUR 7–8.5 billion of that insured.	About EUR 30 billion pledged by federal and state governments for rebuilding; added pressure on tourism and retail sectors.

2. Risk & Vulnerability Assessment

Investigation records show that three-quarters of Ahr valley deaths occurred outside officially mapped danger zones, and fatalities were unusually common on ordinary ground floors and in the street, not only in the basements and campsites that hazard maps had flagged as highest-risk. This indicates that formal vulnerability mapping significantly underestimated who was actually exposed.

The socio-economic burden fell unevenly. Post-disaster surveys of older adults found that social-health outcomes were shaped less by demographic factors than by geography: neighbourhoods such as Bad Neuenahr-Ahrweiler and Heppingen emerged as clear social-vulnerability hotspots, where residents struggled to maintain access to reliable information and aid networks, even though social cohesion and place attachment remained largely intact for the wider older-adult population. Separately, household-level research on flood prevention found that income and gender shaped how residents perceived their own capacity to prepare: lower-income households placed more weight on joint flood-prevention efforts with neighbours, while women placed more weight on the availability of information and professional counselling services. Livelihood disruption was concentrated in the region's viticulture and small tourism-dependent businesses, whose physical assets and seasonal income cycles left little buffer against a multi-year reconstruction timeline.

3. Community Resilience Factors

Despite the scale of the disaster, the Ahr valley's response was shaped heavily by pre-existing social capital. Long-term residents with deep neighbourhood ties, shared cultural identity and active local organisations provided a baseline of social connectedness that outside agencies could not replicate on short notice. Research into the emergency response in Mayschoß documented the emergence of what has been termed a 'semiprofessional crisis management team', citizen groups that drew on professional disaster-management knowledge while operating through traditional local institutions such as wine cooperatives and neighbourhood associations, at times subordinating formal response structures to locally defined priorities.

This pattern was echoed in accounts from municipal leadership: local officials described the immediate post-flood solidarity among residents as one of the most striking features of the recovery, even as enthusiasm and outside attention gradually declined over the following months of slower-than-expected reconstruction. Community-based organisations that regularly ran social programmes before the flood, of the kind observed in Dernau, appear to have measurably reduced isolation among older residents afterward, suggesting that pre-existing community infrastructure is itself a resilience asset, not only a recovery resource.

However, researchers studying citizen-led response also flagged a structural tension: successful collaboration between agencies and community groups depended on trust and sustained relationships built before the disaster, and where such relationships were absent, community capacity was underused or excluded from formal coordination altogether. This points to a policy gap distinct from the warning-system failure, official disaster management in Germany has not yet built durable, pre-agreed partnerships with the informal networks that, in practice, carried much of the emergency response.

4. Scientific & Institutional Gaps

4.1 Institutional Fragmentation

Responsibility for warnings in Germany is split across federal, state and district levels. Warnings are meant to move from the federal Modular Warning System (MoWaS) through apps such as NINA and KATWARN and through local sirens, but the decision to order an evacuation rests with district authorities rather than Berlin. Germany's own civil-protection chief later acknowledged that the chain did not work optimally, describing his office as holding considerable expertise but comparatively little jurisdiction. A nationwide alert-system test in September 2020 had already exposed technical delays, and these were not fully resolved before the following July.

4.2 Data and Technology Limitations

Power cuts and network outages disabled app-based alerts precisely when they were needed most, and a number of sirens were found to be broken or simply absent in the worst-hit towns. Cell-broadcast SMS alerts, already in use in several neighbouring EU countries, were not yet part of Germany's toolkit at the time of the disaster. No single national register existed to track disaster losses consistently, which weakened both post-event planning and the ability to link the disaster systematically to broader climate trends.

4.3 AI and ML Adoption Status

Machine-learning approaches to flood forecasting have advanced rapidly since 2021, and their relevance to cases like the Ahr valley is direct. Deep-learning architectures such as LSTM networks have demonstrated strong performance in short-horizon river-level forecasting, including in data-scarce basins where conventional physics-based models struggle. AI-driven forecasts have improved accuracy and precision, filled data gaps and reduced computational cost by drawing on more diverse data sources than traditional approaches, and global initiatives such as Google's Flood Hub now issue AI-generated flood forecasts several days in advance using largely public data. Research applying integrated physics-based and machine-learning models has specifically revisited the July 2021 western Germany event as a benchmark case for testing improved subsurface and streamflow prediction.

Adoption nonetheless remains uneven and contested. Independent reassessments of large-scale AI flood-forecasting systems caution that predictive skill often declines precisely at the extreme, high-consequence magnitudes that matter most for evacuation decisions, and that benchmark comparisons can overstate real-world readiness. For Germany's warning chain, this suggests AI and ML tools are a promising complement to, but not yet a substitute for, the institutional and communication reforms discussed elsewhere in this report, a forecasting gain at the modelling stage is only useful if it survives the handoff to district-level decision-makers.

5. Mitigation Strategies & Best Practices

5.1 Structural Measures

- Rebuild bridges and river crossings with clearances set above the highest recorded flood level, as is now standard practice in Ahr valley reconstruction.
- Repair and expand siren networks in flood-prone districts, with independent backup power so they continue operating during outages.
- Combine engineered flood defences with natural retention measures (floodplain restoration, upstream water retention) as part of an integrative protection strategy.

5.2 Non-Structural Measures

- Introduce cell-broadcast SMS alerts nationally so warnings do not depend on a resident having downloaded a specific app.
- Update flood hazard maps to include extreme, low-probability scenarios, since most 2021 deaths occurred outside previously mapped danger zones.
- Formalise training and capacity-building partnerships between district emergency services and community organisations identified in Section 4, building the trust relationships that determined whether citizen-led response was integrated or excluded.
- Run regular, realistic nationwide alert-system tests, correcting the kind of technical delays exposed in the 2020 test well before the next event.

6. Risk Communication & Early Warning

Detection was not the weak link in this disaster: EFAS notified national and state authorities on 10 July, three to four days ahead of the worst flooding. The gap opened in the steps between that notification and a resident being told to leave home. Post-event surveys found that roughly one in three residents in the flash-flood zones received no warning at all, and among those who did, only about 5 percent said the message had actually prepared them for what happened.

Message design has received comparatively less attention than the technical systems used to distribute warnings, even though clearer wording is known to change how people respond. Future warning messages need to be built around clarity rather than speed of delivery alone, using maps, simple graphics and short action steps, which residents in post-event surveys consistently said they preferred. Gender-sensitive design matters here too: household research found that women placed comparatively more weight on the availability of clear information and professional guidance when deciding how to prepare, suggesting that generic, technically worded alerts may under-serve a meaningful share of the population. Relying on more than one channel at once, sirens, cell broadcast, media and local community networks, ensures that the failure of any single channel does not leave a town uninformed.

7. Policy Recommendations

- Integrated governance: Create a fixed, legally binding protocol linking federal/European forecasts to automatic local action, removing reliance on separate judgement calls at each administrative level.

- Climate adaptation: Treat the July 2021 rainfall intensity as a preview of future risk, given attribution research linking its severity to climate change, and revise infrastructure and hazard-mapping standards accordingly.
- Community participation: Formally incorporate community-led response networks into district emergency planning, building the pre-disaster trust relationships shown in Section 4 to determine whether citizen capacity is used or excluded.
- Technology integration: Pair AI and ML-based flood forecasting with clear institutional ownership of the resulting alerts, so improved lead time at the modelling stage translates into faster local decisions rather than being lost in handover.
- Inclusive communication: Mandate multi-channel, plainly worded warning messages, tested for comprehension across age and gender groups, rather than relying on any single technical channel.

8. Conclusion

The Ahr valley disaster shows that an accurate forecast is not, by itself, enough to prevent large-scale loss of life. Germany's EFAS and DWD forecasts gave several days of lead time, but split responsibilities, warning channels that depended on electricity and mobile networks, and messages that did not convey real urgency meant that lead time was largely wasted. Community-level social capital and citizen-led response absorbed much of the resulting gap, but this resilience was informal and, in places, actively excluded from official coordination.

The lesson for Germany, and for any country building or reforming its own early warning system, is that forecasting technology, including emerging AI and ML tools, has to be paired with clear institutional ownership, more than one way to reach people, formal recognition of community-based response capacity, and messages that ordinary residents can understand and act on immediately. Building resilience through science-based planning, social capital and emerging technology is not a matter of choosing one over the others; the July 2021 event demonstrates that all three must function together.

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STUDENT RESEARCH PAPER

Climate Change Impacts on Food Security and Agricultural Systems in Pakistan

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Executive Summary

Climate change has emerged as one of the most pressing global challenges of the twenty-first century, profoundly affecting natural ecosystems, human health, economic development, and food production systems. Developing countries such as Pakistan are particularly vulnerable due to their dependence on climate-sensitive sectors, limited adaptive capacity, rapid population growth, and increasing environmental degradation. Agriculture contributes approximately one-fifth of Pakistan's Gross Domestic Product (GDP) and provides employment to a significant proportion of the country's labour force, making food security intrinsically linked to climatic conditions. However, the increasing frequency and intensity of floods, droughts, heatwaves, irregular precipitation, glacier lake outburst floods (GLOFs), pest infestations, and land degradation are placing unprecedented pressure on agricultural productivity, water resources, and rural livelihoods. These climate-induced hazards not only threaten national food availability but also undermine economic stability, increase poverty, exacerbate malnutrition, and widen socio-economic inequalities.

The findings indicate that climate change is intensifying disaster risks across Pakistan by disrupting agricultural production, reducing crop yields, degrading natural resources, increasing water scarcity, and damaging critical infrastructure. Smallholder farmers, women, children, landless labourers, and marginalized rural communities remain the most vulnerable because of limited access to financial resources, climate information, modern agricultural technologies, and institutional support. Although Pakistan has made significant progress in disaster risk reduction through the National Disaster Management Authority (NDMA), Provincial Disaster Management Authorities (PDMAs), and national climate adaptation policies, several challenges persist, including fragmented institutional coordination, inadequate climate data integration, limited use of geospatial technologies, insufficient early warning dissemination, and constrained research capacity for localized climate impact assessments.

1. REGIONAL CONTEXT & HAZARD PROFILE

Pakistan is one of the country's most vulnerable to the impacts of climate change due to its unique geographical location, diverse topography, and high dependence on climate-sensitive sectors such as agriculture, water resources, and livestock. Situated in South Asia, the country extends from the glaciated mountain ranges of the Himalayas, Karakoram, and Hindu Kush in the north to the coastal belt of the Arabian Sea in the south. This geographical diversity exposes Pakistan to a wide spectrum of natural hazards, including riverine floods, flash floods, droughts, heatwaves, glacier lake outburst floods (GLOFs), landslides, tropical cyclones, dust storms, and sea-level rise. The Indus River Basin, which supports more than 90% of the country's agricultural production, is heavily influenced by glacier melt and monsoon rainfall, making it highly susceptible to climatic variability. Agriculture contributes approximately 22% of Pakistan's Gross Domestic Product (GDP) and employs nearly 37% of the labour force, while providing livelihoods for the majority of the rural population. Consequently, climate-induced disruptions directly threaten national food security, economic growth, and sustainable development.

Understanding disaster risk requires a clear distinction between the concepts of hazard, exposure, vulnerability, and risk.

A **hazard** refers to a potentially damaging natural or humaninduced event capable of causing loss of life, injury, environmental degradation, or damage to infrastructure and livelihoods. In Pakistan, climate-related hazards include floods, droughts, heatwaves, cold waves, GLOFs, cyclones, pest outbreaks, and smog episodes.

Exposure refers to the presence of people, agricultural land, livestock, infrastructure, and ecosystems located within hazard-prone areas. Communities living along the Indus River floodplains, arid regions of Balochistan and Sindh, mountainous northern valleys, and densely populated urban Centers are particularly exposed to multiple hazards. **Vulnerability** describes the susceptibility of these exposed populations and systems to suffer adverse impacts due to physical, social, economic, environmental, and institutional factors. Poverty, inadequate infrastructure, low literacy levels, limited access to technology, dependence on rain-fed agriculture, weak governance, and gender inequality significantly increase vulnerability.

Risk emerges from the interaction between hazards, exposure, and vulnerability while being moderated by the coping capacity of institutions and communities. Therefore, disaster risk is not solely determined by the occurrence of natural hazards but also by the ability of society to anticipate, prepare for, respond to, and recover from those hazards.

2. RISK & VULNERABILITY ASSESSMENT

Climate change has significantly increased the risk profile of Pakistan's agricultural sector by intensifying the frequency, magnitude, and unpredictability of climate-induced hazards. The country's economy and food systems are highly dependent on agriculture, making them particularly vulnerable to floods, droughts, heatwaves, erratic rainfall, and water scarcity. These hazards not only reduce agricultural productivity but also disrupt the entire food supply chain, from production and transportation to storage, processing, and market distribution. The interaction between climatic hazards, socio-economic inequalities, environmental degradation, and limited institutional capacity has transformed food security into a multidimensional disaster risk challenge. Consequently, understanding both the physical risks and the underlying vulnerabilities is essential for developing effective disaster risk reduction and climate adaptation strategies.

3. COMMUNITY RESILIENCE FACTORS

Community resilience is widely recognized as one of the most effective approaches for reducing disaster risk and strengthening climate adaptation in vulnerable regions. In Pakistan, where agriculture remains the primary source of livelihood for millions of rural households, resilient communities possess the capacity to anticipate, prepare for, respond to, and recover from climate-induced hazards while maintaining their essential social, economic, and environmental functions. Resilience is not determined solely by the availability of physical infrastructure but also by the strength of social networks, institutional support, local knowledge, access to information, financial resources, and the ability of communities to adapt to changing climatic conditions. Strengthening these capacities is essential for minimizing disaster losses and ensuring long-term food security in the face of increasing climate variability.

From an operational perspective, strengthening community resilience directly supports the objectives of the Sendai Framework for Disaster Risk Reduction (2015–2030), Pakistan's National Disaster Management Plan, and the National Adaptation Plan by promoting anticipatory action, preparedness, response, recovery, and long-term resilience. For NDMA, PDMAs, District Disaster Management Authorities (DDMAs), and line departments, investing in community resilience provides a cost-effective strategy for reducing disaster losses and protecting food systems against future climate risks.

TABLE 1 KEY COMMUNITY RESILIENCE FACTORS FOR CLIMATE-RESILIENT FOOD SYSTEMS (PLACEHOLDER)

RESILIENCE FACTOR	CURRENT SITUATION IN PAKISTAN	RECOMMENDED IMPROVEMENT
SOCIAL CAPITAL	Strong informal community networks	Strengthen community disaster committees
INDIGENOUS KNOWLEDGE	Traditional farming and water conservation	Integrate with scientific climate services
COMMUNITY PARTICIPATION	Limited involvement in planning	Promote participatory DRR and local governance
TECHNOLOGY ADOPTION	Low AI and GIS utilization at community level	Expand GIS, Remote Sensing, AI, and mobile advisory services

RESILIENCE FACTOR	CURRENT SITUATION IN PAKISTAN	RECOMMENDED IMPROVEMENT
CAPACITY BUILDING	Limited climate education	Regular disaster preparedness training and farmer extension programmes
FINANCIAL RESILIENCE	Low insurance coverage	Expand crop insurance and climate finance mechanisms

4. SCIENTIFIC & INSTITUTIONAL GAPS

Climate change has significantly increased the complexity of disaster risk management in Pakistan, exposing critical scientific, technological, and institutional deficiencies that limit the country's ability to effectively anticipate, prepare for, respond to, and recover from climate induced disasters. Although Pakistan has established several national policies, disaster management institutions, and climate adaptation frameworks, their implementation is often constrained by fragmented governance, inadequate scientific research, limited technological integration, and insufficient coordination among stakeholders. Addressing these gaps is essential for strengthening food security, enhancing climate resilience, and achieving sustainable development. A comprehensive understanding of these deficiencies provides the foundation for evidence-based policymaking and the development of innovative disaster risk reduction strategies.

From an operational perspective, addressing these scientific and institutional gaps is fundamental for enhancing Pakistan's disaster risk management system. Establishing an integrated national climate information platform, expanding the use of Artificial Intelligence, Geographic Information Systems, Remote Sensing, drones, and Big Data analytics, strengthening institutional coordination among NDMA, PDMAs, DDMAs, PMD, SUPARCO, PCRWR, and line departments, and investing in research and capacity development would significantly improve hazard monitoring, vulnerability assessment, and evidence-based decision-making. These improvements would directly support anticipatory action, preparedness, emergency response, recovery, and long-term resilience while contributing to Pakistan's commitments under the

Sendai Framework for Disaster Risk Reduction (2015–2030), the Paris Agreement, the National Adaptation Plan, and the Sustainable Development Goals (SDGs). Strengthening scientific capacity and institutional effectiveness is therefore indispensable for protecting Pakistan's food systems and reducing the long-term impacts of climate change

TABLE 2 SCIENTIFIC AND INSTITUTIONAL GAPS AFFECTING CLIMATE-RESILIENT FOOD SYSTEMS IN PAKISTAN (PLACEHOLDER)

Gap Area	Current Challenge	Recommended Improvement
Climate Research	Limited localized climate models	Develop district-level climate projections
Data Management	Fragmented datasets and poor data sharing	Establish a National Climate and Geospatial Data Platform
Technology	Limited adoption of AI, GIS, Remote Sensing (RS), drones, and IoT	Invest in digital transformation and smart agriculture
Institutional Coordination	Overlapping mandates and weak collaboration	Strengthen inter-agency coordination mechanisms
Capacity Building	Shortage of trained personnel	Continuous technical training and professional development

Gap Area	Current Challenge	Recommended Improvement
Community Integration	Limited use of indigenous knowledge	Integrate local knowledge into adaptation planning
Gender Mainstreaming	Weak inclusion of women in DRR planning	Promote gender-responsive disaster management

5. MITIGATION STRATEGIES AND BEST PRACTICES

Climate change mitigation and adaptation are essential components of sustainable disaster risk reduction, particularly in countries like Pakistan where agriculture forms the backbone of the national economy and rural livelihoods. While mitigation focuses on reducing greenhouse gas (GHG) emissions and enhancing carbon sequestration to address the root causes of climate change, adaptation aims to minimize the adverse impacts of climate variability by increasing the resilience of communities, ecosystems, and infrastructure. In the context of food security and agricultural systems, effective mitigation strategies require an integrated approach that combines structural and non-structural measures, technological innovation, ecosystem restoration, institutional strengthening, and community participation. Such an approach not only reduces disaster risks but also contributes to sustainable agricultural development, environmental conservation, and long-term economic stability.

From an operational perspective, these mitigation strategies directly support all phases of the disaster management cycle by reducing hazard exposure, minimizing vulnerability, and increasing adaptive capacity. Structural measures strengthen disaster preparedness and reduce physical damage, while non-structural measures improve community awareness, institutional readiness, and adaptive decision-making. Emerging technologies enhance anticipatory action through real-time monitoring and predictive analytics, enabling NDMA, PDMAs, District Disaster Management Authorities (DDMAs), and line departments to allocate resources more efficiently and respond rapidly to climate-related emergencies. By integrating structural interventions, ecosystem restoration, technological innovation, and community-based adaptation into national disaster management policies, Pakistan can build resilient food systems capable of withstanding future climate challenges while advancing its commitments under the Sendai Framework for Disaster Risk Reduction (2015–2030), the Paris Agreement, the National Adaptation Plan, and the Sustainable Development Goals (SDGs).

TABLE 3 CLIMATE CHANGE MITIGATION STRATEGIES FOR CLIMATE-RESILIENT FOOD SYSTEMS IN PAKISTAN (PLACEHOLDER)

Category	Examples	Expected Benefits
Structural Measures	Flood embankments, reservoirs, drip irrigation, cold storage facilities, climate-resilient roads	Reduced disaster losses, improved water management, lower post-harvest losses
Nature-Based Solutions	Afforestation, agroforestry, watershed restoration, wetland conservation, mangrove restoration	Carbon sequestration, biodiversity conservation, soil protection, flood mitigation
Climate-Smart Agriculture	Crop diversification, conservation agriculture, drought-resistant crops, precision farming	Increased agricultural productivity, improved resilience, reduced greenhouse gas emissions
Technology Integration	Artificial Intelligence (AI), Geographic Information Systems (GIS), Remote Sensing, Google Earth Engine (GEE), drones, Internet of Things (IoT), Big Data	Better forecasting, crop monitoring, hazard mapping, and evidence-based decision-making

Category	Examples	Expected Benefits
Capacity Building	Farmer training, extension services, awareness campaigns, disaster preparedness programmes	Improved adaptive capacity and strengthened community resilience
Financial & Policy Instruments	Crop insurance, climate finance, green investments, renewable energy incentives	Reduced economic vulnerability and enhanced sustainable development

6. RISK COMMUNICATION & EARLY WARNING SYSTEMS

Effective risk communication and early warning systems (EWS) are fundamental components of disaster risk reduction and climate resilience, enabling governments, institutions, and communities to anticipate hazards, reduce vulnerabilities, and minimize disaster-related losses. In Pakistan, where climate-induced disasters such as floods, droughts, heatwaves, glacial lake outburst floods (GLOFs), cyclones, and smog episodes occur with increasing frequency and intensity, timely dissemination of accurate and actionable information is essential for protecting lives, livelihoods, and food systems. An effective early warning system extends beyond hazard forecasting; it integrates risk assessment, continuous monitoring, clear communication, institutional coordination, and community preparedness to ensure that vulnerable populations receive timely information and possess the capacity to respond appropriately before disasters occur. Consequently, strengthening risk communication mechanisms has become a national priority within Pakistan's disaster management framework.

From an operational perspective, effective risk communication and early warning systems directly support all phases of the disaster management cycle, including anticipatory action, preparedness, response, recovery, and resilience-building. Timely and reliable warning information enables farmers to protect crops and livestock, communities to evacuate safely, emergency responders to pre-position resources, and government agencies to coordinate relief operations more efficiently. Strengthening people-Centerd, technology-enabled, and gender responsive early warning systems will therefore play a critical role in safeguarding Pakistan's food security, reducing disaster losses, and supporting sustainable climate adaptation. By integrating scientific forecasting, modern geospatial technologies, institutional collaboration, and community participation, Pakistan can develop a robust early warning framework that aligns with the Sendai Framework for Disaster Risk Reduction (2015–2030), the Paris Agreement, and the Sustainable Development Goals (SDGs).

TABLE 4 COMPONENTS OF AN EFFECTIVE RISK COMMUNICATION AND EARLY WARNING SYSTEM (PLACEHOLDER)

Component	Current Challenges	Recommended Improvements
Risk Knowledge	Limited localized hazard and vulnerability assessments	Develop GIS-based multi-hazard risk maps and district-level vulnerability databases.
Monitoring & Forecasting	Sparse monitoring stations and fragmented data	Expand AI, Remote Sensing (RS), Internet of Things (IoT) sensors, and satellite-based forecasting systems.
Communication & Dissemination	Delayed warnings and limited outreach to remote communities	Use SMS, mobile applications, radio, television, social media, mosque announcements, and local volunteers in multiple languages.
Response Capability	Limited preparedness and community awareness	Conduct regular evacuation drills, simulation exercises, and disaster preparedness training.

Component	Current Challenges	Recommended Improvements
Institutional Coordination	Weak inter-agency communication protocols	Establish integrated communication among NDMA, PDMAs, PMD, SUPARCO, DDMAs, and line departments.
Technology Integration	Limited use of AI and digital platforms	Develop real-time disaster dashboards, mobile advisory systems, and cloud-based decision-support platforms.

7. POLICY RECOMMENDATIONS

Addressing the impacts of climate change on Pakistan's food security and agricultural systems requires an integrated policy framework that combines scientific innovation, institutional coordination, community participation, and sustainable resource management. Climate change is no longer solely an environmental issue but a national development and security challenge that directly affects agricultural productivity, water availability, economic growth, public health, and disaster resilience.

The National Disaster Management Authority (NDMA) should strengthen its leadership role by establishing a National Climate and Food Security Risk Intelligence Platform that integrates Artificial Intelligence (AI), Geographic Information Systems (GIS), Remote Sensing (RS), Google Earth Engine (GEE), and Big Data analytics for real-time monitoring of climate hazards and agricultural conditions. to improve preparedness and inter-agency coordination. Strengthening partnerships with universities, research organizations, and international development agencies will further enhance scientific research and evidence-based policymaking.

At the provincial level, Provincial Disaster Management Authorities (PDMAs) should integrate climate adaptation into provincial disaster management plans by strengthening district-level preparedness and community resilience.

The District Disaster Management Authorities (DDMAs) should prioritize community-based disaster risk reduction by strengthening Village Disaster Management Committees and supporting participatory planning at the local level.

The Ministry of National Food Security and Research should accelerate the implementation of Climate-Smart Agriculture (CSA) by promoting drought-tolerant and heat-resistant crop varieties, efficient irrigation technologies, conservation agriculture, integrated pest management, and sustainable soil management practices.

The Ministry of Climate Change and Environmental Coordination should strengthen the integration of climate adaptation into national development planning by implementing the National Adaptation Plan, expanding ecosystem-based adaptation programmes, and promoting nature-based solutions such as afforestation, watershed management, wetland restoration, and sustainable land management.

Universities should establish collaborative research programmes with NDMA, PDMAs, PMD, SUPARCO, PCRWR, and provincial departments to develop evidence-based solutions tailored to Pakistan's climatic and socio-economic conditions.

Community participation must remain a cornerstone of national climate adaptation policy. Government institutions should actively involve local communities, women, youth, farmers' organizations, civil society organizations, and indigenous groups in planning, implementing, and evaluating disaster risk reduction programmes.

Indigenous knowledge related to water conservation, crop management, seasonal forecasting, and natural resource management should be systematically documented and integrated with scientific research to develop locally appropriate adaptation strategies.

Gender-responsive policies should ensure equal access to education, financial resources, agricultural technologies, extension services, and decision-making opportunities, recognizing the critical role that women play in food production and household resilience.

Technological innovation should be mainstreamed across all levels of disaster management and agricultural planning. National investment should focus on expanding Artificial Intelligence, Geographic Information Systems, Remote Sensing, Google Earth Engine, drones, Internet of Things (IoT) sensors, and cloud-based data platforms to improve hazard monitoring, early warning systems, crop health assessment, water resource management, and emergency response.

From an operational perspective, these policy recommendations directly support the priorities of the Sendai Framework for Disaster Risk Reduction (2015–2030), the Paris Agreement,

Pakistan's National Adaptation Plan, the National Disaster Management Plan, and the Sustainable Development Goals (SDGs). Implementing these recommendations will strengthen anticipatory action, improve preparedness, enhance emergency response capacity, accelerate post-disaster recovery, and build long-term resilience within Pakistan's food systems.

TABLE 5 INSTITUTIONAL POLICY RECOMMENDATIONS FOR STRENGTHENING CLIMATE-RESILIENT FOOD SYSTEMS IN PAKISTAN (PLACEHOLDER)

Institution	Key Policy Recommendation	Expected Outcome
NDMA	Develop a National Climate and Food Security Risk Intelligence Platform using AI, GIS, Remote Sensing (RS), and Big Data.	Improved multi-hazard monitoring and evidence-based decision-making.
PDMAs	Establish Provincial GIS and Climate Information Centers.	Enhanced provincial preparedness and rapid disaster response.
DDMAs	Strengthen community-based disaster risk reduction (CBDRR) and establish village disaster management committees.	Increased local preparedness and community resilience.
Ministry of National Food Security & Research	Promote Climate-Smart Agriculture (CSA), crop insurance, and digital agricultural extension services.	Improved agricultural productivity and enhanced farmer resilience.
Ministry of Climate Change & Environmental Coordination	Expand ecosystem-based adaptation (EbA) and implement climate-resilient policies.	Reduced environmental degradation and enhanced climate adaptation.
Universities & Research Institutions	Strengthen interdisciplinary research, innovation, and technology development.	Evidence-based policy development and a skilled human resource base.
Local Communities & Civil Society	Promote participatory planning, indigenous knowledge, and gender-inclusive governance.	Stronger social resilience and sustainable community development.

8. CONCLUSION

Climate change has emerged as one of the most significant threats to Pakistan's food security, agricultural productivity, and sustainable development. As a country characterized by diverse climatic conditions, fragile ecosystems, and a heavy dependence on agriculture, Pakistan is increasingly exposed to climate-induced hazards such as floods, droughts, heatwaves, glacier lake outburst floods (GLOFs), irregular precipitation, and land degradation. These hazards not only reduce agricultural production and threaten national food security but also disrupt rural livelihoods, increase poverty, accelerate environmental degradation, and place additional pressure on already vulnerable communities. The findings of this study demonstrate that climate change is no longer solely an environmental issue; rather, it represents a complex socioeconomic and disaster risk challenge requiring integrated and long-term policy interventions.

From a policy perspective, this research provides practical recommendations for integrating climate adaptation, food security, and disaster risk reduction into national and provincial development planning. Strengthening institutional coordination, expanding multi-hazard early warning systems, promoting climate-smart agriculture, improving geospatial data sharing, investing in AI-enabled decision-support systems, and enhancing public awareness will significantly improve Pakistan's capacity to manage climate risks. Furthermore, aligning these interventions with the Sendai Framework for Disaster Risk Reduction (2015–2030), the Paris Agreement, Pakistan's National Adaptation Plan, and the Sustainable Development Goals (SDGs) will support national commitments toward sustainable development, climate resilience, and disaster preparedness.

Table 6 Summary of Key Findings and Strategic Actions (Placeholder)

Key Finding	Strategic Action	Lead Institutions
Increasing Climate Hazards Threaten Food Systems	Strengthen climate adaptation and disaster risk reduction.	NDMA, PDMAs, Ministry of Climate Change
High Vulnerability of Farming Communities	Promote climate-smart agriculture, crop insurance, and livelihood diversification.	Ministry of National Food Security & Research, Provincial Agriculture Departments
Weak Institutional Coordination	Establish integrated governance and data-sharing mechanisms.	NDMA, PMD, SUPARCO, PCRWR
Limited Adoption of Emerging Technologies	Expand AI, GIS, Remote Sensing, Google Earth Engine (GEE), drones, and IoT applications.	NDMA, Universities, Research Institutions
Insufficient Community Engagement	Strengthen community-based disaster risk reduction (CBDRR) and gender-responsive planning.	DDMAs, Local Governments, Civil Society

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STUDENT RESEARCH PAPER

Anticipatory Action for Heatwaves in Pakistan: Current Interventions and Future Enhancements

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Executive Summary

Pakistan is among the world's most heat-exposed countries, with temperatures exceeding 53°C on record and a single 2015 Karachi heatwave killing over 1,200 people. This report examines Pakistan's shift from reactive emergency response to forecast-based anticipatory action (AA), reviewing the hazard profile, institutional gaps, and field interventions delivered by NDMA, PMD, WFP/FAO, and NGO partners. It identifies a core research gap in the near absence of independently evaluated, spatially-resolved heat-risk data feeding into trigger design and recommends embedding AI/GIS-based forecasting, pre-arranged district-level financing, and gender-sensitive communication into NDMA's newly launched National Anticipatory Action Strategy (2025/26).

1. Regional Context & Hazard Profile

Hazard, exposure, vulnerability, and risk together define heat disaster risk while the hazard is the heatwave itself (an extended period of anomalously high temperature); exposure is the population and assets in its path; vulnerability is the susceptibility of exposed groups to harm; and risk is their interaction. Human caused climate change made the 2022 India-Pakistan heatwave roughly 30 times more likely and 1°C hotter than in a pre-industrial climate (World Weather Attribution, 2022). Karachi's 2015 event remains the defining case, and satellite-based studies confirm the city's urban heat island is intensifying, with built-up area increasing over 6% between 2013 and 2023 alongside rising land-surface temperatures (Ejaz et al., 2025). Jacobabad, Sindh, and southern Punjab now regularly record among the highest temperatures globally, with the trend line pointing toward earlier-onset and longer heatwave seasons.

Recommendation: NDMA and PMD should formally classify heat as a recurring, seasonal hazard within the National Disaster Risk Reduction Strategy 2025–2030, with a standing pre-summer risk briefing, rather than continuing to treat each event as an emergent crisis.

2. Risk & Vulnerability Assessment

Heat risk in Pakistan is socially stratified. Outdoor and daily-wage laborers, the elderly, and residents of dense informal settlements bear disproportionate exposure, compounded by unreliable electricity and poor housing ventilation. Livelihood disruption is significant: extreme heat reduces outdoor working hours, threatens agricultural labor and livestock, and strains urban food supply chains. Gendered vulnerability is well documented as women's caregiving roles and mobility restrictions keep them in poorly cooled homes for longer periods, while formal warning systems disproportionately reach men (Mustafa et al., 2015).

Recommendation: *District Administrations should mandate disaggregated (sex-, age-, and income-based) heat-vulnerability data collection as a precondition for cooling-center siting and cash-transfer targeting.*

3. Community Resilience Factors

Where formal systems under reach, informal networks fill the gap such as mosques, community elders, and local NGOs (e.g., Sibi's locally-led cooling response) already function as trusted first points of contact and indigenous heat coping knowledge. Timing outdoor labor, communal water-sharing, shaded rest areas remains widely practiced but rarely integrated into official plans.

Recommendation: *Line departments should formally contract community-based organizations and religious/social institutions as last-mile responders within Heat Health Action Plans, rather than treating them as informal supplements.*

4. Scientific & Institutional Gaps

Three gaps stand out. First, research gap whose impact evidence (e.g., WHH's reported 85% heatstroke reduction in Jacobabad/Bahawalpur) comes from NGO project reporting rather than independent, peer-reviewed evaluation; the Razzak et al. (2022) randomised trial in Karachi remains a rare exception. Second, technology gap for AI/ML-based forecasting and GIS-based heat-vulnerability mapping exist in the academic literature (Wu et al., 2022) but are not yet operationally integrated into PMD/NDMA trigger systems. Third, institutional gap is there as heat coordination currently runs through voluntary dialogue platforms rather than a standing, mandated inter-agency body, and data deficiencies persist between city-level plans (Karachi, Lahore) with no shared national database.

Recommendation: *NDMA should commission an independent national evaluation unit for anticipatory action, and require any nationally-funded pilot to include pre-registered impact evaluation as a funding condition.*

5. Mitigation Strategies & Best Practices

- Structural: cooling centers in mosques/malls, cool roof retrofits, urban green infrastructure and tree cover in heat island districts, improved housing ventilation standards.
- Non-structural: heatwave prevention kits, anticipatory cash transfers, adjusted school/outdoor-work timings, community-health-worker heat-literacy training (Razzak et al., 2022).

Karachi's tiered Heat Health Action Plan (advisory–warning–emergency), modeled on Ahmedabad's 2013 plan, remains Pakistan's most mature framework and has since been adapted into Lahore's Heatwave Management Plan (2025–2028), indicating early replication.

6. Risk Communication & Early Warning

Pakistan's formal early warning system is technically capable but remains institutionally top-down as gender analysis of comparable EWS in Pakistan found women were often excluded from risk messaging and planning due to reliance on male-centric information channels (Mustafa et al., 2015). Effective heat communication requires multi-channel delivery (mosque announcements, community health workers, SMS) reaching women and non-literate populations directly, not only heads of household.

Recommendation: *PMD and NDMA should co-design gender-disaggregated communication protocols, with women community health workers formally resourced as message carriers at union-council level.*

7. Policy Recommendations (Policy Relevance)

NDMA: Institutionalize a standing Heat Coordination Cell; publish an annual public scorecard of trigger activations, funds disbursed, and cases prevented; secure a dedicated multi-year contingency financing line for heat, distinct from the general disaster fund.

PDMAs: Translate the National AA Strategy into provincial heat-risk financing plans and mandate annual heat-preparedness drills ahead of each summer season, coordinated with provincial health departments.

District Administrations / Line Departments: Operationalize ward/union council level cooling center networks, integrate community organizations as formal responders, and collect disaggregated vulnerability data to guide targeting.

8. Innovation Section: AI, GIS & Emerging Technologies

Remote sensing and GIS already provide the evidence base needed to modernize Pakistan's heat response. Satellite-derived land-surface-temperature and heat-health-vulnerability mapping (Wu et al., 2022) can pinpoint intra city hotspots at a resolution existing PMD station networks cannot match, while machine-learning models trained on historical temperature, humidity, and mortality data could improve trigger accuracy beyond current threshold-based systems. Parametric financing is already piloted through Start Network's "Start Ready" mechanism, which triggered automatic payouts ahead of mid-2026 heat in Nawabshah, Dadu, and Jacobabad — demonstrates that automated, data-driven disbursement is operationally viable in Pakistan today (The Insurer, 2026).

Recommendation: *NDMA/PMD should fund a national GIS-based heat-vulnerability atlas, updated annually via satellite data, and pilot AI-assisted trigger forecasting in 2–3 high-risk districts before nationwide rollout; drone-based thermal surveys could further validate hotspot mapping in dense informal settlements.*

9. Operational Linkage

These findings map directly onto the disaster management cycle. Anticipatory action and preparedness are strengthened by GIS-based hotspot mapping and pre-arranged, trigger-based financing (Sections 8–9); response is improved through gender-sensitive, multi-channel early warning and community-based last-mile delivery (Sections 4 and 7); recovery benefits from disaggregated vulnerability data that targets post-heatwave health and livelihood support to those most affected (Section 3); and resilience-building is reinforced over time through structural mitigation (cool roofs, green infrastructure) and institutionalized community networks (Sections 4 and 6) Together, these link the research directly to Pakistan's climate change adaptation and disaster risk management framework rather than treating heat as an isolated hazard.

10. Conclusion

Pakistan has moved from a single city's improvised 2015 response to a national anticipatory action strategy within a decade is a genuine achievement. The novelty this report identifies lies less in inventing new interventions than in closing the gap between proven pilots (tiered alerts, cash transfers, community education, parametric financing) and their independently evaluated, technologically modernized, gender-inclusive, nationwide operationalization. If NDMA, PDMAs, and district administrations treat the 2025/26 strategy as a floor rather than a ceiling embedding GIS/AI-based forecasting, dedicated financing, and community ownership then Pakistan can build a heat-resilience system that functions anticipatorily every summer, for every district, not only in the cities that suffered the worst events first.

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STUDENT RESEARCH PAPER

Climate Change Impacts on Food Security and Agricultural Systems: A Pakistan Perspective

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Executive Summary

Climate change has become one of the most pressing environmental challenges affecting Pakistan's food security and agricultural systems. Agriculture plays a vital role in the country's economy by contributing to employment, food production, and rural livelihoods. However, rising temperatures, changing rainfall patterns, frequent floods, droughts, and increasing water scarcity are reducing agricultural productivity and threatening the livelihoods of farming communities. This report examines the major impacts of climate change on Pakistan's agricultural sector, including its effects on crop production, livestock, water resources, and overall food security. It also discusses how climate-related disasters have increased production costs, disrupted food supply chains, and contributed to rising food prices and food insecurity, particularly among vulnerable populations. The report recommends adopting climate-smart agricultural practices, improving irrigation and water management, developing climate resilient crop varieties, strengthening disaster preparedness, and investing in agricultural research and farmer education. Effective government policies and collaboration between public institutions, researchers, and local communities are also essential for building a resilient agricultural sector. By implementing these strategies, Pakistan can reduce the negative impacts of climate change, improve food security, and promote sustainable agricultural development for future generations.

- Definitions

Hazard: A potentially damaging natural or climate-related event, such as floods, droughts, heatwaves, heavy rainfall, or storms, capable of causing loss of life, property damage, or environmental degradation.

Exposure: The presence of people, agricultural land, livestock, infrastructure, and other assets in areas that may be affected by climate hazards.

Vulnerability: The degree to which individuals, communities, ecosystems, or agricultural systems are susceptible to damage due to physical, social, economic, and environmental conditions.

Risk: The likelihood of harmful consequences arising from the interaction between a hazard, the level of exposure, and the vulnerability of the affected population or system. Understanding these concepts provides the basis for assessing climate-related risks and developing effective adaptation strategies to strengthen Pakistan's agricultural systems and ensure long-term food security.

Regional Context & Hazard Profile

Literature Review and Climate Trends: Climate change has become a major challenge to Pakistan's agricultural sector and food security. According to recent studies, the country has experienced a steady increase in average temperatures, changing rainfall patterns, more frequent heatwaves, and greater variability in monsoon seasons. These climatic changes have negatively affected crop productivity, water availability, and livestock production. Research also indicates that Pakistan's dependence on agriculture, combined with limited adaptive capacity, makes it one of the country’s most vulnerable to climate-related risks.

Vulnerability Profile: Pakistan's vulnerability to climate change is influenced by environmental, economic, and social factors. Agriculture contributes significantly to the national economy and provides livelihoods for a large proportion of the rural population. However, dependence on climate-sensitive farming, increasing water scarcity, population growth, land degradation, and limited access to climate-resilient technologies increase the country's vulnerability. Smallholder farmers are particularly at risk due to limited financial resources and reduced capacity to adapt to changing climatic conditions.

Figure 1. Pakistan climate vulnerability maps

Historical Climate-Related Events: Pakistan has experienced several severe climate-related disasters over the past two decades. The 2010 floods affected approximately 20 million people and caused widespread damage to agricultural land, irrigation systems, and rural infrastructure. Similarly, the 2022 floods submerged nearly one-third of the country, destroying crops, livestock, and transportation networks while significantly disrupting food production and supply chains. In addition, recurring droughts and prolonged heatwaves have reduced agricultural productivity in many regions, highlighting the increasing impacts of climate change on the country's food security.

3 Risk & Vulnerability Assessment

Socio-Economic Impacts of Climate Change: Climate change is creating significant socioeconomic challenges in Pakistan by affecting agricultural productivity, rural incomes, and economic stability. Since a large portion of the population depends directly or indirectly on agriculture, climate-related disruptions have widespread consequences. Reduced crop yields, increasing production costs, water shortages, and damage caused by extreme weather events can decrease farmers' incomes and increase economic uncertainty. Climate-related disasters also place additional pressure on public resources by increasing the need for emergency response, infrastructure repair, and food assistance. Rising food prices due to reduced agricultural production can further affect low-income households and increase economic inequality.

Livelihood Disruption: Agriculture-based communities are among the most affected by climate change. Floods, droughts, heatwaves, and irregular rainfall patterns can damage crops, reduce livestock productivity, and limit employment opportunities in rural areas. Small-scale farmers, agricultural laborers, and livestock-dependent households face greater risks because they often have limited financial resources and fewer options for recovery. Repeated climate shocks can force rural communities to adopt negative coping strategies, including reducing food consumption, selling productive assets, or migrating to urban areas in search of alternative employment.

Impacts on Food Security: Climate change directly threatens Pakistan's food security by affecting food availability, accessibility, and stability. Changes in temperature and rainfall patterns influence the production of major crops such as wheat, rice, cotton, and maize. Water scarcity and extreme weather events further increase risks to agricultural output and food supply chains. Reduced production can lead to higher food prices, increased dependence on food imports, and greater challenges in ensuring adequate nutrition, particularly among vulnerable populations.

Vulnerable Groups: Certain groups are more exposed to climate-related risks due to their social and economic conditions. These include smallholder farmers, rural communities, lowincome households, children, elderly populations, and communities living in climate-sensitive areas. Limited access to financial support, technology, healthcare, and disaster preparedness measures increases their vulnerability.

Gender Dimensions of Climate Vulnerability: Climate change impacts men and women differently due to differences in social roles, responsibilities, and access to resources. In many rural areas of Pakistan, women play an important role in agricultural activities, livestock management, and household food security. However, they often have limited access to land ownership, financial services, agricultural training, and decision-making opportunities. Strengthening women's participation in climate adaptation programs, improving access to resources, and supporting gender-inclusive policies are essential for building resilient agricultural communities. Overall, addressing climate risks requires an inclusive approach that considers economic conditions, livelihood needs, food security challenges, and the specific vulnerabilities of different population groups.

4 Community Resilience Factors

Role of Social: Capital Social capital plays an important role in helping communities respond to and recover from climate-related challenges. In Pakistan, strong social relationships, trust among community members, and collective cooperation support disaster response and agricultural recovery. Rural communities often rely on mutual assistance during floods, droughts, and other climate-related events by sharing resources, providing labor support, and helping affected households restore their livelihoods. Strong community connections can improve access to information, financial support, and emergency assistance, enabling vulnerable groups to better cope with climate impacts.

Community Networks and Local Organizations: Community networks, including farmer groups, local organizations, and informal support systems, contribute significantly to climate resilience. These networks help farmers exchange knowledge about improved farming practices, weather conditions, water management, and climate adaptation techniques. Local institutions and community-based organizations can support disaster preparedness by creating awareness, organizing training programs, and improving coordination between farmers, government departments, and development organizations. Strengthening these networks can enhance community capacity to manage climate risks effectively.

Indigenous Knowledge and Traditional Practices: Indigenous knowledge developed through generations of farming experience provides valuable approaches for adapting to changing environmental conditions. Pakistani farming communities have traditionally used practices such as crop diversification, traditional water conservation methods, seasonal farming patterns, and selection of locally suitable crop varieties to manage environmental challenges. Integrating local knowledge with modern scientific approaches can improve climate adaptation strategies by creating solutions that are both practical and suitable for local conditions.

Local Coping Mechanisms: Communities affected by climate change use various coping mechanisms to reduce risks and protect their livelihoods. These include adjusting planting seasons, adopting drought-resistant crops, improving water storage practices, diversifying income sources, and using livestock as an alternative livelihood resource. However, repeated and severe climate events can reduce the effectiveness of traditional coping methods. Therefore, strengthening local resilience requires support through climate-smart agriculture, access to technology, financial assistance, early warning systems, and capacity-building programs. Building community resilience is essential for reducing vulnerability and ensuring sustainable food security. By combining local knowledge, social networks, and modern adaptation strategies, Pakistan can improve the ability of agricultural communities to withstand future climate challenges.

5. Scientific & Institutional Gaps

Research Gaps: Although climate change research in Pakistan has increased in recent years, significant knowledge gaps remain regarding its long-term impacts on agriculture and food security. More localized research is needed to understand climate risks at district and community levels, including changes in crop productivity, water availability, soil health, and livestock systems. Limited integration between climate science, agricultural research, and socio-economic studies reduces the effectiveness of adaptation planning. Greater investment in interdisciplinary research is required to develop practical solutions that address the specific needs of farmers and vulnerable communities.

Technology Limitations: The adoption of modern agricultural technologies in Pakistan remains limited due to financial constraints, lack of awareness, and inadequate access to technical support. Many farmers continue to depend on traditional farming methods that may be less effective under changing climatic conditions. Limited access to climate-resilient seeds, efficient irrigation systems, remote sensing technologies, and digital agricultural services restricts the ability of farming communities to adapt. Expanding access to affordable and appropriate technologies is essential for improving agricultural resilience.

Artificial Intelligence (AI) and Machine Learning (ML) Adoption Status: Artificial Intelligence (AI) and Machine Learning (ML) have significant potential to improve climate adaptation and agricultural decision-making. These technologies can support weather forecasting, crop monitoring, pest and disease prediction, water management, and early warning systems. However, the use of AI and ML in Pakistan's agricultural sector is still at an early stage. Challenges include limited digital infrastructure, shortage of technical expertise, lack of high-quality agricultural datasets, and limited awareness among farmers and institutions. Increasing investment in digital agriculture and data-driven solutions can enhance climate resilience.

Institutional Weaknesses: Institutional challenges also affect Pakistan's ability to respond effectively to climate change. Coordination gaps between government departments, research organizations, and local stakeholders can delay the implementation of adaptation measures. Limited financial resources, insufficient technical capacity, and weak monitoring systems reduce the effectiveness of climate policies and agricultural programs. Strengthening institutional collaboration, improving governance, and enhancing capacity-building initiatives are necessary for effective climate action.

Data Deficiencies: Reliable and accessible climate and agricultural data are essential for effective planning and decision-making. Pakistan faces challenges related to limited long-term climate records, insufficient agricultural monitoring systems, and gaps in district-level data collection. Improving data availability through modern monitoring systems, remote sensing, digital platforms, and integrated databases can support better risk assessment, early warning systems, and evidence-based climate adaptation strategies. Addressing these scientific and institutional gaps is critical for strengthening Pakistan's ability to manage climate risks, protect agricultural systems, and ensure long-term food security.

6. Mitigation Strategies & Best Practices

Overview of Mitigation Strategies: Addressing climate change impacts on Pakistan's food security and agricultural systems requires a combination of structural and non-structural measures. Effective mitigation and adaptation strategies can reduce climate risks, improve agricultural productivity, and strengthen the resilience of farming communities. These approaches should focus on sustainable resource management, improved technology adoption, and enhancing the capacity of communities to respond to climate challenges.

Improved Water Management: Developing efficient irrigation systems, improving water storage capacity, and promoting water conservation techniques can help address increasing water scarcity and support sustainable agricultural production.

Climate-Resilient Agricultural Infrastructure: Strengthening agricultural infrastructure, including flood protection systems, drainage networks, storage facilities, and rural transportation systems, can reduce losses caused by extreme weather events.

Climate-Resilient Crop Varieties: Promoting drought-resistant, heat-tolerant, and diseaseresistant crop varieties can improve crop survival and maintain productivity under changing climatic conditions.

Early Warning and Monitoring Systems: Improving weather forecasting, climate monitoring, and agricultural advisory systems can help farmers prepare for floods, droughts, and other climate-related hazards.

Capacity Building: Strengthening the capacity of farmers, agricultural extension workers, and local institutions through training programs can improve the adoption of climate-smart agricultural practices.

Awareness and Education: Raising awareness about climate risks, sustainable farming methods, water conservation, and disaster preparedness can help communities make informed decisions and reduce vulnerability.

Farmer Training Programs: Providing farmers with training on modern agricultural technologies, improved crop management, digital farming tools, and climate adaptation techniques can enhance their ability to respond to changing environmental conditions.

Policy and Institutional Support: Effective coordination between government agencies, research institutions, and local communities is necessary to ensure successful implementation of climate adaptation initiatives.

Best Practices for Climate-Resilient Agriculture: Several best practices can support sustainable agricultural development in Pakistan, including climate-smart agriculture, crop diversification, integrated pest management, efficient irrigation techniques, agroforestry, and improved soil conservation practices. Combining structural investments with awareness, training, and community participation can significantly reduce climate risks and strengthen Pakistan's agricultural resilience. These measures are essential for protecting food security and supporting sustainable livelihoods under changing climate conditions.

7. Risk Communication & Early Warning

Importance of Risk Communication: Effective risk communication is essential for reducing the impacts of climate-related hazards on Pakistan's agricultural systems and vulnerable communities. Timely and accurate information about floods, droughts, heatwaves, and extreme weather events enables farmers, local authorities, and communities to take preventive actions and reduce potential losses. A strong risk communication system should ensure that climate information reaches all segments of society in a clear, accessible, and understandable manner. Communication methods should consider local languages, literacy levels, and the specific needs of different communities.

Gender-Sensitive Early Warning Systems: Women often face greater challenges during climate-related disasters due to differences in access to information, resources, mobility, and decision-making opportunities. Therefore, early warning systems should be designed to address gender-specific needs and ensure equal access to climate information. Gender-sensitive approaches include involving women in disaster preparedness planning, improving their access to weather alerts, providing climate awareness training, and supporting their participation in community decision-making processes. This ensures that women can take timely actions to protect household food security, livestock, and livelihoods.

Community Engagement: Community participation is a key component of effective early warning and disaster risk management. Local communities should be actively involved in identifying risks, developing response plans, and implementing adaptation measures. Engaging farmers, local leaders, community organizations, and agricultural extension workers can improve trust and increase the effectiveness of warning systems. Community-based approaches also help incorporate local knowledge and ensure that climate information is relevant to local conditions.

Communication Strategies: To improve climate risk communication in Pakistan, multiple communication channels should be utilized, including:

Mobile phone alerts and digital platforms for timely weather information.

Local radio and television programs for reaching wider populations.

Farmer advisory services providing climate and agricultural guidance.

Community meetings and awareness campaigns in rural areas.

Collaboration between government institutions, research organizations, and local communities.

An effective risk communication framework should combine modern technology with community-based approaches. Strengthening early warning systems and ensuring inclusive communication can reduce climate-related losses, improve disaster preparedness, and enhance the resilience of Pakistan's agricultural communities.

8. Policy Recommendations

Integrated Governance and Institutional Coordination: Effective climate action requires strong coordination among government institutions, research organizations, private-sector stakeholders, and local communities. Pakistan should strengthen collaboration between climate, agriculture, water, and disaster management departments to develop integrated policies that address climate risks in a coordinated manner. Improving institutional capacity, strengthening monitoring systems, and ensuring effective implementation of climate policies are essential for reducing vulnerabilities in agricultural systems. Clear roles and responsibilities among institutions can improve decision-making and enhance climate resilience.

Strengthening Climate Adaptation Measures: Climate adaptation should become a central component of agricultural planning and development strategies. Pakistan should promote climate-smart agriculture practices, improve water management systems, and encourage the use of climate-resilient crop varieties. Investment in sustainable farming methods, soil conservation, efficient irrigation, and improved agricultural infrastructure can help farmers manage climate-related challenges. Adaptation programs should focus especially on vulnerable farming communities that face greater risks from floods, droughts, and changing weather patterns.

Community Participation and Inclusive Decision-Making: Local communities should be actively involved in climate adaptation planning and implementation. Farmers, women, youth, and local organizations possess valuable knowledge about environmental conditions and traditional coping practices. Strengthening community participation through awareness programs, farmer training, and local climate initiatives can improve the effectiveness of adaptation strategies. Inclusive decision-making ensures that policies address the practical needs of affected communities.

Technology Integration and Innovation: Technology integration is essential for improving climate resilience and agricultural productivity. Pakistan should promote the use of digital agriculture tools, remote sensing, weather forecasting systems, and data-driven decision-making platforms. Artificial Intelligence (AI), Machine Learning (ML), and other emerging technologies can support crop monitoring, climate prediction, pest management, and early warning systems. Expanding digital infrastructure, improving data availability, and building technical capacity will help maximize the benefits of these technologies.

Long-Term Policy Direction: A comprehensive climate resilience framework should combine scientific research, institutional cooperation, community participation, and technological innovation. By adopting a coordinated and inclusive approach, Pakistan can strengthen food security, protect agricultural livelihoods, and develop sustainable systems capable of responding to future climate challenges.

9. Conclusion

Climate change presents a significant challenge to Pakistan's food security and agricultural systems by affecting crop production, water resources, rural livelihoods, and economic stability. Increasing temperatures, changing rainfall patterns, floods, droughts, and other climate-related hazards are creating growing risks for farming communities and vulnerable populations. Building resilience against climate change requires a comprehensive approach based on science-driven planning, effective governance, and community participation. Scientific research, climate data, and risk assessment tools are essential for developing informed policies and implementing effective adaptation strategies. Evidence-based planning can help identify vulnerabilities, improve resource management, and support sustainable agricultural development. Social capital and community networks also play a critical role in strengthening resilience. Local cooperation, farmer organizations, and community-based initiatives can improve disaster preparedness, information sharing, and recovery efforts. Similarly, indigenous knowledge and traditional farming practices provide valuable insights into local adaptation methods and can complement modern scientific approaches. Emerging technologies, including Artificial Intelligence (AI), Machine Learning (ML), remote sensing, and digital agricultural platforms, offer new opportunities to enhance climate monitoring, early warning systems, and agricultural decision-making. However, successful technology integration requires improved infrastructure, reliable data systems, and capacity building among farmers and institutions. By combining scientific innovation, local knowledge, social participation, and supportive policies, Pakistan can develop a more resilient agricultural sector. Strengthening these areas will be essential for protecting food security, supporting vulnerable communities, and ensuring sustainable agricultural development in the face of future climate challenges.

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STUDENT RESEARCH PAPER

Climate Change Impacts on Food Security and Agricultural Systems

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Executive Summary

Climate change has emerged as one of the greatest threats to global food security and agricultural sustainability. Pakistan, being highly vulnerable to climate-induced disasters such as floods, droughts, heatwaves, and erratic rainfall, faces increasing challenges in maintaining agricultural productivity and protecting rural livelihoods. This report examines the impacts of climate change on food security and agricultural systems from a Disaster Risk Management (DRM) perspective, drawing primarily on the systematic literature review by Farah et al. (2025) and supported by recent national and international evidence. The report highlights Pakistan's climate vulnerability, the socio-economic consequences of climate-related disasters, and the importance of community resilience and institutional preparedness. It emphasizes that climate-smart agriculture, effective disaster risk reduction, early warning systems, and coordinated governance are essential for strengthening resilience. The report recommends integrating climate adaptation with disaster risk reduction policies, promoting sustainable agricultural practices, investing in research and technology, and enhancing collaboration among government agencies, local communities, and development partners to ensure long-term food security.

1. Regional Context & Hazard Profile

Climate change has become one of the most significant global challenges of the twenty-first century, affecting ecosystems, economies, and human well-being. Among all sectors, agriculture is one of the most vulnerable because it depends heavily on climatic conditions such as temperature, rainfall, soil moisture, and water availability. According to the Intergovernmental Panel on Climate Change (IPCC, 2023), rising global temperatures, changing precipitation patterns, and the increasing frequency of extreme weather events are already reducing agricultural productivity and threatening global food security. These impacts are particularly severe in developing countries, where agriculture is not only a source of food but also the primary livelihood for millions of people.

The systematic literature review by Farah et al. (2025) examined 77 SCOPUS-indexed studies published between 2015 and 2024 to understand how climate change influences agricultural productivity. The review concluded that rising temperatures, irregular rainfall, floods, droughts, pest outbreaks, and land degradation are significantly reducing crop yields across different regions of the world. The authors further noted that developing countries are disproportionately affected because of limited financial resources, inadequate technological capacity, weak institutional support, and greater dependence on climate-sensitive sectors. Importantly, the review highlights that although climate-smart agricultural practices and technological innovations can reduce these impacts, their adoption remains limited in many low- and middle-income countries.

Pakistan's Regional Context

Pakistan is recognized as one of the countries most vulnerable to climate change despite contributing less than one percent of global greenhouse gas emissions. Its geographical location, diverse climatic zones, rapidly growing population, dependence on the Indus River system, and agriculture-based economy make it particularly susceptible to climate-related hazards. Agriculture contributes approximately 23.54% of Pakistan's Gross Domestic Product (GDP) and provides employment to more than 37% of the national labour force (Government of Pakistan, 2025). Furthermore, nearly 62% of the country's population lives in rural areas, where livelihoods depend directly or indirectly on farming, livestock, and natural resources. Consequently, any disruption in climate conditions has immediate economic, social, and food security implications.

Pakistan experiences a wide range of climatic conditions, from the glaciers of the northern mountains to the arid deserts of Sindh and Balochistan. The country possesses more than 13,000 glaciers, making it home to the largest concentration of glaciers outside the polar regions. While these glaciers are an important source of freshwater for agriculture and domestic use, accelerated glacier melting due to rising temperatures has increased the risk of Glacial Lake Outburst Floods (GLOFs), flash floods, and long-term water insecurity. According to the Pakistan Meteorological Department (PMD), the country's annual average temperature in 2024 was approximately 23.52°C, around 0.71°C above the long-term average, while national rainfall reached 390 mm, approximately 31% above normal. Although increased rainfall may appear beneficial, its uneven distribution has resulted in severe flooding in some regions and prolonged droughts in others, demonstrating the growing variability associated with climate change.

Climate Change Trends and Their Implications

Recent climate observations indicate that Pakistan is experiencing more frequent and intense climate extremes than in previous decades. Heatwaves have become increasingly common across southern Punjab, Sindh, and Balochistan, leading to heat stress in crops and livestock, increased evapotranspiration, and reduced agricultural productivity. Similarly, erratic monsoon rainfall has disrupted planting and harvesting seasons, making traditional farming calendars less reliable. These changes affect the production of major crops such as wheat, rice, cotton, maize, and sugarcane, all of which are critical for national food security and economic stability.

The Pakistan Economic Survey (2024–25) reports that the agriculture sector grew by only 0.56%, while major crop production declined by 13.49% due to adverse weather conditions, water shortages, and climate variability. Wheat production decreased to 31.58 million tonnes, cotton production fell by approximately 30.7%, and maize production declined by 15.4% compared to the previous year. These statistics demonstrate that climate change is no longer a future concern but a present-day challenge affecting agricultural output, farmer incomes, and national economic growth.

- Historical Climate-Related Disasters in Pakistan

Pakistan has experienced numerous climate-induced disasters over the past two decades, illustrating its increasing exposure to environmental hazards. The devastating floods of 2010 affected around 20 million people, destroyed extensive agricultural land, damaged irrigation infrastructure, and caused billions of dollars in economic losses. More recently, the catastrophic 2022 floods became one of the worst climate disasters in the country's history. According to the Government of Pakistan and the Post-Disaster Needs Assessment (PDNA), approximately 33 million people were affected, over 4.4 million acres of agricultural land were damaged, and more than 1.1 million livestock animals were lost. Total economic damages and losses were estimated at approximately US$30 billion. These floods severely disrupted food production, increased food prices, damaged rural livelihoods, and highlighted the urgent need for disaster-resilient agricultural systems.

In addition to floods, Pakistan frequently experiences droughts, particularly in Sindh, Balochistan, and southern Punjab, where rainfall is scarce and groundwater resources are limited. These droughts reduce water availability for irrigation, decrease crop productivity, increase livestock mortality, and contribute to food insecurity among vulnerable communities. Similarly, recurrent heatwaves and pest outbreaks continue to threaten agricultural sustainability and rural livelihoods. Collectively, these historical events demonstrate that climate change has intensified both the frequency and severity of natural hazards, making disaster risk reduction an essential component of agricultural planning and national development.

- Key Definitions in the Context of Disaster Risk Management

Understanding the concepts of hazard, exposure, vulnerability, and risk is fundamental to Disaster Risk Management (DRM) because these concepts explain how disasters occur and why some communities are affected more severely than others. According to the United Nations Office for Disaster Risk Reduction (UNDRR, 2015), a disaster is not caused by a hazard alone; rather, it results from the interaction between hazards, exposure, and vulnerability.

A **hazard** is defined as a dangerous natural or human-induced event or process that has the potential to cause loss of life, injury, environmental degradation, or damage to property and livelihoods. In the context of climate change, hazards include floods, droughts, heatwaves, cyclones, glacier lake outburst floods (GLOFs), pest infestations, and irregular rainfall patterns. Pakistan experiences all of these hazards with increasing frequency due to changing climatic conditions. For example, prolonged heatwaves reduce soil moisture and crop productivity, while intense rainfall events trigger floods that destroy standing crops, irrigation systems, and transportation infrastructure.

Exposure refers to the people, infrastructure, crops, livestock, natural resources, and economic activities located in areas where hazards may occur. Pakistan's agricultural sector has a very high level of exposure because most farming communities depend directly on climate-sensitive natural resources. Large populations living in floodplains along the Indus River and its tributaries, rain-fed farming areas of the Potohar Plateau, and drought-prone districts of Sindh and Balochistan remain continuously exposed to climate-related hazards. Critical infrastructure such as irrigation canals, roads, storage facilities, and markets is also exposed to floods and extreme weather events, increasing the likelihood of economic disruption.

Vulnerability refers to the physical, social, economic, environmental, and institutional conditions that make individuals or communities more susceptible to the impacts of hazards. In Pakistan, vulnerability is influenced by widespread rural poverty, dependence on subsistence agriculture, inadequate irrigation infrastructure, limited access to climate-resilient technologies, poor disaster preparedness, weak institutional capacity, and insufficient financial resources. Smallholder farmers are particularly vulnerable because they often lack crop insurance, savings, access to credit, and modern agricultural technologies. Gender inequality further increases vulnerability, as women frequently have limited access to land ownership, agricultural inputs, financial services, and decision-making processes despite playing a crucial role in farming and household food security.

Risk is the probability of harmful consequences resulting from the interaction of hazards, exposure, and vulnerability. It can be understood as the likelihood of losses affecting lives, livelihoods, agricultural production, infrastructure, and ecosystems. Disaster risk increases when highly exposed populations with limited adaptive capacity experience frequent and intense climate hazards. Therefore, reducing disaster risk requires not only controlling hazards where possible but also decreasing exposure and strengthening the resilience of vulnerable communities through preparedness, adaptation, and sustainable development.

- Pakistan's Vulnerability Profile

Pakistan's vulnerability to climate change is shaped by a combination of environmental, economic, demographic, and institutional factors. Agriculture remains one of the country's most climate-sensitive sectors, contributing approximately **23.54% of GDP** and employing more than **37% of the labour force** (Government of Pakistan, 2025). Because a large proportion of the rural population depends on farming and livestock for income, climate-related disasters directly threaten livelihoods, food availability, and national economic stability.

Water scarcity represents another major source of vulnerability. Pakistan's agriculture depends heavily on the Indus Basin Irrigation System, one of the world's largest irrigation networks. However, increasing temperatures, glacier retreat, changing river flows, groundwater depletion, and inefficient irrigation practices are reducing water availability for agricultural production. Simultaneously, rapid population growth, urbanization, and competition for water resources are placing additional pressure on already limited supplies.

Socio-economic conditions further increase vulnerability. High poverty rates, unequal access to education, limited healthcare services, weak rural infrastructure, and inadequate social protection reduce the ability of households to prepare for and recover from disasters. Smallholder farmers often cultivate marginal lands that are highly susceptible to flooding, drought, soil erosion, and land degradation. Financial constraints prevent many farmers from adopting climate-smart technologies, improved seed varieties, efficient irrigation systems, and crop insurance schemes that could reduce climate risks.

Institutional vulnerability also remains a significant challenge. Although Pakistan has made considerable progress in strengthening disaster management through institutions such as the National Disaster Management Authority (NDMA), Provincial Disaster Management Authorities (PDMAs), and the Pakistan Meteorological Department (PMD), coordination among agencies, data-sharing mechanisms, and implementation of climate adaptation policies still require improvement. Limited technical capacity, fragmented governance, and inadequate investment in scientific research restrict the effectiveness of disaster preparedness and climate resilience programmes.

Synthesis

The literature consistently demonstrates that climate change is intensifying Pakistan's hazard profile while simultaneously increasing the exposure and vulnerability of agricultural systems and rural communities. The systematic review by **Farah et al. (2025)** concludes that rising temperatures, erratic rainfall, floods, droughts, and land degradation are major drivers of declining agricultural productivity worldwide, with developing countries experiencing the greatest impacts. These findings closely reflect Pakistan's current situation, where repeated climate-induced disasters continue to threaten food production, economic growth, and rural livelihoods.

From a Disaster Risk Management perspective, understanding the interaction between hazards, exposure, vulnerability, and risk is essential for designing effective adaptation and resilience strategies. Climate-smart agriculture, integrated water resource management, scientific risk assessment, community participation, and institutional coordination should therefore become central components of national development planning. By addressing the underlying drivers of vulnerability and strengthening adaptive capacity, Pakistan can reduce disaster risks, improve food security, and build more resilient agricultural systems capable of withstanding future climate challenges.

- Risk & Vulnerability Assessment

Climate change poses significant socio-economic risks by reducing agricultural productivity, disrupting livelihoods, and threatening food security across Pakistan. Agriculture contributes approximately 23.54% to the national GDP and employs more than 37% of the labour force; therefore, climate-induced losses directly affect economic stability and rural incomes. Floods, droughts, heatwaves, and pest outbreaks reduce crop yields, damage irrigation infrastructure, and increase livestock mortality, leading to food shortages and rising prices. Repeated disasters also force households to adopt negative coping strategies such as selling productive assets or reducing food consumption. Smallholder farmers, landless labourers, women, children, and economically disadvantaged communities are particularly vulnerable because of limited access to financial resources, technology, and social protection mechanisms. Women often experience disproportionate impacts as they play vital roles in agricultural production, household food management, and caregiving while having limited access to land ownership, agricultural inputs, and decision-making processes. Strengthening resilience among these vulnerable groups is therefore essential for reducing disaster risk and achieving sustainable food security.

- Community Resilience Factors

Community resilience is a critical component of Disaster Risk Reduction because local communities are the first to respond to climate-related disasters. Social capital, strong community networks, and collective action enhance the ability of households to prepare for, respond to, and recover from disasters. Indigenous knowledge also plays an important role in climate adaptation, as local farmers have developed traditional practices for water conservation, crop diversification, seasonal forecasting, and sustainable land management over generations. Community-based organizations, farmer groups, and local leadership facilitate information sharing, mutual assistance, and coordinated disaster preparedness. Integrating indigenous knowledge with scientific research and modern technologies can strengthen climate adaptation strategies and improve agricultural resilience. Capacity-building programmes, awareness campaigns, and farmer training further enhance communities' ability to adopt climate-smart agricultural practices and respond effectively to early warning information. Building resilient communities therefore requires strengthening social cohesion, recognizing local knowledge systems, encouraging participatory decision-making, and promoting partnerships between communities, government institutions, and development organizations.

- Scientific & Institutional Gaps

Climate change has become one of the most widely researched global challenges, yet significant scientific and institutional gaps continue to limit the effectiveness of climate adaptation and Disaster Risk Reduction (DRR), particularly in developing countries such as Pakistan. Although substantial progress has been made in understanding the impacts of climate change on agriculture, many existing studies remain fragmented, geographically limited, or focused on single aspects of climate risk. The systematic literature review by Farah et al. (2025)**,** which analyzed 77 SCOPUS-indexed studies published between 2015 and 2024**,** concluded that while considerable evidence exists regarding the adverse effects of climate change on agricultural productivity, important knowledge gaps remain in understanding regional variations, long-term adaptation effectiveness, and the integration of emerging technologies into agricultural systems. The review emphasizes that developing countries require more location-specific, interdisciplinary, and policy-oriented research to effectively address climate-related agricultural challenges.

One major scientific gap is the limited availability of high-quality, localized, and long-term climate and agricultural data**.** Most climate projections are prepared at national or global scales and often fail to capture local variations in temperature, rainfall, soil conditions, groundwater availability, and crop performance. Such information is essential for developing accurate climate models, forecasting agricultural productivity, and designing effective adaptation strategies. In Pakistan, inconsistencies in meteorological records, limited monitoring stations in remote regions, and fragmented databases among government institutions reduce the accuracy of climate risk assessments. The absence of integrated data systems also restricts evidence-based planning and timely policy interventions.

Another important challenge is the limited adoption of advanced technologies in Pakistan's agricultural and disaster management sectors. Around the world, technologies such as Artificial Intelligence (AI), Machine Learning (ML), Remote Sensing, Geographic Information Systems (GIS), Internet of Things (IoT), drones, and satellite imagery are increasingly being used to monitor crops, assess soil moisture, predict pest outbreaks, estimate crop yields, forecast weather events, and support early warning systems. AI and ML algorithms can analyze large datasets to identify climate trends, predict droughts or floods, optimize irrigation schedules, and provide farmers with location-specific recommendations. Similarly, remote sensing technologies enable continuous monitoring of vegetation health, land degradation, and water resources, supporting rapid decision-making before and after disasters.

Despite these global advances, the adoption of AI- and ML-based agricultural technologies in Pakistan remains at an early stage. Digital agriculture initiatives are still limited to pilot projects, research institutions, and selected private-sector applications. Many smallholder farmers lack access to smartphones, internet connectivity, digital advisory services, and technical training required to benefit from these innovations. High implementation costs, inadequate infrastructure, limited technical expertise, and low digital literacy further restrict the widespread use of modern technologies. Consequently, agricultural planning and disaster response often rely on traditional methods that are less efficient in addressing rapidly changing climate conditions.

Institutional weaknesses also present significant barriers to climate resilience. Pakistan has established important organizations such as **the** National Disaster Management Authority (NDMA)**,** Provincial Disaster Management Authorities (PDMAs)**, the** Pakistan Meteorological Department (PMD)**,** and various agricultural research institutions. While these organizations have made considerable progress in disaster preparedness and emergency response, coordination among institutions remains a persistent challenge. Climate adaptation, agriculture, water management, disaster risk reduction, and environmental protection are often managed by different ministries and agencies with overlapping responsibilities. This fragmented governance structure can result in duplication of efforts, delays in information sharing, inconsistent policy implementation, and inefficient allocation of financial resources.

Furthermore, institutional capacity at the provincial and district levels remains uneven. Many local governments and extension services face shortages of trained personnel, financial resources, technical equipment, and modern forecasting tools. Agricultural extension systems often struggle to provide timely climate information, technological support, and advisory services to farmers, particularly in remote rural areas. Limited investment in scientific research, inadequate funding for innovation, and weak collaboration between universities, research organizations, government agencies, and farming communities further reduce the effectiveness of adaptation programmes.

Data deficiencies represent another critical challenge. Reliable information on crop losses, climate hazards, soil health, groundwater resources, and socio-economic vulnerability is often scattered across multiple institutions, making comprehensive risk assessments difficult. Standardized data collection methods, integrated digital databases, and real-time information-sharing mechanisms are still underdeveloped. These deficiencies affect policy formulation, disaster preparedness, emergency response, and post-disaster recovery planning. Strengthening data governance through improved monitoring systems, open-access databases, and inter-agency collaboration would significantly enhance evidence-based decision-making.

Addressing these scientific and institutional gaps requires a comprehensive and integrated approach. Pakistan should invest in climate research, strengthen meteorological and agricultural monitoring systems, promote AI- and ML-based decision-support tools, expand digital agriculture initiatives, and improve coordination among NDMA, PDMAs, the Pakistan Meteorological Department, agricultural departments, universities, and research institutions. Capacity building, financial investment, public-private partnerships, and stronger collaboration between scientists, policymakers, and local communities are equally important. Closing these gaps will enable Pakistan to develop more effective climate adaptation strategies, strengthen Disaster Risk Reduction, improve agricultural productivity, and enhance national food security in the face of increasing climate risks.

- Mitigation Strategies & Best Practices

Reducing the impacts of climate change on agriculture requires both structural and non-structural mitigation measures. Structural measures include the development of climate-resilient irrigation systems, construction of flood protection infrastructure, rainwater harvesting facilities, watershed management, soil conservation techniques, and improved storage facilities for agricultural products. Non-structural measures focus on strengthening human and institutional capacities through farmer education, community awareness campaigns, disaster preparedness training, and agricultural extension services. Climate-Smart Agriculture (CSA) offers practical solutions such as drought-resistant crop varieties, crop diversification, conservation agriculture, precision farming, and efficient irrigation technologies. According to Farah et al. (2025), adopting climate-smart practices can improve agricultural productivity while reducing vulnerability to climate-related hazards. Regular capacity-building programmes, collaboration between research institutions and farming communities, and integration of climate information into agricultural planning are essential for promoting sustainable farming practices and enhancing long-term resilience.

- Risk Communication & Early Warning

Effective risk communication and early warning systems are fundamental components of Disaster Risk Reduction because they enable timely action before disasters occur. Multi-hazard early warning systems should provide accurate, reliable, and location-specific information on floods, droughts, heatwaves, and other climate hazards affecting agriculture. Gender-sensitive communication strategies are essential to ensure that women, smallholder farmers, elderly people, and other vulnerable groups receive timely and understandable warnings. Community engagement through local organizations, farmer associations, village committees, and extension workers improves trust and encourages preparedness actions.

Communication channels such as mobile phone alerts, radio broadcasts, television, social media, and community volunteers should be integrated to maximize outreach. Collaboration among NDMA, Pakistan Meteorological Department (PMD), Provincial Disaster Management Authorities, and local administrations is necessary to ensure efficient dissemination of warnings. Strengthening public awareness and promoting community participation can significantly reduce disaster losses and enhance agricultural resilience.

- Policy Recommendations

Pakistan should adopt an integrated policy framework that combines climate adaptation, Disaster Risk Reduction, and sustainable agricultural development. The government should promote Climate-Smart Agriculture through improved seed varieties, efficient irrigation technologies, conservation agriculture, and sustainable land management practices. Investment in climate research, digital technologies, Artificial Intelligence, and weather-based crop insurance should be expanded to strengthen agricultural resilience. Institutional coordination among NDMA, PDMAs, agriculture departments, research organizations, Pakistan Meteorological Department, and local communities should be enhanced to ensure effective implementation of adaptation measures. Farmer training programmes and agricultural extension services should be strengthened to improve awareness and adoption of climate-resilient practices. Community participation, indigenous knowledge, and gender-inclusive decision-making should be integrated into disaster risk management policies. These measures will contribute to reducing disaster risks, improving food security, and achieving sustainable rural development.

- Conclusion

Climate change poses a serious and growing threat to Pakistan's agricultural systems, food security, and rural livelihoods. The findings of Farah et al. (2025), together with recent national evidence, demonstrate that rising temperatures, changing rainfall patterns, floods, droughts, and other climate hazards are already reducing agricultural productivity and increasing disaster risks. Building resilience requires a comprehensive approach that integrates science-based planning, climate-smart agriculture, Disaster Risk Reduction, and sustainable development strategies. Strengthening social capital, community participation, and indigenous knowledge can enhance local adaptive capacity, while emerging technologies such as Artificial Intelligence, remote sensing, and early warning systems can improve preparedness and decision-making. Effective institutional coordination, evidence-based policies, and continuous investment in research and capacity building are essential for protecting agriculture and ensuring long-term food security. By adopting these integrated approaches, Pakistan can build more resilient agricultural systems and better safeguard the livelihoods of present and future generations.

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STUDENT RESEARCH PAPER

Climate Change as the Driver of Key Disasters Hazard Profile and Climate Risk Analysis of Jonglei State

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Hazard Profile and Climate Risk Analysis of Jonglei State

Executive summary

This study examines climate change as a key driver of disasters in South Sudan, with a focus on Jonglei State. The findings show that climate change is increasing the frequency and intensity of hazards, particularly flooding, droughts, and disease outbreaks. Jonglei State faces a very high flood risk due to its geographical location along the White Nile floodplain and its dependence on climate-sensitive livelihoods.

The impacts of these disasters include loss of lives and property, displacement of communities, reduced agricultural production, food insecurity, increased poverty, and damage to critical infrastructure and public services. Vulnerable groups, including farmers, pastoralists, women, and children, are disproportionately affected.

The study recommends strengthening climate adaptation and disaster risk reduction measures, investing in early warning systems, promoting climate-smart agriculture, improving flood management infrastructure, and enhancing ecosystem restoration to build resilience and reduce future disaster risks.

Introduction

Climate change is a major environmental and development challenge in South Sudan. Although the country contributes little to global greenhouse gas emissions, it remains highly vulnerable to climate-related hazards such as floods, droughts, food insecurity, disease outbreaks, and displacement. These impacts continue to affect livelihoods, economic development, and community well-being (IPCC, 2023; World Bank, 2023). Jonglei State is among the most vulnerable regions due to its location within the Nile Basin and Sudd wetlands. In recent years, recurrent flooding has caused significant damage to crops, livestock, infrastructure, and settlements, increasing humanitarian needs and disrupting livelihoods (FAO, 2020; UNICEF, 2024).

Objective of the Study

The primary objective of this study is to assess how climate change drives major disasters in South Sudan, particularly in Jonglei State, and to identify policy measures that can strengthen climate resilience and disaster risk reduction. Specific objectives include:

Examining the relationship between climate change and disaster occurrence.

Identifying major climate-related hazards affecting Jonglei State.

Recommending measures for climate adaptation and disaster risk reduction.

Context Description of Jonglei State

Jonglei State, located in eastern South Sudan with its capital in Bor, is the country's largest state by area. The state's economy is largely dependent on agriculture, livestock, and fishing, making communities highly vulnerable to climate-related shocks (UNDP, 2023). Due to its extensive floodplains along the White Nile and the Sudd wetlands, Jonglei is highly prone to flooding. In recent years, climate change has increased the frequency and severity of floods, resulting in displacement, loss of livelihoods, and damage to agricultural production (FAO, 2020; FAO, 2021).

Hazard Profile of Jonglei State

Flooding (Very High Risk)

Flooding is the most significant hazard affecting Jonglei State due to its location within the White Nile floodplain. Increased rainfall, rising river levels, and upstream water flows have led to recurrent flooding in counties such as Bor South, Twic East, Duk, Fangak, Ayod, Canal/Pigi, and Nyirol (FAO, 2020). These floods have caused extensive damage to farmland, livestock, infrastructure, and livelihoods, making Jonglei one of the most flood-affected states in South Sudan (FAO, 2020; OCHA, 2025).

Drought and Dry Spells (Moderate Risk)

Despite being known for flooding, Jonglei also experiences periodic droughts and prolonged dry spells. These result in water shortages, crop failure, reduced pasture availability, livestock migration, and increased food insecurity. Changes in rainfall distribution have heightened drought risk in some areas, particularly during years of below-average precipitation (IPCC, 2023; FAO, 2023).

Disease Outbreaks (High Risk)

Climate hazards often trigger disease outbreaks, including cholera, acute watery diarrhea, malaria, dysentery, and respiratory infections. Floodwaters contaminate water sources and create breeding grounds for disease vectors, increasing public health risks (UNICEF, 2024; OCHA, 2025).

Major Climate Change-Driven Disasters and their impacts

Floods

Warmer air retains more moisture, leading to heavier rainfall and increased flooding. Floods destroy homes, roads, schools, health facilities, farmlands, and water systems. In Jonglei State, recurrent flooding has displaced thousands of households and disrupted livelihoods for several years (FAO, 2020; OCHA, 2025).

Droughts

Higher temperatures increase evaporation and reduce soil moisture, contributing to extended dry periods. Droughts result in crop failure, water shortages, livestock mortality, and reduced food production (FAO, 2023; IPCC, 2023).

Heatwaves and extreme temperatures

Climate change has increased the frequency and severity of heat stress. Rising temperatures negatively affect human health, agricultural productivity, livestock well-being, and labor performance (WMO, 2023).

Disease Outbreaks

Floods and temperature increases contribute to outbreaks of malaria, cholera, and other communicable diseases. Vulnerable populations are often disproportionately affected due to poor access to health services (UNICEF, 2024; OCHA, 2025).

Socio-Economic Impacts

Climate-related disasters in South Sudan and Jonglei State have significant socio-economic implications. These disasters result in the loss of lives and property, forcing many households to abandon their homes and leading to large-scale population displacement. They reduce agricultural production and livestock productivity, thereby threatening food security and household incomes (UNDRR, 2022; FAO, 2023). Climate-related hazards also contribute to increased poverty, dependency on humanitarian assistance, and disruption of education and healthcare services. In addition, they damage infrastructure such as roads, schools, health facilities, water points, and markets. Collectively, these impacts undermine economic growth, weaken community resilience, and slow national development efforts (World Bank, 2023; OCHA, 2025).

Impacts on Vulnerable Communities

The effects of climate change disproportionately affect vulnerable groups, including smallholder farmers, pastoralists, women and girls, children, elderly persons, and people living with disabilities. These groups often have limited resources and adaptive capacity, making it difficult to cope with climate-related shocks (UNDP, 2023).

In Jonglei State, climate-induced floods have significantly affected children's education, nutrition, health, and protection. Flooding has also limited access to healthcare and essential services, particularly in remote communities (UNICEF, 2024).

Conclusion

Climate change has become a major driver of disasters in South Sudan by increasing the frequency and severity of floods, droughts, disease outbreaks, and other extreme events. Jonglei State represents one of the country's most climate-vulnerable regions due to its geographical location, dependence on climate-sensitive livelihoods, and recurring exposure to floods (FAO, 2020; IPCC, 2023). The growing impacts of climate change threaten lives, livelihoods, food security, infrastructure, and sustainable development. Addressing these challenges requires integrated approaches that combine climate adaptation, disaster risk reduction, environmental management, and community resilience building (UNDRR, 2022; World Bank, 2023).

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STUDENT RESEARCH PAPER

Industrial and Technological Disasters Triggered by Natural Disasters (NaTech Disasters)

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Executive Summary

Natural Hazard Triggering Technological (NaTech) disasters occur when natural hazards such as earthquakes, floods, tsunamis, hurricanes, or landslides damage industrial facilities, causing hazardous material releases, fires, explosions, or infrastructure failure. Climate change and rapid industrialization have increased the frequency and severity of these events worldwide. Effective risk assessment, resilient infrastructure, emergency planning, and technological innovation are essential for reducing NaTech risks and protecting communities and ecosystems.

- Regional Context & Hazard Profile

NaTech disasters have become an emerging global concern due to increasing urbanization and industrial development in hazard-prone areas. Countries such as Japan, the United States, China, and Pakistan face significant risks from earthquakes, floods, cyclones, and extreme weather events.

Pakistan is particularly vulnerable because of recurring floods, seismic activity, and expanding industrial zones located near rivers and densely populated regions. Major hazards include flooding, earthquakes, heatwaves, and landslides, all of which can trigger technological accidents involving chemical industries, fuel storage facilities, and power infrastructure.

- Risk & Vulnerability Assessment

The consequences of NaTech disasters extend beyond physical damage to industries. Hazardous chemical releases contaminate air, soil, and water resources, threatening human health and biodiversity. Industrial shutdowns disrupt livelihoods, food supply chains, and national economies.

Vulnerable populations—including low-income communities, women, children, elderly people, and emergency responders—experience greater impacts due to limited preparedness and reduced access to resources during emergencies.

- Community Resilience Factors

Community resilience depends on public awareness, local disaster preparedness, effective emergency response systems, and collaboration between industries, government agencies, and local communities. Indigenous knowledge and community participation strengthen disaster preparedness by improving local response strategies and reducing recovery time.

- Scientific & Institutional Gaps

Many developing countries lack comprehensive NaTech risk assessments, updated industrial safety standards, and integrated hazard databases. Limited adoption of Geographic Information Systems (GIS), Artificial Intelligence (AI), remote sensing, and early warning technologies further reduces preparedness. Weak institutional coordination and insufficient enforcement of environmental regulations remain major challenges.

- Mitigation Strategies & Best Practices

Mitigation measures include hazard-resistant industrial design, regular safety inspections, risk mapping, chemical storage improvements, flood protection barriers, and emergency shutdown systems. Non-structural measures include disaster preparedness training, public awareness campaigns, capacity building, emergency response planning, and periodic evacuation drills.

- Risk Communication & Early Warning

An effective early warning system should provide timely and accurate information to industries, emergency responders, and nearby communities. Risk communication must be clear, accessible, and inclusive, ensuring that vulnerable groups receive warnings through multiple communication channels, including mobile alerts, television, radio, and social media.

- Policy Recommendations

Integrate NaTech risk management into national disaster management policies.

Strengthen industrial safety regulations and environmental monitoring.

Promote climate-resilient industrial infrastructure.

Encourage public-private partnerships for disaster preparedness.

Expand the use of GIS, AI, and remote sensing technologies for hazard monitoring.

Improve coordination among disaster management authorities, environmental agencies, and industrial sectors.

Table 1. Summary of Major NaTech Hazards, Impacts, and Mitigation Measures

Natural Hazard	Potential Technological Disaster	Environmental & Socio-economic Impacts	Recommended Mitigation Measures
Earthquake	Chemical spills, refinery fires, pipeline rupture	Air and water pollution, infrastructure damage, injuries, economic losses	Seismic-resistant infrastructure, automatic shutdown systems, regular safety inspections
Flood	Overflow of hazardous waste, fuel leakage, industrial contamination	Water contamination, disease outbreaks, ecosystem degradation, displacement	Flood barriers, elevated storage tanks, improved drainage, emergency response plans
Tsunami	Damage to nuclear plants, oil terminals, chemical storage facilities	Radioactive release, marine pollution, long-term ecological damage	Coastal protection, hazard zoning, resilient facility design, evacuation planning
Hurricane/Cyclone	Power failure, explosions, chemical leaks	Business interruption, environmental pollution, public health risks	Climate-resilient infrastructure, backup power systems, early warning systems
Landslide	Damage to industrial buildings and pipelines	Soil contamination, transportation disruption, property damage	Slope stabilization, geotechnical monitoring, land-use planning

- Conclusion

NaTech disasters represent a growing challenge due to climate change, urban expansion, and increasing industrialization. Reducing their impacts requires science-based planning, resilient infrastructure, effective governance, technological innovation, and strong community participation. Investing in preparedness and sustainable industrial development will significantly reduce future disaster risks and enhance national resilience.

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STUDENT RESEARCH PAPER

Flash Floods and Landslides in Mountainous Regions

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Executive Summary

Mountainous regions are among the most disaster-prone environments due to their steep terrain, unstable geological conditions, intense rainfall, glacier melt, and increasing impacts of climate change. Two of the most significant hazards affecting these regions are flash floods and landslides, both of which develop rapidly and can cause catastrophic damage to human lives, infrastructure, livelihoods, and ecosystems. The frequency and intensity of these hazards have increased globally due to changing climate patterns, unplanned urbanization, deforestation, and environmental degradation.

Globally, disasters such as the 1999 Vargas Tragedy (Venezuela), the 2021 Melamchi Flash Flood (Nepal), the 2023 Sikkim Glacial Lake Outburst Flood (India), and the 2014 Oso Landslide (USA) demonstrate the devastating consequences of mountain hazards. In Pakistan, the 2010 Super Floods, 2022 Monsoon Floods, and the 2010 Attabad Landslide remain major examples of climate-induced disasters that exposed vulnerabilities in disaster preparedness and infrastructure resilience.

This report assesses the regional hazard profile, vulnerability, community resilience, scientific and institutional gaps, mitigation strategies, and policy recommendations. It also highlights the role of emerging technologies—including Artificial Intelligence (AI), Geographic Information Systems (GIS), Remote Sensing, drones, Big Data, and the Internet of Things (IoT) in improving disaster risk reduction. The findings support Pakistan's disaster management framework by strengthening anticipatory action, preparedness, response, recovery, and resilience building, with recommendations directed towards NDMA, PDMAs, District Administrations, line departments, and relevant ministries.

Regional Context & Hazard Profile

Mountainous regions cover a significant portion of the Earth's land surface and support millions of people. However, these regions are highly susceptible to flash floods and landslides due to steep slopes, weak geological formations, seismic activity, heavy precipitation, glacier melt, and unsustainable land use practices. Climate change has accelerated glacier retreat and increased the occurrence of extreme rainfall events, significantly raising disaster risks worldwide.

A **flash flood** is a sudden and rapidly occurring flood that develops within minutes or a few hours after intense rainfall, cloudbursts, dam failures, or Glacial Lake Outburst Floods (GLOFs). These floods move with high velocity, carrying rocks, debris, and sediments that increase their destructive potential.

A **landslide** is the downward movement of rock, soil, or debris caused by heavy rainfall, earthquakes, erosion, slope instability, or human interventions such as deforestation, mining, and road construction.

Flash floods and landslides frequently occur together in mountainous regions, multiplying their impacts. Disaster risk is determined by four key components:

Hazard: Natural events such as heavy rainfall, cloudbursts, earthquakes, glacier melt, and unstable slopes.

Exposure: Population, infrastructure, agriculture, and economic assets located within hazard-prone areas.

Vulnerability: Physical, social, economic, and environmental conditions that increase susceptibility to damage.

Risk: The probability of losses resulting from the interaction of hazards, exposure, and vulnerability.

Global Perspective:

Several catastrophic disasters illustrate the growing risks in mountainous regions:

Vargas Tragedy, Venezuela (1999): Intense rainfall triggered flash floods and landslides that killed an estimated 10,000–30,000 people and destroyed thousands of homes.

Melamchi Flash Flood, Nepal (2021): Heavy rainfall and glacial processes triggered a destructive debris flow that devastated communities and infrastructure.

Sikkim Glacial Lake Outburst Flood, India (2023): A sudden breach of a glacial lake caused catastrophic flash flooding, destroying bridges, hydropower infrastructure, and settlements.

Oso Landslide, USA (2014): Heavy rainfall triggered one of the deadliest landslides in U.S. history, resulting in 43 fatalities.

Pakistan's Hazard Profile:

Pakistan ranks among the countries most vulnerable to climate change despite contributing less than 1% of global greenhouse gas emissions. Approximately 60% of the country's terrain consists of mountainous areas, including the Himalayas, Karakoram, and Hindu Kush, making regions such as Khyber Pakhtunkhwa, Gilgit-Baltistan, Azad Jammu & Kashmir, and northern Balochistan highly susceptible to flash floods and landslides.

Major disasters include:

2010 Super Floods: Nearly 20 million people affected, approximately 2,000 deaths, and widespread destruction of infrastructure and agriculture.

2022 Monsoon Floods: More than 33 million people affected, over 1,700 deaths, and economic losses exceeding US$30 billion. Mountain districts such as Swat, Chitral, Dir, Kohistan, and Shangla experienced severe flash flooding.

Attabad Landslide (Hunza, 2010): The landslide blocked the Hunza River, formed Attabad Lake, displaced thousands of residents, and disrupted the Karakoram Highway.

Seasonal landslides continue to affect Neelum Valley, Kaghan Valley, Upper Dir, Kohistan, Chitral, and Gilgit-Baltistan, disrupting transportation and isolating communities.

- Risk & Vulnerability Assessment

The impacts of flash floods and landslides extend far beyond immediate physical destruction. Mountain communities often rely on agriculture, livestock, forestry, and tourism, making them highly vulnerable to disruptions caused by disasters.

Major impacts include:

Loss of human lives and injuries.

Destruction of homes, roads, bridges, schools, hospitals, and communication infrastructure.

Damage to agricultural land, crops, livestock, and irrigation systems.

Food insecurity and loss of household income.

Environmental degradation through erosion, sediment deposition, and river course changes.

Displacement of communities and interruption of education and healthcare services.

Women, children, elderly persons, persons with disabilities, and economically disadvantaged households are disproportionately affected because they often have limited access to resources, mobility, and disaster information. Therefore, disaster risk reduction strategies must adopt inclusive and gender-sensitive approaches.

Community Resilience Factors

Community resilience is a critical component of disaster risk reduction. Indigenous knowledge, strong social networks, and local coping mechanisms often enable communities to respond effectively before external assistance arrives.

Key resilience factors include:

Community-Based Disaster Risk Management (CBDRM).

Village Disaster Management Committees.

Local volunteer rescue groups.

Traditional knowledge for identifying hazard-prone areas and safe evacuation routes.

Sustainable watershed and forest management.

Public awareness and school safety programmes.

Strengthening social capital through collaboration between communities and government institutions enhances preparedness, emergency response, and long-term recovery.

Scientific & Institutional Gaps

Despite significant improvements in disaster management, important challenges remain. **Scientific Gaps**

Limited real-time monitoring of rainfall, river discharge, glaciers, and unstable slopes.

Insufficient landslide susceptibility mapping.

Limited climate modelling for localized hazard prediction.

Inadequate research on compound disasters involving both floods and landslides. **Institutional Gaps**

Weak coordination among government agencies.

Inconsistent enforcement of land-use planning and building regulations.

Limited community participation in disaster planning.

Insufficient investment in scientific research and local preparedness.

Innovation and Technology

Emerging technologies offer significant opportunities for improving disaster risk management:

Artificial Intelligence (AI): Predicts flood and landslide risks using weather forecasts, hydrological data, and historical records.

Geographic Information Systems (GIS): Supports hazard mapping, evacuation planning, and resource allocation.

Remote Sensing: Monitors rainfall, glacier movement, vegetation loss, and land-use changes using satellite imagery.

Drones: Conduct rapid damage assessments, support search and rescue operations, and deliver emergency supplies.

Big Data and IoT: Integrate information from weather stations, rainfall gauges, river sensors, and mobile networks to improve real-time situational awareness.

Mitigation Strategies & Best Practices

Reducing disaster risk requires a combination of structural and non-structural measures. **Structural Measures**

Slope stabilization and retaining walls.

Check dams and river training structures.

Climate-resilient roads, bridges, and drainage systems.

Flood protection embankments.

Bioengineering techniques to stabilize vulnerable slopes.

Non-Structural Measures

Hazard zoning and land-use planning.

Afforestation and watershed conservation.

Community awareness programmes.

Capacity building for local governments.

Regular evacuation drills and simulation exercises.

Enforcement of disaster-resilient building codes.

These measures should be integrated into development planning to reduce long-term disaster risks.

Risk Communication & Early Warning

An effective Early Warning System (EWS) is only successful when warnings reach vulnerable communities in a timely, understandable, and actionable manner.

Priority actions include:

Expanding Multi-Hazard Early Warning Systems.

Integrating PMD forecasts with GIS-based risk maps.

Using SMS alerts, community radio, and social media for rapid communication.

Developing gender-sensitive and disability-inclusive warning mechanisms.

Strengthening community volunteer networks for evacuation and awareness.

Conducting regular public education campaigns on disaster preparedness.

Policy Recommendations

National Disaster Management Authority (NDMA)

Strengthen Multi-Hazard Early Warning Systems through AI, GIS, Remote Sensing, and satellite-based monitoring.

Develop national flash flood and landslide susceptibility maps.

Promote anticipatory action through forecast-based financing.

Strengthen coordination among NDMA, PMD, SUPARCO, Rescue 1122, and provincial authorities.

Provincial Disaster Management Authorities (PDMAs)

Update hazard maps and district contingency plans regularly.

Conduct community-based preparedness and evacuation exercises.

Establish GIS-enabled Emergency Operation Centers.

Enhance coordination with district administrations and local governments.

District Administrations and Line Departments

Enforce land-use planning and restrict construction in high-risk areas.

Improve drainage systems, slope stabilization, and watershed management.

Promote afforestation and ecosystem restoration.

Install rainfall gauges, river monitoring systems, and community-based early warning mechanisms.

Relevant Ministries

Integrate disaster risk reduction and climate adaptation into national development planning.

Invest in resilient infrastructure and scientific research.

Promote partnerships with universities and international organizations for innovation and capacity building.

Operational Linkage & Conclusion

The recommendations presented in this report directly support Pakistan's disaster management and climate change framework.

Anticipatory Action: AI-based forecasting, GIS hazard mapping, satellite monitoring, and forecast based financing enable authorities to act before disasters occur.

Preparedness: Community awareness, hazard mapping, emergency drills, and institutional capacity building improve readiness.

Response: Drones, GIS, satellite imagery, and digital communication systems strengthen search and rescue, damage assessment, and relief coordination.

Recovery: Climate-resilient reconstruction, livelihood restoration, slope stabilization, and ecosystem rehabilitation reduce future vulnerabilities.

Resilience Building: Long-term investments in climate adaptation, watershed management, resilient infrastructure, community participation, and emerging technologies improve resilience against future disasters.

In conclusion, flash floods and landslides are becoming more frequent and severe due to climate change and environmental degradation. Experiences from global disasters such as the Vargas Tragedy, Melamchi Flash Flood, Sikkim GLOF, and Oso Landslide, together with Pakistan's 2010 Super Floods, 2022 Monsoon Floods, and Attabad Landslide, demonstrate that disaster losses can be significantly reduced through integrated governance, science-based planning, technological innovation, and community participation. Strengthening collaboration among NDMA, PDMAs, District Administrations, line departments, research institutions, and local communities will be essential for building a safer and more disaster-resilient Pakistan.

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STUDENT RESEARCH PAPER

The Role of Local Governments in Strengthening Disaster Risk Reduction

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Executive Summary

Local governments are the frontline institutions in disaster risk reduction (DRR), they are uniquely positioned to translate national strategies into community-level action. The Sendai Framework for Disaster Risk Reduction (2015–2030) and initiatives such as Making Cities Resilient 2030 (MCR2030) emphasize their indispensable role in risk governance, preparedness, resilience building, and sustainable development. Evidence from international frameworks and case studies demonstrates that effective local DRR depends on strong institutional capacity and political commitment, meaningful community engagement through participatory planning, integration of DRR into routine development processes, and multi-stakeholder coordination across sectors and levels of government. Despite notable progress, persistent challenges remain, including weak institutional coordination, limited technical expertise, and data deficiencies. Addressing these gaps requires innovative, context-sensitive solutions that harness emerging technologies such as Artificial Intelligence (AI), Geographic Information Systems (GIS), Remote Sensing, drones, and big data analytics. By combining institutional strength, participatory governance, and technological innovation, local governments can transform disaster management from reactive response into proactive resilience building, thereby safeguarding lives, protecting livelihoods, and embedding resilience within sustainable development pathways.

Regional Context and Hazard Profile

The escalating frequency and severity of disasters worldwide have underscored the critical importance of disaster risk reduction (DRR) as a policy priority. This review synthesizes existing literature on the role of local governments in strengthening DRR, analyzing vulnerability profiles, and evaluating the trends and challenges facing local-level disaster governance. The evidence demonstrates that local governments are uniquely positioned to implement DRR, yet their effectiveness is often constrained by systemic challenges including limited resources, reactive approaches, and lack of political goodwill.

Hazard, Exposure, Vulnerability, and Risk

Hazard refers to a natural or human-made process or phenomenon that may cause loss of life, property damage, or social and economic disruption.

Exposure encompasses the presence of people, infrastructure, livelihoods, and assets in hazard-prone areas. Exposure measures can include the number of people or types of assets, and can be combined with vulnerability estimates to quantify risk.

Vulnerability refers to physical, social, economic, or environmental conditions that increase susceptibility to the impact of a hazard. Vulnerability is multidimensional, encompassing factors such as poor building design, inadequate infrastructure protection, lack of public awareness, poverty, weak governance, and limited institutional capacity.

Resilience refers to the capacity of systems to absorb losses and recover from hazard events. Local governments play a pivotal role in strengthening community resilience through DRR strategies that reduce existing risks, prevent new risks, and manage residual risks.

Historical Trends and the Vulnerability Profile

Disaster impacts have continued to escalate globally, despite decades of international frameworks and commitments. Historical analysis reveals that the period following the United Nations' declaration of the 1990s as the "decade for natural disaster risk reduction" witnessed increased disaster strikes. Subsequent frameworks, such as the Hyogo Framework for Action (2005-2015), yielded limited progress in reducing vulnerability.

The vulnerability profile of communities is shaped by intersecting social and economic factors. Poverty, precarious living conditions, lack of access to emergency services, and weak governance are identified as underlying risk drivers that perpetuate vulnerability. Local governments are often at the frontlines of addressing these systemic vulnerabilities, yet they face significant challenges in doing so effectively.

Risk and Vulnerability Assessment

Disasters generate multidimensional socio-economic impacts that disproportionately burden vulnerable groups, underscoring the critical role of local governments in risk and vulnerability assessment. Vulnerability is further stratified by social categories, with women, children, the elderly, and persons with disabilities bearing disproportionate burdens.

Local governments are uniquely positioned to mitigate these risks through participatory, gender-responsive vulnerability assessments and targeted interventions such as livelihood support, capital grants, low-interest loans, and job creation initiatives. However, implementation remains constrained by limited resources, weak institutional coordination, and insufficient integration of vulnerability considerations into planning.

Community Resilience Factors

Community resilience is shaped by the interplay of social capital, grassroots networks, indigenous knowledge, and locally evolved coping mechanisms. These community-based assets complement formal government interventions, with local governments playing a pivotal role in validating, institutionalizing, and strengthening them.

Social capital - defined by trust, reciprocity, and shared norms emerges as a critical determinant of preparedness and recovery. Dense networks enable resource sharing, coordination, and support for vulnerable groups. Empirical evidence highlights trust as the most influential factor in shaping public perceptions of disaster management effectiveness.

Grassroots networks operationalize social capital by mobilizing communities. Local governments can strengthen these networks through technical training, formal recognition, and integration into official DRR planning.

Indigenous knowledge and coping mechanisms represent transgenerational expertise in hazard adaptation. Practices such as traditional weather prediction, community-based early warning, and culturally embedded support systems have historically sustained resilience. formal DRR often neglects indigenous knowledge, underscoring the need for co-production frameworks led by local governments.

Scientific & Institutional Gaps

Institutional weaknesses are evident in the disjunction between formal mandates (institutions-in-form) and operational practice (institutions-in-use). Gaps in preparedness, coordination, infrastructure, legal enforcement, and climate integration undermine local effectiveness.

Data deficiencies further constrain local DRR. Quantitative risk assessment is hindered by scarcity of reliable data, poor integration of geospatial tools, and limited digital literacy among personnel. Many municipalities remain reliant on paper-based assessments.

Technological limitations compound these challenges. Local governments often rely on static hazard maps and descriptive assessments, limiting predictive capacity. Although machine learning and earth observation technologies are promising, adoption remains fragmented.

Mitigation Strategies best practices

Local governments occupy a central role in disaster risk reduction (DRR) through the implementation of integrated mitigation strategies that combine structural and non-structural measures.

Structural measures encompass physical interventions designed to reduce hazard impacts. Common structural measures for disaster risk reduction include dams, flood levies, ocean wave barriers, earthquake-resistant construction and evacuation shelters.

Non-structural measures emphasize institutional and community capacity. Common non-structural measures include building codes, land-use planning laws and their enforcement, research and assessment, information resources and public awareness programmes.

Optimal outcomes in local DRR are achieved when structural and non-structural measures are implemented within an integrated framework. Such approaches emphasize community engagement, institutional capacity building, and sustainable financing, thereby embedding resilience into both physical infrastructure and social systems.

Risk Communication & Early Warning

Local governments occupy a pivotal role in disaster risk communication, serving as the critical interface between technical early warning information and community level action.

Gender sensitive approaches are increasingly recognized as essential to effective EWS.

Community engagement is the linchpin of risk communication.

Local governments can strengthen risk communication by integrating gender and disability perspectives, employing local languages and accessible formats, embedding indigenous knowledge, and establishing coordination mechanisms that unite diverse stakeholders.

Policy Recommendations

Integrated governance and institutional strengthening: They are essential in bridging the gap between formal mandates (institutions-in-form) and operational practice (institutions-in-use). Embedding DRR into Integrated Development Plans, zoning regulations, and municipal advisory forums ensures systematic integration into urban planning and service delivery.

Climate adaptation integration: Embedding adaptation into local disaster planning ensures resilience by aligning land-use, infrastructure, and budgets with future climate realities. It also promotes nature-based solutions and sustainable development, transforming DRR from short-term response into long-term resilience building.

Community participation and inclusive governance: This foster **community ownership** of DRR initiatives. This ownership enhances resilience because communities are more likely to adopt, sustain, and adapt measures that they helped design.

Technology integration and data systems: Geographic Information Systems (GIS), Remote Sensing, drones, and big data analytics enable local authorities to visualize risks, monitor hazard patterns, and plan targeted interventions.

Conclusion

Resilience-building requires integrated governance that bridges scientific, social, cultural, and technological dimensions. Local governments must act as enablers, fostering environments where communities leverage their own assets alongside scientific and technological advances. Achieving these demands political commitment, sustained investment, cross-sectoral coordination, and genuine community partnership. When local governments embrace inclusive and adaptive approaches, they build resilience that safeguards lives, livelihoods, and sustainable development.**References**

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STUDENT RESEARCH PAPER

Ecological Risk Assessment of Human-Impacted Coastal Zones: A Framework for the Karachi Coast, Pakistan

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Executive Summary

The Karachi coast, spanning the mangrove-fringed Indus Delta creeks in the east to Manora and Sandspit in the west, sustains fisheries, mangrove ecosystems, and port-based livelihoods for millions, yet remains one of Pakistan's most ecologically stressed coastal stretches. Untreated industrial and municipal effluent from the Layari and Malir rivers, along with port operations, land reclamation, and unregulated fishing, has progressively degraded mangrove cover, water quality, and nearshore biodiversity.

This research proposes an Ecological Risk Assessment (ERA) framework for the Karachi coast that combines hazard identification, exposure mapping, and ecological sensitivity analysis to classify risk across distinct coastal segments. Rather than treating pollution, habitat loss, and overexploitation as separate issues, the framework evaluates their cumulative and interacting effects on mangrove ecosystems, water quality, and fisheries productivity.

By overlaying human-activity pressure data with ecological sensitivity indicators using GIS-based mapping, the framework generates a coastal risk zonation that can guide targeted regulation, restoration prioritization, and monitoring by Sindh's environmental and coastal management authorities.

1. Regional Context & Hazard Profile

Karachi's coastline hosts Pakistan's two largest ports, a dense industrial belt along the Layari river corridor, and remnants of the Indus Delta mangrove forest, one of the largest arid-zone mangrove systems in the world. These ecosystems have historically buffered the coast against storm surge, supported juvenile fish nurseries, and stabilized sediment along the shoreline.

Decades of untreated sewage and industrial discharge, primarily through the Layari and Malir rivers, have degraded water quality along the harbour and adjoining creeks. Land reclamation for housing and port expansion, combined with unregulated coastal fishing and mangrove wood-cutting, has further reduced mangrove cover in several segments of the coast.

Climate-related pressures, including sea-level rise and reduced freshwater and sediment flow from the Indus River, compound these human-driven stresses, leaving the coast more vulnerable to erosion and saline intrusion. Assessing ecological risk requires accounting for both these direct anthropogenic pressures and the underlying climatic trends that amplify them.

- Risk & Vulnerability Assessment

Ecological degradation along the Karachi coast carries direct socio-economic consequences for fishing communities in areas such as Ibrahim Hyderi, Rehri Goth, and the Korangi creek settlements, where livelihoods depend on nearshore fish and shrimp stocks. Declining catch volumes linked to habitat loss and pollution disproportionately affect small-scale fishers, including women involved in fish processing and net-mending, who have limited alternative income sources.

Vulnerability is unevenly distributed across the coastline: industrial discharge points and reclaimed land areas show the highest ecological stress, while remaining mangrove stands in the eastern creeks retain comparatively higher ecological function. Without a systematic risk assessment, conservation and regulatory attention tends to concentrate on visible pollution events rather than the areas of highest underlying ecological sensitivity.

- Community Resilience Factors

Fishing communities along the Karachi coast possess detailed local knowledge of seasonal fish movement, creek navigation, and historical changes in mangrove cover, built up over generations of dependence on these ecosystems. Community-led mangrove replanting initiatives in parts of the Indus Delta and Korangi creek have demonstrated that local stewardship, when supported institutionally, can meaningfully contribute to habitat recovery.

The proposed framework includes a community observation component, in which local fishers and mangrove planting groups report visible changes in water quality, fish availability, and mangrove health. This local reporting complements satellite and water-quality monitoring, strengthening both the accuracy of the risk assessment and the sense of ownership communities hold over coastal restoration outcomes.

ERA Framework Components

Component	Purpose	Expected Outcome
Pollution Hazard Mapping	Identify discharge points and pollutant loads	Hotspot identification
Mangrove & Habitat Sensitivity	Assess ecological value by segment	Sensitivity classification
Exposure Overlay (GIS)	Combine hazard and sensitivity layers	Composite risk zonation
Fisheries Impact Indicators	Track catch trends and species diversity	Livelihood risk signal
Community Observation Network	Ground-truth ecological change	Locally verified data

Current Practice vs. Proposed ERA Framework

Existing Practice	ERA Framework
Isolated pollution monitoring	Integrated hazard-exposure-sensitivity model
Reactive response to incidents	Proactive risk zonation and prioritization
Limited spatial resolution	GIS-based coastal segment mapping
Minimal community input	Structured community observation network
Single-issue regulation	Cumulative, multi-stressor risk assessment

- Scientific & Institutional Gaps

Existing studies on the Karachi coast have documented industrial pollution levels, mangrove cover change, and fisheries decline largely as separate lines of research, with limited integration into a single risk assessment that captures their cumulative ecological effect. Water-quality monitoring by relevant agencies is often periodic and localized, rather than continuous and coast-wide.

Institutionally, responsibility for coastal management in Karachi is distributed across multiple bodies, including the Sindh Environmental Protection Agency, Karachi Port Trust, and fisheries departments, without a shared spatial risk framework to coordinate their monitoring and regulatory priorities. This fragmentation limits the ability to identify which coastal segments require urgent intervention.

The proposed ERA framework addresses this gap by establishing a shared, GIS-based risk zonation that can be used across agencies, supported by remote sensing for mangrove cover change detection and periodic water-quality sampling for pollution hazard mapping.

- Mitigation Strategies & Best Practices

Structural measures should prioritize wastewater treatment infrastructure along the Layari and Malir river outfalls, targeted at the highest-risk segments identified through the ERA zonation, alongside continued mangrove restoration in degraded but ecologically recoverable creek areas. Non-structural measures should include stricter enforcement of existing discharge regulations and seasonal fishing restrictions in nursery habitats identified as ecologically sensitive.

International best practice in coastal ecological risk assessment typically combines pollutant load mapping with habitat sensitivity indices to prioritize limited restoration and enforcement resources; applying this approach to Karachi would allow authorities to direct interventions towards the segments where ecological and livelihood risk is highest, rather than spreading resources evenly across the coastline.

- Risk Communication & Early Warning

Findings from the ERA framework should be communicated to fishing communities through union council and fisher-cooperative channels, using clear, non-technical risk zonation maps that indicate areas of declining water quality or habitat health. Advance notice of pollution events, such as industrial discharge spikes, would allow fishing communities to adjust activity in affected creek areas.

Community observation reports should feed back into the risk assessment on a regular cycle, creating a two-way communication process between coastal residents and the agencies responsible for water quality and habitat management, and helping to build public trust in monitoring outcomes.

- Policy Recommendations

Adopt the ERA framework as a shared spatial risk-assessment tool across the Sindh Environmental Protection Agency, Karachi Port Trust, and fisheries departments.

Establish continuous water-quality and mangrove-cover monitoring at identified high-risk segments of the Karachi coast.

Prioritize wastewater treatment investment along the Layari and Malir river outfalls based on ERAidentified hotspots.

Institutionalize community observation networks among fishing communities to support ground-truthing of ecological risk data.

Integrate GIS and remote sensing tools into routine coastal monitoring to track cumulative human-activity impacts over time.

Enforce seasonal and spatial fishing restrictions in habitats classified as high ecological sensitivity under the ERA zonation.

Conclusion

The Karachi coast faces a combination of industrial pollution, habitat loss, and unregulated resource use that current single-issue monitoring approaches are not designed to capture in full. The proposed Ecological Risk Assessment framework offers a structured, GIS-supported approach to mapping cumulative ecological risk across the coastline, linking pollution hazard, habitat sensitivity, and fisheries impact into a single decision-support tool.

Adoption of this framework by relevant Sindh coastal management authorities would support more targeted restoration, regulation, and community engagement, contributing to a more resilient and ecologically functional Karachi coast for both marine ecosystems and the communities who depend on them.

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STUDENT RESEARCH PAPER

Comparative Analysis of GLOF Management in Pakistan, Nepal, and Bhutan

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Executive Summary

Glacial Lake Outburst Floods (GLOFs) are among the fastest-intensifying climate hazards in the Hindu Kush Himalaya (HKH), where warming-driven glacier retreat is enlarging existing lakes and creating new ones above communities that often have less than twenty minutes' warning before a breach. This report compares how Pakistan, Nepal and Bhutan understand and manage GLOF risk, drawing on peer-reviewed literature, government and UN agency reports, and 2025–2026 field reporting.

All three countries have invested in structural works (artificial lake lowering in Nepal and Bhutan; protective infrastructure in Pakistan) and community-based early warning systems (CBEWS). Yet each faces the same underlying weakness: early warning and monitoring infrastructure that lapses once donor-funded projects conclude, thin coverage of the most remote valleys, weak transboundary data-sharing, and limited integration of gender-sensitive design, indigenous knowledge, and emerging AI/ML monitoring tools into otherwise technically sound systems.

Key recommendations: (i) institutionalize recurring domestic financing for EWS operation and maintenance rather than relying solely on project cycles; (ii) close remaining coverage gaps in the highest-risk valleys of Gilgit-Baltistan; (iii) embed gender-sensitive design and indigenous knowledge into community-based early warning and resilience planning; (iv) pilot AI/ML-based satellite monitoring of glacial lakes to complement field surveillance; and (v) deepen regional cooperation with Nepal and Bhutan through ICIMOD and the HKH CryoHub for transboundary data-sharing and peer learning.

1. Regional Context & Hazard Profile

Four concepts anchor this report's risk framework. **Hazard** is the physical phenomenon itself, here, the sudden release of water impounded by a glacier or moraine dam. **Exposure** refers to the people, settlements, infrastructure and livelihoods situated in a GLOF's potential path. **Vulnerability** describes the characteristics that make exposed people or systems more or less able to anticipate, cope with, and recover from the hazard, including poverty, remoteness, gender, and institutional capacity. **Risk** is the resulting likelihood and magnitude of harmful consequences, arising from the interaction of hazard, exposure and vulnerability [3].

Regional Trends

The HKH, often termed the "Third Pole" for the volume of ice it stores outside the polar regions, is warming faster than the global average, accelerating glacier retreat and glacial lake expansion across Pakistan, Nepal and Bhutan [2][4]. Gilgit-Baltistan in particular is experiencing one of the fastest warming trends in Asia, directly accelerating the formation of unstable glacial lakes in the region [8]. Automated satellite-based monitoring studies confirm that Himalayan glacial lakes have grown consistently in number and surface area over the past three decades, with the most rapid expansion occurring in the last ten years [20][21].

Country Vulnerability Profiles & Historical Events

Pakistan. Pakistan's glacial hazard zone spans Gilgit-Baltistan (GB) and northern Khyber Pakhtunkhwa (KP), where the Karakoram and Hindu Kush ranges converge. GB alone holds an estimated 5,218 glaciers and 2,420 glacial lakes, 52 rated potentially dangerous [9]; across GB and KP combined, over 3,000 glacial lakes place roughly 7.1 million people at risk [8]. During the 2022 heatwave, approximately 75 GLOF events occurred in a single season; the Shishper Glacier struck Hassanabad village, Hunza, in both 2022 and again in October 2023 [8][12]. Heatwave-driven alerts have recurred each year since, including the catastrophic August 2025 Gilgit-Baltistan floods.

Nepal. Nepal's exposure spans the Koshi, Gandaki and Karnali basins, including the Everest and Annapurna regions, with 1,466 glacial lakes and 47 identified as critical priority [16][18]. The 1985 Dig Tsho GLOF remains a textbook case; ICIMOD and UNDP record 26 GLOF events since 1977, 14 originating within Nepal [16]. In July 2025, a transboundary outburst on the Bhotekoshi/Sunkoshi system, traced to a glacial lake in Tibet, swept away or damaged roughly ten hydropower projects, Nepal's costliest GLOF-related disaster in 15 years [20].

Bhutan. Bhutan's highest-risk zone is Lunana, Gasa District, within the Pho Chhu basin, holding roughly 2,700–2,800 glacial lakes, 24–25 potentially dangerous [1][3]. The defining event remains the 7 October 1994 Lugge Tsho GLOF, which killed 21 people and damaged Punakha Dzong after an 18-million-cubic-metre surge reached Punakha in seven hours [24][28]. Neighbouring Thorthormi and Raphstreng lakes were subsequently assessed as capable of an even larger failure, nearly three times the 1994 volume [25][26].

Table 1. Hazard Profile Snapshot

Indicator	Pakistan	Nepal	Bhutan
Hazard zone	Karakoram & Hindu Kush (GB, KP)	Koshi, Gandaki & Karnali basins	Lunana / Pho Chhu basin
Glacial lakes	2,400+ in GB; 3,000+ GB & KP	1,466 nationwide	2,700–2,800 nationwide
Dangerous lakes	33–52	47 priority lakes	24–25
Population exposed	~7.1 million (GB & KP)	71,752 in Imja Valley alone	Punakha-Wangdi valley population
Landmark event	2023 Shisper GLOF, Hunza	1985 Dig Tsho GLOF	1994 Lugge Tsho GLOF (21 deaths)
Most recent major event	2025–26 heatwave GLOFs, GB	July 2025 Bhotekoshi/Rasuwa GLOF	2015 Lemthang Tsho (partial)

Source: Compiled by the author; see Annex references.

2. Risk & Vulnerability Assessment

GLOFs disrupt livelihoods well beyond the immediate flood path. In Pakistan's Hunza valley, the Shishper GLOFs destroyed irrigation channels, orchards and roads that households depend on for subsistence farming and tourism income, with recovery periods extending over multiple growing seasons [9]. Across the HKH, glacial lake expansion threatens hydropower generation, an economic mainstay in Nepal and Bhutan, and downstream irrigation systems that underpin regional food security; Nepal's July 2025 Bhotekoshi disaster alone damaged around ten hydropower projects [20].

Vulnerable groups. Elderly residents, children, people with disabilities, and semi-nomadic herding households in remote valleys such as Bhutan's Lunana face disproportionate exposure due to limited mobility, distance from services, and dependence on glacier-fed pastures and water [8].

Gender dimensions. A qualitative study of the Shishper GLOF in Hunza found that women faced compounded hardship from structural inequalities, restricted mobility, and limited decision-making power during evacuation and recovery, consistent with broader HKH-wide findings that climate hazards widen pre-existing gender and social inequalities [9][8]. Male out-migration for livelihoods elsewhere in the HKH further shifts flood-response burdens onto women who remain, even as they are often excluded from formal disaster-planning processes [5][7].

3. Community Resilience Factors

Social capital and community networks consistently determine how quickly a valley recovers from a GLOF. In Pakistan's 2025 Gilgit-Baltistan floods, a local shepherd's informal, word-of-mouth warning reportedly saved hundreds of lives in one valley where the formally installed early warning system had failed, a direct illustration of social capital substituting for infrastructure [11].

Traditional and indigenous ecological knowledge, including elders' observation of lake colour, water sound, and seasonal glacier behaviour, and customary grazing and communal resource-management institutions long practised across the Hindu Kush and Sikkim Himalaya, remains an under-used resilience asset [14][17]. Research on integrating such knowledge into disaster risk reduction in Nepal, India and Bangladesh finds it most effective when combined with, rather than replaced by, scientific monitoring [16][15].

A review of community-based GLOF risk mitigation approaches across the HKH concludes that heavy reliance on technology-driven early warning has sometimes created a disconnect between scientific expertise and practical, community-level risk reduction, and recommends deliberately integrating local knowledge with institutional coordination to strengthen resilience in glacierised regions [12].

4. Scientific & Institutional Gaps

Research and Technology Limitations

Remote, high-altitude glacial lakes remain difficult and costly to survey in situ, and existing field measurement networks across the HKH are sparse relative to the scale of the hazard [19]. A 2025 Himalayan Glacial Lake Monitoring Network (HiGLMN) proposal highlights that transboundary lakes with cross-border GLOF potential are especially under-monitored [19].

AI/ML Adoption Status

Machine learning and deep learning methods, random forest classifiers, convolutional neural networks, and multi-sensor data fusion using Sentinel-1/2 and PlanetScope imagery, have demonstrated over 90% accuracy in automated glacial lake mapping in Himalayan test basins, and a decade-long review (2015–2024) documents rapid growth in such research [20][21][23][24]. However, adoption remains largely confined to academic and research settings; none of the three countries examined has yet operationalised AI/ML-based lake monitoring within its national early warning agencies (PMD, DHM/NDRRMA, or NCHM), leaving a persistent gap between available technology and institutional practice [22][24].

Institutional Weaknesses and Data Deficiencies

- Early warning systems installed under donor-funded projects in all three countries have repeatedly lapsed once project financing ended, documented at Nepal's Tsho Rolpa (2002) and in Pakistan's 2025 Gilgit-Baltistan floods [8][15].
- Coordination gaps persist between national authorities (NDMA), provincial/regional bodies (PDMA, GBDMA), and district administrations, particularly during live emergencies [11].
- Transboundary data-sharing with China remains largely absent; Nepal's NDRRMA reportedly only learned of the July 2025 Bhotekoshi GLOF once floodwaters reached the border area [20].
- Gender and social-inclusion considerations are rarely built into formal hazard assessments or EWS design in any of the three countries, despite documented differential impacts [9][5].

5. Mitigation Strategies & Best Practices

Structural Measures

- Artificial lake lowering: Nepal's Tsho Rolpa (~3 m, 1997–98) and Imja Tsho (3.4 m, 2016); Bhutan's Thorthormi Lake (3.7–5 m via manual channel excavation, 2008–2012) [15][25].

- Protective infrastructure: Pakistan's GLOF-I/II projects combine sensor networks, protective works, irrigation-channel rehabilitation and bio-engineered slope stabilisation across 24 valleys in GB and KP [13].

Non-Structural Measures

- Community-Based Disaster Risk Management Committees, safe havens and rehearsed evacuation routes, scaled across dozens of Pakistani valleys under GLOF-II [13].
- Adaptive redesign: Nepal's shift from the "too techno-centric" original Tsho Rolpa system toward the community-owned CBFGORRP model after the former's 2002 failure [15][17].
- Regional knowledge-sharing: Bhutan's dissemination of its Thorthormi lake-lowering methodology to Pakistan and Nepal via UNDP's Adaptation Learning Mechanism [25].

6. Risk Communication & Early Warning

Effective GLOF early warning in the region layers automated sensors and sirens with SMS alerts and community-institution relay, as implemented at Nepal's Imja Tsho, where alerts reach six downstream settlements and a further 50 kilometres via SMS, linked to local disaster-management institutions protecting an estimated 71,752 people [15].

Gender-sensitive design remains largely absent from current systems: warning messages, drill schedules and committee membership across all three countries are rarely tailored to account for women's differing mobility, literacy, or communication-access patterns, despite evidence that these factors shape who receives and acts on a warning in time [9][8]. Community engagement works best where local committees hold genuine operational responsibility rather than a purely advisory role, the central lesson from Nepal's post-Tsho Rolpa redesign [15].

7. Policy Recommendations

- Integrated governance: Establish a recurring, non-donor-dependent budget line for EWS operation and maintenance, with clear lead-responder protocols between NDMA, GBDMA and KP-PDMA for each valley.
- Climate adaptation mainstreaming: Embed GLOF risk into provincial and district development plans, prioritising the currently uncovered valleys of Ghizer, Diamer and parts of Hunza.
- Community participation: Expand Community-Based Disaster Risk Management Committees' operational authority over day-to-day EWS checks, and formally include women and marginalised groups in committee membership and drill design.
- Technology integration: Pilot AI/ML-based satellite monitoring (following HiGLMN-type approaches) to complement field surveillance, and invest in post-event attribution capacity to resolve GLOF-versus-flash-flood uncertainty.
- Regional cooperation: Formalise participation in ICIMOD's HKH CryoHub and the Hindu Kush Himalaya Glaciers and Mountain Economy Network to access transboundary data and Nepal's/Bhutan's accumulated lessons.

8. Conclusion

Pakistan, Nepal and Bhutan confront a common, intensifying hazard shaped by shared geography but managed through distinct institutional pathways. Structural interventions and community-based early warning have delivered real, partial success, yet all three countries share an unresolved sustainability gap once donor financing ends, alongside thin integration of gender-sensitive design, indigenous knowledge, and emerging AI/ML monitoring capability. Building genuine resilience will require pairing science-based planning and technology with the social capital, traditional knowledge, and inclusive governance that communities already possess, and deeper regional cooperation to manage a hazard that does not respect national borders.

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Annex A, List of Acronyms and Abbreviations

Acronym	Full Form
C2DRM	Climate Change & Disaster Risk Management
CBEWS	Community-Based Early Warning System
CBFGORRP	Community-Based Flood and GLOF Outburst Risk Reduction Project
DHM	Department of Hydrology and Meteorology (Nepal)
DRR/DRRM	Disaster Risk Reduction (and Management)
EWS	Early Warning System
GB	Gilgit-Baltistan
GBDMA	Gilgit-Baltistan Disaster Management Authority
GLOF	Glacial Lake Outburst Flood
HKH	Hindu Kush Himalaya
ICIMOD	International Center for Integrated Mountain Development
KP	Khyber Pakhtunkhwa
ML/AI	Machine Learning / Artificial Intelligence
NCHM	National Center for Hydrology and Meteorology (Bhutan)
NDMA	National Disaster Management Authority (Pakistan)
NDRRMA	National Disaster Risk Reduction and Management Authority (Nepal)
PDMA	Provincial Disaster Management Authority
PMD	Pakistan Meteorological Department
TEK/TLK	Traditional Ecological / Local Knowledge
UNDP	United Nations Development Programme

STUDENT RESEARCH PAPER

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

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Executive Summary

Recurrent flooding remains one of Pakistan's most consequential hazards, repeatedly disrupting four interdependent supply chains: transport, food and agriculture, humanitarian relief, and health-system logistics. Evidence from the 2010 and 2022 floods reveals a layered risk profile spanning infrastructure failures, commodity shortfalls, communication breakdowns, socioeconomic exclusion, and institutional weaknesses — with social capital, NGOs, and indigenous knowledge playing a critical but partial role in sustaining last-mile resilience.

Technology and data gaps, especially around connectivity and the integration of AI/remote sensing, remain significant constraints, with AI/ML adoption still at a research and pilot stage. Structural measures (resilient infrastructure, facility siting) and non-structural measures (SOPs, community participation, accountability mechanisms) together offer the most viable path to resilience.

Key recommendations:

synchronized early warning governance

risk-informed land-use planning

formal inclusion of communities, women, and marginalized groups in DRM planning

low-resource, multi-channel technology deployment

Visibility of supply chain and accountability systems

1. Regional Context & Hazard Profile

Floods are repeatedly identified as a major and frequent hazard in Pakistan and the broader Asian regional context, with rising flood occurrence exposing populations and socio-ecological systems to multiple vulnerabilities. In Pakistan, climate-related disasters, especially floods, place sustained stress on four interdependent supply chains: (i) transport and road networks; (ii) food and agriculture production and storage; (iii)

Figure 1: Framework of Supply Chain Risk and Resilient Pathways

humanitarian relief supply chains covering shelter, water, sanitation and hygiene (WASH), and food; and (iv) health-system logistics.

Historical Events

The 2010 floods affected 13.4 million people across roughly one-fifth of Pakistan's land area, displacing more than 12 million people and destroying 1.7 million homes. The response relied heavily on military assets to restore transport infrastructure and road access, yet access remained constrained in conflict-affected areas such as Balochistan [3.2]. Nationally produced relief stocks, including tents, were depleted, and domestic production capacity could not match demand.

The 2022 floods again impaired transportation systems, road networks, and health-care infrastructure, making timely service delivery difficult. Primary health-care facilities were reported to be submerged, forcing improvised access such as doctors reaching hospitals by boat. Communities in the greatest need were, in some cases, excluded from aid distribution while less-affected areas received resources, pointing to systemic distribution failures.

Hazard, Exposure, Vulnerability, and Risk

Within this hazard profile, exposure is driven by settlement patterns, weak land-use enforcement, and the concentration of critical infrastructure (transport corridors, health facilities, markets) in flood-prone zones. Vulnerability is compounded by poverty, illiteracy, gender norms, and limited access to information, while institutional weaknesses in preparedness, coordination, and accountability elevate overall risk. The resulting risk profile is therefore not simply a function of hazard intensity, but of the interaction between hazard, exposure, and the socioeconomic and institutional vulnerabilities detailed in the following section.

2. Risk & Vulnerability Assessment

Evidence from Pakistan's flood literature points to a layered risk profile affecting supply chains at multiple levels.

2.1 Physical and Infrastructure Vulnerabilities

- Transport impairment and access loss: The 2022 floods impaired transportation systems, road networks, and health-care infrastructure, making timely service delivery difficult. In 2010, the response depended heavily on military assets for restoring transport infrastructure and road access, but access was constrained in conflict-affected areas such as Balochistan.
- Facility inundation: Primary health-care facilities were reported to be submerged, forcing improvised access, including doctors reaching hospitals by boat.

2.2 Commodity and Inventory Vulnerabilities

- Relief stock depletion and production limits: In 2010, nationally produced relief stocks such as tents were depleted, and production capacity could not match demand.
- Household access to necessities and market linkages: Field evidence indicates that a majority of surveyed households could not access necessities during floods, with respondents identifying a poor connection between producers and consumers as part of broader warning, communication, and supply disruption dynamics.

2.3 Information and Communication Vulnerabilities

- Last-mile warning and information failures: Community accounts highlight power failures, lack of access to TV or radio, poor cellphone signals, and lack of knowledge of emergency websites as reasons warnings were not received.
- Confusing multi-source messaging and lack of standards: Warnings can be confusing when they originate from multiple sources without synchronization; respondents also note the absence of established nomenclature, procedures, or standards, leading to incorrect, irrelevant, or missing information.

2.4 Socioeconomic Impacts, Food Security, and Vulnerable Groups

- Poverty and illiteracy constrain access to warnings and response actions: Poor, illiterate, and underprivileged populations may not receive warnings delivered via TV, radio, or online channels, and may not understand professional or scientific terminology.
- Livelihood and food-security disruption: Loss of access to necessities, unmet needs for water, sanitation, food, and medicine persisted for months after the 2010 floods, reflecting sustained livelihood and food-security disruption.
- Gender dimensions: Cultural and social constraints and stereotypes about women contribute to the difficulties women face during evacuations, and government DRM agencies show limited comprehension of gender equality and social inclusion considerations.

2.5 Institutional and Governance Weaknesses

- Reactive response and weak preparedness: Institutions have historically adopted a reactive rather than proactive approach, with disaster mitigation efforts described as largely absent, delayed or intermittent response, and weak political resolve.

- Accountability deficits in relief and donations: Donation collection occurred widely but without an accountability system, associated with corrupt practices; aid distribution failures were observed where the most affected populations were left stranded.
- Exclusion from planning: Community survey evidence reports limited involvement of communities, and particularly marginalized groups, in planning and preparedness, undermining warning uptake and response.3. Community Resilience Factors

Pakistan evidence emphasizes that community-level networks are not merely social add-ons; they materially affect supply-chain continuity by shaping warning interpretation, evacuation behavior, and last-mile coordination.

3.1 NGOs as Bridging Social Capital

NGOs are described as bridging actors between local communities and formal disaster-management institutions, tailoring solutions to community needs, facilitating communication between vulnerable populations and authorities, and raising awareness through campaigns. Where official warning channels fail, for example due to media access gaps, NGOs and local channels can help overcome dissemination barriers.

3.2 Volunteer and Community Dissemination Networks

Community leaders cite alternative communication modalities, including sirens and loudspeakers, with warning dissemination moving through chains of people and volunteer groups using megaphones — an explicit example of local coping that substitutes for weak digital connectivity.

3.3 Indigenous and Traditional Knowledge

Including indigenous knowledge is considered essential for community adherence to warnings, yet national and provincial contingency plans often fail to incorporate such knowledge or target-community needs [1.4]. Examples of indigenous knowledge signals, including animal-behavior monitoring and traditional astronomy, are documented, though such knowledge may be insufficient for rapid, intense events, implying a need to integrate it with scientific monitoring rather than treat it as a standalone solution [1.6], [1.7].

3.4 Inclusion as a Resilience Mechanism

Evidence links exclusion from preparedness and planning to lower response rates. Engaging women and other marginalized groups is highlighted as a resilience mechanism, alongside the observation that government DRM agencies show limited comprehension of gender equality and social inclusion principles [1.4].

4. Scientific & Institutional Gaps

4.1 Technology Limitations and Data Deficiencies

- Connectivity and power constraints directly limit technology-dependent warning systems and information flows, including power failures, poor cell signals, lack of access to TV or radio, and inability to use emergency websites [1.4].
- Data gaps constrain evidence-based planning: Evidence-based contingency planning ideally relies on socioeconomic data, but such records are often unavailable in flood-prone areas, limiting preparedness reach and utility [1.4].
- Top-down early warning implementation and weak two-way information exchange reduce the relevance and legitimacy of warnings for communities [1.2].

4.2 Institutional Weaknesses

- Lack of political will and implementation: Reported barriers include emergency plans not being implemented and inadequate political commitment [1.3].
- Lack of standards and procedures for warning dissemination, and poor coordination between producers and users of warnings, are repeatedly cited [1.3], [1.4].
- Accountability failures in donation and relief flows are documented in 2022, including diversion and capture, alongside a lack of observed, transparent cash transfers in the field [2.2].

4.3 Research Gaps and AI/ML Adoption Status

Pakistan flood-preparedness research explicitly identifies a need to investigate the integration of emerging technologies, particularly remote sensing and artificial intelligence, for flood risk assessment and management, indicating that this integration remains an open research and implementation frontier [4.1]. Within the evidence reviewed, there is no Pakistan-specific empirical evidence of operational AI/ML deployment in supply-chain decision-making during disasters; the adoption status therefore cannot be robustly characterized beyond the stated scope for investigating such integration [4.1].

Figure 2. Fishbone Diagram of Flood Induced Supply Chain Disruptions

5. Mitigation Strategies & Best Practices

5.1 Structural Measures

- Land-use planning, zoning, and flood-resistant building standards to reduce exposure of markets, warehouses, and critical services [4.1], [2.2].
- Strategic siting of critical facilities, including health services and transport facilities, so they can continue uninterrupted operations during floods [2.2].
- Hard engineering and infrastructure maintenance, such as dams, embankments, and upkeep of existing infrastructure, were prioritized as leading flood mitigation strategies [4.1].

5.2 Non-Structural Measures (Capacity Building, Awareness, Training)

- Two-way information exchange and local-language warning dissemination, with improved communication infrastructure tailored to the target group [1.2], [1.4].
- Standard operating procedures (SOPs) for evacuation, rescue, and aid distribution, supported by frequent exercises and specialized responder training [4.1].
- Community participation and inclusion of women and marginalized groups in DRM planning and implementation, to increase adherence and reduce information failures [1.4].
- Accountability mechanisms for donations and relief allocations, to reduce diversion and ensure the most affected populations receive assistance [2.2].

6. Risk Communication & Early Warning

Community accounts consistently identify power failures, lack of access to TV or radio, poor cellphone signals, and unfamiliarity with emergency websites as core reasons warnings are not received [1.4]. Warnings originating from multiple, unsynchronized sources are described as confusing, compounded by the absence of established nomenclature, procedures, or standards for dissemination [1.4].

Gender-sensitive early warning requires addressing the cultural and social constraints that make evacuation more difficult for women, alongside the limited comprehension of gender equality and social inclusion within government DRM agencies [1.4], [1.5]. Community engagement mechanisms, such as sirens, loudspeakers, and volunteer megaphone networks, have emerged as effective local substitutes where digital and broadcast channels fail [1.5].

Effective communication strategies going forward should combine two-way information exchange, local-language alerts, synchronized multi-agency messaging, and trusted community messengers, so that warnings are both received and acted upon by the populations most at risk [1.2], [1.3].

7. Policy Recommendations

The following table integrates the evidence into an implementable, vulnerability-linked policy package covering governance, climate adaptation, community participation, and technology integration.

Table. Major climate-disaster supply chain vulnerabilities in Pakistan linked to evidence, structural and non-structural resilience measures, responsible institutions, and enabling data/technology tools.

Vulnerability / Risk	Structural Measures	Non-Structural Measures	Lead Institutions	Data / Technology Enablers
Transport / road disruption	Elevate and climate-proof critical roads, bridges, culverts, logistics hubs, and last-mile access routes; strategically site health and relief facilities on safer ground.	Pre-agreed alternate routing, multimodal logistics plans, district continuity plans, mutual-aid agreements, prioritized corridor reopening protocols.	NHA, provincial C&W departments, NDMA, PDMAs, district administrations, armed forces, Rescue 1122.	GIS road-status dashboards, satellite/drone damage assessment, trafficable-route mapping, offline mobile reporting.
Warning dissemination & communication failures	Backup power for telecom towers and siren systems; community notice boards, flood markers, resilient telecom nodes.	Standardized warning SOPs and nomenclature, local-language alerts, synchronized multi-agency messaging, two-way feedback channels, drills.	PMD, NDMA, PDMAs, PTA, telecom operators, district administrations, local media, NGOs.	Cell broadcast/SMS, IVR, radio, sirens, loudspeakers, social media integration, multilingual alert platforms.
Exclusion of marginalized groups	Inclusive evacuation centers, gender-sensitive WASH and shelter design, safe access routes for women, elderly, children, persons with disabilities.	Community-based planning, quotas for women/marginalized groups in DRM committees, integration of indigenous knowledge into contingency plans.	NDMA, PDMAs, Social Welfare/Women Development departments, local governments, NGOs.	Disaggregated beneficiary databases, participatory mapping, local-language apps/forms, grievance redress systems.
Weak accountability / donation flows	Secure, auditable warehousing and distribution points; designated cash-out locations and protected records infrastructure.	Transparent donation governance, third-party audits, digital beneficiary verification, public disclosure of allocations.	Ministry of Finance, NDMA, PDMAs, Auditor General, BISP/Ehsaas-type agencies, humanitarian clusters.	E-payments/mobile money, digital beneficiary registries, barcode/QR tracking, open relief dashboards.
Flood-prone land use and building	Flood-resilient building codes, raised plinths, embankments/drainage upgrades, retention areas, relocation from	Land-use regulation, enforcement campaigns, settlement planning, hazard disclosure,	Provincial/local planning authorities, municipal governments, irrigation departments, EPA,	Flood hazard maps, cadastral overlays, remote sensing for encroachment detection, digital land records.

Vulnerability / Risk	Structural Measures	Non-Structural Measures	Lead Institutions	Data / Technology Enablers
	highest-risk corridors.	relocation compensation frameworks.	housing departments.	
Loss of stored food / warehouse stocks	Elevated and distributed warehouses, cold-chain backup, flood-protected grain and medicine storage, decentralized buffer stocks.	Pre-positioning, supplier diversification, framework contracts, stock rotation, priority rationing rules.	PASSCO/provincial food departments, NDMA, PDMAs, health departments, WFP/NGOs, private logistics providers.	Inventory visibility systems, warehouse management systems, demand forecasting, remote stock sensors.
Limited community resources (boats, shelters)	Pre-positioned boats, life jackets, mobile storage units, raised shelters, community rescue points.	Training/equipping volunteer rescue teams, shelter management committees, evacuation drills, NGO-community partnerships.	District DMAs, Rescue 1122, local governments, community committees, NGOs, Red Crescent.	Community asset registries, shelter occupancy tracking, GPS-tagged rescue assets, offline coordination apps.

8.1 Integrated, Multi-Level Governance

- Establish synchronized, multi-source warning governance, including common procedures and a one-message policy per hazard window, to reduce confusing and inconsistent alerts [1.4].
- Institutionalize cross-agency SOPs for evacuation, rescue, and aid distribution, and run frequent exercises and specialized training [4.1].

8.2 Climate Adaptation Through Risk-Informed Land Use

- Enforce flood-prone land-use restrictions and flood-resistant building standards; implement zoning and safe relocation for high-risk communities [4.1], [2.2].
- Prioritize continuity of health and transport services through strategic siting and resilient design, directly addressing documented submergence and road-impairment failures [2.2].

8.3 Community Participation as Core Infrastructure

- Build formal community governance roles into early warning and contingency planning, including structured inclusion of women and marginalized groups, with inclusion linked to performance metrics such as response rates and warning comprehension [1.4].
- Fund and equip community volunteer networks, including sirens, loudspeakers, and local rescue teams, as a redundancy layer for low-connectivity settings [1.5], [1.7].

8.4 Technology Integration for Low-Resource Realities

- Replace tech-only assumptions with resilient, multi-channel dissemination, including radio, SMS, sirens, loudspeakers, and community announcements, explicitly accounting for power failures and weak mobile signals [1.4].
- Develop two-way information exchange systems so communities can confirm, interpret, and provide situational updates, addressing documented producer-consumer coordination failures [1.2], [1.3].

8.5 Data Foundations and Accountability

- Address missing socioeconomic records in flood-prone areas by building disaggregated community registries and participatory mapping pipelines to enable evidence-based contingency planning [1.4].
- Implement transparent donation and relief governance, including audits, digital registries, and grievance redress, to address documented accountability failures and inequitable distribution [2.2].

8.6 AI/ML and Remote Sensing: From Research Scope to Staged Pilots

- Given explicit calls to explore remote sensing and AI for flood risk assessment and management, implement staged pilots focused first on flood-extent mapping, road-passability inference, and hotspot prioritization, paired with governance and data safeguards, before higher-stakes autonomous decision-making [4.1].

9. Conclusion

Building resilience in Pakistan's flood-exposed supply chains requires the integration of science-based planning, social capital, indigenous knowledge, and emerging technologies. The evidence reviewed in this report shows that physical, informational, socioeconomic, and institutional vulnerabilities interact to undermine transport, food, relief, and health-system logistics during flood events.

Community networks, NGOs, and indigenous knowledge systems already play a meaningful role in sustaining last-mile resilience, but they are insufficient on their own, particularly for rapid, high-intensity events. Sustained resilience will depend on integrating these community-level strengths with strengthened structural investment, gender-sensitive and multi-channel risk communication, transparent governance and accountability, robust socioeconomic data foundations, and carefully staged adoption of remote sensing and AI/ML tools. Taken together, these measures offer a practical, evidence-based pathway toward more resilient supply chains in the face of recurrent climate-related disasters in Pakistan.

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Annex A: Note on In-Text Citation Codes

Citation codes refer to distinct evidence excerpts drawn from Shah et al. (2023); [2.1]–[2.2] refer to Abdullah et al. (2024); [3.1]–[3.3] refer to Schiffling et al. (2022); and [4.1] refers to Alam et al. (2024). These codes are used throughout the report to trace specific findings back to their source excerpt.

Annex B: Suggested Further Annex Materials

- Hazard and flood-extent maps for the districts referenced (e.g., Khyber Pakhtunkhwa, Nowshera, Dera Ismail Khan, Balochistan).
- Vulnerability and risk matrices summarizing Section 3 by supply-chain node.
- Case study summaries of the 2010 and 2022 flood responses.
- Checklists for SOP development referenced in Section 6 and 8.

STUDENT RESEARCH PAPER

Development of the Dynamic Readiness Assessment and Resource Optimization Framework (DRAROF): A System Dynamics Approach for Relief Warehouse Readiness and Resource Allocation in NDMA Pakistan

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Executive Summary

Pakistan faces recurring disasters such as floods, earthquakes, droughts, heatwaves, and landslides, all of which demand rapid and well-coordinated humanitarian response. While the National Disaster Management Authority (NDMA) maintains strategically located relief warehouses, current preparedness assessments are largely based on static inventory records and do not adequately evaluate operational readiness or the efficiency of resource mobilization during emergencies.

This research proposes the Dynamic Readiness Assessment and Resource Optimization Framework (DRAROF), a conceptual framework that applies systems thinking and system dynamics principles to strengthen disaster preparedness within NDMA. Rather than assessing preparedness solely through stock availability, DRAROF evaluates the interaction between warehouse inventory, transportation capacity, replenishment processes, institutional coordination, and operational feedback to provide a holistic assessment of readiness.

The framework introduces a Grievance Redress Mechanism (GRM) as a continuous feedback loop that captures information from responders, district administrations, and affected communities regarding shortages, delayed deliveries, and logistical constraints. This information supports adaptive planning and continuous improvement of humanitarian operations. Future implementation using Python would enable scenario-based simulations to support anticipatory action, optimize resource allocation, and improve disaster response planning across Pakistan.

1. Regional Context & Hazard Profile

Pakistan is one of the most disaster-prone countries in South Asia due to its geographical location, climatic variability, and rapidly changing environmental conditions. Seasonal floods, earthquakes, droughts, landslides, glacial lake outburst floods (GLOFs), and extreme heat events frequently affect millions of people, causing loss of life, infrastructure damage, displacement, and economic disruption. Climate change has further intensified the frequency and severity of these hazards, increasing pressure on national disaster management institutions.

The devastating floods of 2022 highlighted the importance of efficient humanitarian logistics and exposed several operational challenges, including transportation disruptions, unequal distribution of relief supplies, delayed deliveries, and difficulties in reaching vulnerable communities. Although NDMA maintains pre-positioned relief warehouses across the country, existing preparedness assessments mainly focus on stock availability rather than evaluating how efficiently resources can be mobilized under changing disaster conditions.

Viewing humanitarian logistics through a systems thinking perspective recognizes that warehouse inventories, transportation networks, institutional coordination, infrastructure accessibility, and emergency demand are interconnected components of one dynamic system. Understanding these relationships is essential for improving anticipatory disaster preparedness and operational readiness.

2. Risk & Vulnerability Assessment

Delayed or inefficient relief distribution significantly increases disaster risk, particularly for vulnerable populations such as women, children, older adults, persons with disabilities, and low-income households. Limited access to food, clean water, shelter, and healthcare during emergencies can rapidly worsen humanitarian conditions and prolong recovery.

Operational vulnerabilities include inaccurate inventory information, transportation bottlenecks, inadequate coordination among responding agencies, and the absence of real-time preparedness assessment. Existing systems often identify these issues only after response operations have begun, reducing the effectiveness of emergency interventions. Developing a dynamic readiness assessment framework would allow NDMA to identify logistical weaknesses before disasters occur and improve the allocation of critical relief resources.

3. Community Resilience Factors

Community resilience is strengthened when disaster management institutions actively engage with local communities and incorporate their experiences into preparedness planning. Social networks, community organizations, local volunteers, and indigenous knowledge provide valuable information regarding local needs and response priorities.

DRAROF incorporates a Grievance Redress Mechanism (GRM) as a structured feedback system through which district administrations, field responders, humanitarian organizations, and affected communities can report shortages, damaged supplies, inaccessible locations, and delayed assistance. This continuous feedback enhances transparency, accountability, and institutional learning while improving future preparedness planning. By integrating community perspectives into decision-making, the framework contributes to more resilient and inclusive disaster management.

DRAROF Components Table

Component	Purpose	Expected Outcome
Warehouse Readiness	Monitor inventory availability	Improved preparedness
Resource Allocation	Optimize relief distribution	Faster response
Transportation Capacity	Assess logistics capability	Reduced delivery delays
GRM	Collect field feedback	Continuous improvement
System Dynamics	Simulate disaster scenarios	Better planning
Python Simulation	Scenario analysis	Evidence-based decisions

Current System vs Proposed DRAROF

Existing Practice	DRAROF Framework
Static inventory records	Dynamic readiness assessment
Manual monitoring	Continuous monitoring
Limited feedback	Integrated GRM
Reactive planning	Proactive planning
Single indicators	Multi-dimensional indicators
Limited simulations	Python-based simulations

4. Scientific & Institutional Gaps

Current humanitarian logistics research has extensively examined inventory optimization, warehouse location selection, transportation routing, and supply chain efficiency. However, these studies often focus on individual components rather than evaluating the disaster logistics system as an interconnected whole.

Within disaster management institutions, preparedness assessments generally rely on static indicators such as stock levels or warehouse capacity. These measures provide limited insight into operational readiness under dynamic disaster scenarios where transportation conditions, resource demand, infrastructure accessibility, and institutional coordination continuously change.

This research addresses both scientific and institutional gaps by proposing the Dynamic Readiness Assessment and Resource Optimization Framework (DRAROF). The framework applies system dynamics to conceptualize humanitarian logistics as an interconnected system in which inventory, transportation, replenishment, deployment capacity, and stakeholder feedback collectively influence disaster preparedness. The integration of a Grievance Redress Mechanism further introduces a continuous learning process that enables adaptive decision making and improves future response planning.

The framework also establishes a foundation for future integration with Artificial Intelligence (AI), Geographic Information Systems (GIS), Remote Sensing, Big Data analytics, and Pythonbased simulation models, supporting evidence-based disaster management and innovation within NDMA.

5. Mitigation Strategies & Best Practices

To enhance disaster preparedness, NDMA should transition from inventory-based assessments towards comprehensive operational readiness evaluations. Preparedness indicators should include deployment capability, transportation accessibility, replenishment efficiency, warehouse functionality, and institutional coordination.

Implementation of digital inventory systems, standardized readiness indicators, regular simulation exercises, inter-agency coordination mechanisms, and continuous staff capacity building can substantially improve humanitarian logistics performance. Python-based simulation models can further support preparedness planning by evaluating multiple disaster scenarios, identifying potential bottlenecks, and assessing alternative resource allocation strategies before emergencies occur.

6. Risk Communication & Early Warning

Effective preparedness depends on timely communication among NDMA, Provincial Disaster Management Authorities (PDMAs), District Disaster Management Authorities (DDMAs), humanitarian organizations, and local communities. Early warning information should be integrated with warehouse readiness assessments so that relief resources can be pre-positioned before disasters escalate.

The proposed GRM complements conventional early warning systems by providing real-time operational feedback from the field. This two-way communication process enables decisionmakers to identify emerging logistical challenges, improve coordination, and strengthen public confidence in disaster management institutions. Gender-sensitive communication strategies and inclusive community participation should remain central components of disaster preparedness.

7. Policy Recommendations

To strengthen disaster preparedness and humanitarian logistics in Pakistan, the following policy actions are recommended:

Adopt DRAROF as a conceptual framework for assessing operational readiness within NDMA relief warehouses.

Develop standardized national readiness indicators that evaluate logistics performance in addition to inventory availability.

Institutionalize Grievance Redress Mechanisms to improve organizational learning and evidence-based decision-making.

Promote the use of Python-based system dynamics simulations for preparedness planning and anticipatory resource allocation.

Integrate AI, GIS, Remote Sensing, and Big Data technologies into disaster logistics decision-support systems.

Strengthen coordination among NDMA, PDMAs, DDMAs, line departments, and humanitarian partners through integrated digital platforms.

Conduct regular preparedness assessments, simulation exercises, and capacity-building programmes to improve institutional resilience.

8. Conclusion

As disaster risks continue to evolve, humanitarian logistics systems must move beyond static inventory management towards dynamic operational preparedness. The proposed Dynamic Readiness Assessment and Resource Optimization Framework (DRAROF) introduce a systems-based approach that evaluates the interaction between warehouse resources, logistics processes, institutional coordination, and stakeholder feedback to assess disaster readiness more comprehensively.

Although conceptual in nature, DRAROF provides an innovative foundation for future development of Python-based simulation tools that support anticipatory action, evidence-based resource allocation, and resilient humanitarian logistics. Adoption of this framework by NDMA has the potential to strengthen preparedness, improve response efficiency, and contribute to more adaptive and resilient disaster risk management across Pakistan.

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STUDENT RESEARCH PAPER

Anticipatory Action for Urban Flood Risk Management in Karachi

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Executive Summary

Karachi, Pakistan's largest metropolitan city and economic hub, experiences recurrent urban flooding due to climate change, rapid urbanization, inadequate drainage infrastructure, encroachment of natural waterways, and poor solid waste management. These floods result in economic losses, disruption of transportation, infrastructure damage, public health impacts, and livelihood losses. Anticipatory Action (AA) is a proactive disaster risk management approach that relies on scientific forecasting, predefined triggers, SOPs, and coordinated institutional actions to reduce disaster impacts before they occur. This report evaluates Karachi's flood risk profile, vulnerabilities, institutional challenges, mitigation strategies, and policy recommendations for strengthening resilience.

- Regional Context & Hazard Profile

Karachi is Pakistan's largest city and is highly vulnerable to monsoon flooding. Climate change has intensified extreme rainfall while rapid urbanization has reduced natural drainage. Hazard refers to a potentially damaging event; exposure includes people, infrastructure and assets located in flood-prone areas; vulnerability describes their susceptibility to damage; and risk is the interaction of hazard, exposure and vulnerability. Major drivers include climate change, aging drainage systems, encroached nullahs, poor waste management and high population density. Historical floods have caused road inundation, transport disruption, infrastructure damage, economic losses and public health emergencies.

- Risk & Vulnerability Assessment

Urban flooding damages public infrastructure, homes, businesses and transport systems while disrupting livelihoods and food supply chains. Daily wage earners, informal workers and low-income communities are particularly affected. Vulnerable groups include women, children, elderly persons and persons with disabilities. Gender-sensitive disaster planning is essential because women often face greater caregiving burdens and reduced access to emergency services during disasters.

- Community Resilience Factors

Community resilience depends on strong social networks, local leadership, indigenous knowledge, volunteer organizations and community participation. Local knowledge of flood-prone areas and evacuation routes strengthens preparedness and recovery.

- Scientific & Institutional Gaps

Major gaps include limited real-time hydrological data, insufficient urban flood forecasting, weak GIS and AI integration, coordination challenges among agencies, incomplete flood databases and limited implementation of SOPs. Stronger impact-based forecasting and institutional coordination are required.

- Mitigation Strategies

Structural measures include upgrading storm-water drainage, cleaning drains and nullahs, preventing encroachments and improving drainage design. Non-structural measures include awareness campaigns, community preparedness, simulation exercises, capacity building, SOP development and pre-positioning rescue teams, pumps, boats and relief supplies.

- Risk Communication & Early Warning

Effective anticipatory action requires impact-based weather forecasts from PMD, Emergency Operation Centers, gender-sensitive early warning systems and communication through television, radio, SMS and social media to ensure timely community action.

- Policy Recommendations

Modernize drainage infrastructure, strengthen integrated forecasting systems, improve coordination among NDMA, PMD, KMC and district administrations, institutionalize forecast-based triggers, expand GIS/AI applications, promote climate-resilient planning and increase community participation in disaster risk reduction while aligning with the Sendai Framework.

- Conclusion

Anticipatory Action shifts Karachi from reactive disaster response to proactive risk management. Scientific forecasting, institutional coordination, community preparedness and infrastructure investment can substantially reduce flood losses and build a resilient, climate-adaptive urban future.

References

National Disaster Management Authority (NDMA); Pakistan Meteorological Department (PMD); United Nations Office for Disaster Risk Reduction (UNDRR); Sendai Framework for Disaster Risk Reduction (2015–2030); IPCC Assessment Reports; relevant peer-reviewed literature on urban flood risk management.

STUDENT RESEARCH PAPER

Earth Observation for Disaster Monitoring & Damage Assessment

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Executive Summary

Earth Observation (EO) satellites provide timely information that supports disaster monitoring, early warning, damage assessment, and recovery planning (European Space Agency, 2024; Group on Earth Observations, 2024). This report explains the role of optical and SAR satellite data in disaster management, highlights research and institutional gaps in Pakistan, and recommends practical actions for NDMA, PDMAs, and district administrations. The core recommendation of this report: NDMA and allied agencies should move from occasional satellite use to a routine, institutionalized EO-based monitoring system, paired with local capacity building and it also emphasizes integrating GIS, AI, Remote Sensing, drones, and Big Data to strengthen disaster resilience and save more lives.

Regional Context & Hazard Profile

Pakistan sits at the crossroads of multiple hazards like monsoon floods, glacial lake outbursts, landslides, droughts, and earthquakes driven by its varied terrain and shifting climate. Historical events such as the 2010 and 2022 super floods (Haq et al., 2012; Sajjad et al., 2020; Khan et al., 2025), and repeated landslides in the northern belt show how fast-moving and widespread these hazards can be, often outrunning ground-based monitoring.

In simple terms: hazard is the event itself (a flood or a quake), exposure is what stands in its path (homes, crops, roads), vulnerability is how easily that exposure is harmed, and risk is the combination of all three. Earth observation satellites Satellites help measure each of these by tracking land use, flood water, plant cover, and how fast towns are growing, over long periods of time (NASA Earth Observatory, 2023). Optical sensors (e.g., Landsat and Sentinel-2) provide detailed daytime imagery (European Commission, 2024; U.S. Geological Survey, 2024), while SAR sensors (e.g., Sentinel-1) operate day and night and through clouds, making them valuable during floods and cyclones (Kuntla, 2021; Plank, 2014).

What Local Studies Show

Lahore (land use land cover study, 1992–2020): the city's built-up area kept growing over this period, and it mostly took over land that used to be vegetation making vegetation the most affected land type in the area.

Islamabad (land surface temperature, 2000–2020): surface temperature rose steadily over two decades, with high-heat zones spreading while cooler, green areas shrank mainly to the Margalla Hills and other vegetated pockets.

Khanewal (vegetation cover, 1980–2020): vegetation health and density declined steadily over this period, with dense green cover giving way to sparse growth likely linked to urban expansion or environmental change.

Risk & Vulnerability Assessment

Disasters rarely hit everyone equally. Flooded farmland means lost income for smallholder farmers; damaged roads cut off remote communities from markets and healthcare; and women, children, the elderly, and persons with disabilities typically face the highest exposure with the least resources to recover. Satellite-derived maps of flood extent or crop damage let planners target relief toward the worst-hit and most vulnerable areas first, instead of spreading resources thin.

Community Resilience Factors

Technology works best alongside people, not instead of them. Local knowledge where floodwater has pooled before, which slopes have slipped in past monsoons helps validate and sharpen what satellites detect from above. Community networks and indigenous early-warning practices (watching river levels, reading cloud patterns) remain the first line of defense, especially in areas with patchy internet or power. Combining local knowledge with Earth Observation improves preparedness, response and long-term resilience.

Scientific & Institutional Gaps

Despite growing global use of EO data (Joyce et al., 2009), adoption within Pakistan's disaster management chain remains limited by a few recurring gaps: skilled analysts trained in remote sensing are scarce at the district level; access to high-resolution, near-real-time imagery is often costly or delayed; and there is no standard protocol linking satellite alerts directly to PDMA response triggers. Data also tends to sit in research papers rather than operational dashboards.

Innovation Focus Where Technology Can Close the Gap

AI/Machine Learning: automated flood-extent and building-damage detection from satellite imagery, cutting manual analysis time from days to hours (Braik & Koliou, 2024; Dong & Shan, 2013).

GIS integration: layering hazard, exposure, and infrastructure data into a single operational map for decision-makers.

Drones (UAVs): filling the resolution gap for street-level damage assessment where satellite imagery is too coarse.

Big Data & cloud platforms (e.g., Google Earth Engine): enabling faster processing of large satellite archives without heavy local infrastructure.

Mitigation Strategies & Best Practices

Structural measures: satellite-guided zoning to avoid new construction on flood-prone or unstable land, earthquake-resistant building codes in high-risk zones, and buffer zones between forests and settlements to slow wildfire spread. Non-structural measures: training district officers in reading and using satellite-derived hazard maps, public awareness campaigns using simplified EO visuals, and promoting drought-resistant crops and deep-rooted vegetation on landslide-prone slopes identified through remote sensing.

Risk Communication & Early Warning

Radar (SAR) satellites work day and night and see through cloud and smoke. which matters most exactly when visibility on the ground is worst, such as during floods or cyclones (Tzouvaras, 2021). This be useful, this data must reach communities in plain language and through trusted channels so that information reaches women and marginalized groups who may have less access to mainstream alert systems.

Policy Recommendations

Recommended for NDMA, PDMAs, District Administrations & Line Departments:

NDMA: Institutionalize a standing EO data-sharing agreement with agencies like Copernicus, USGS, and national space bodies (SUPARCO) to guarantee routine imagery access, not just during emergencies.

PDMAs: Establish provincial remote-sensing cells trained to translate satellite alerts into district-level advisories within hours of detection.

District Administrations: Integrate satellite-based hazard maps into local land-use approval processes to discourage construction in high-risk zones.

Line Departments (Agriculture, Irrigation, Local Government): Adopt shared GIS dashboards so damage data flows directly into relief and reconstruction planning, avoiding duplicated field surveys.

Conclusion

Satellites cannot stop a flood or a quake, but they can tell us where danger is building and where damage has struck often before a single field team arrives. Building real resilience means combining this bird's-eye science with local knowledge, trained institutions, and clear communication.

Operational Linkage:

Anticipatory action: satellite trends flag rising flood or drought risk days in advance, triggering prepositioning of relief supplies.

Preparedness: hazard-zone mapping informs evacuation planning and safe-site identification.

Response: near-real-time imagery directs rescue teams to the worst-affected pockets first.

Recovery & resilience: before/after image comparison guides fair, evidence-based reconstruction and rebuilding-back-better planning.

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STUDENT RESEARCH PAPER

Internet of Things (IoT)-Based Systems for Disaster Monitoring and Early Warning

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1. Concept and Context

IoT-based disaster monitoring uses interconnected sensors, communication networks, cloud computing, and artificial intelligence to collect and analyze real-time environmental data. The goal is to detect hazards such as floods, earthquakes, landslides, cyclones, and wildfires at an early stage and provide timely warnings to authorities and the public. Early warning systems improve preparedness, reduce response time, and minimize the loss of life and property. As climate change increases the frequency and intensity of disasters, IoT has become an important technology for disaster risk reduction. In Pakistan, IoT can support monitoring of Indus River floods, glacial lake outburst floods (GLOFs), urban flooding in Karachi, droughts, landslides, and heatwaves.

2. Research Gaps and Novelty

Many existing disaster monitoring systems rely on isolated sensors, delayed data transmission, or manual reporting. Remote areas often have poor internet connectivity, limited power supply, and insufficient integration between monitoring agencies. There is also limited use of AI for predictive analysis and limited integration of IoT data with GIS and satellite observations. The novelty of this work is the proposed integration of IoT sensors, cloud computing, AI, GIS, and multi-channel early warning platforms to create a smarter and more reliable disaster monitoring framework suitable for developing countries such as Pakistan.

3. Policy and Procedure Recommendations

Government agencies should expand IoT sensor networks in disaster-prone regions and establish national standards for data sharing among NDMA, PMD, SUPARCO, provincial authorities, and emergency services. Investments should be made in reliable communication systems, renewable energy for remote sensors, cybersecurity, and routine maintenance. Public awareness and community training should accompany technological improvements so that warnings are understood and acted upon quickly.

4. Innovative Approach and Value Addition

A smart multi-hazard platform is proposed in which IoT sensors continuously collect environmental data, transmit it through wireless or satellite communication, and combine it with GIS, weather forecasts, and satellite imagery. Artificial intelligence and machine learning analyze incoming data to predict disaster risks before they become critical. Automatic alerts can then be delivered through SMS, mobile applications, television, radio, sirens, and emergency operation centers. This integrated approach improves prediction accuracy, reduces response time, supports better decision-making, and strengthens community resilience while reducing economic losses.

5. Conclusion

IoT provides a practical and innovative solution for modern disaster monitoring and early warning. By integrating real-time sensing, cloud computing, AI, and GIS, governments can improve preparedness and emergency response. Strengthening policies, infrastructure, and inter-agency collaboration will help countries such as Pakistan build resilient communities and reduce disaster impacts.

STUDENT RESEARCH PAPER

Germany Floods (2021): Early Warning System and Public Response Analysis

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Executive Summary

The July 2021 floods in western Germany provide an important case study on the effectiveness of early warning systems under climate change. Although Germany possessed advanced forecasting and hydrological monitoring capabilities, more than 180 people lost their lives because accurate forecasts were not consistently translated into timely public action. This report evaluates the relationship between forecasting, warning dissemination and community response, identifies institutional and technological gaps, and proposes recommendations relevant to Pakistan. The analysis concludes that disaster resilience depends on both technological capability and community preparedness.

Regional Context & Hazard Profile

Between 14 and 15 July 2021, prolonged rainfall associated with low-pressure system Bernd caused catastrophic flooding across the Ahr Valley and surrounding regions. Climate change increased the probability and intensity of such rainfall events. Disaster risk resulted from the interaction of hazard, exposure, vulnerability and coping capacity. Settlements along narrow river valleys, ageing infrastructure and limited public preparedness amplified losses. This case illustrates how climate-induced extreme weather can overwhelm even highly developed countries.

Risk & Vulnerability Assessment

The floods destroyed homes, bridges, roads, utilities and public facilities while disrupting livelihoods and local economies. Vulnerable groups included older adults, persons with disabilities, tourists unfamiliar with local hazards and households living in flood-prone areas. Cascading failures in transport, electricity and communication hindered emergency response. The event demonstrated that vulnerability is influenced by social and institutional factors in addition to physical exposure.

Community Resilience Factors

Community volunteers, emergency services and civil society organizations played an important role in rescue and recovery. However, many residents underestimated the warnings because of limited previous experience with such extreme flooding. Building resilience therefore requires continuous public awareness, trust in authorities, regular evacuation drills and stronger local participation.

Scientific & Institutional Gaps

The principal gap was not the accuracy of meteorological forecasts but the effectiveness of warning dissemination and public response. Communication was not always impact-based, evacuation decisions varied across jurisdictions and coordination among agencies was inconsistent. Data integration between forecasting, emergency management and local authorities can be improved. The novelty of this study is its emphasis on warning effectiveness and behavioural response rather than forecast accuracy alone.

Mitigation Strategies & Best Practices

Structural measures include flood retention basins, resilient bridges, improved drainage and river restoration. Non-structural measures include land-use planning, impact-based forecasting, school awareness programmes, evacuation planning, regular drills and capacity building for emergency responders. These measures collectively reduce disaster risk and improve preparedness.

Risk Communication & Early Warning

Warning messages should explain expected impacts, affected locations and required protective actions. Multi-channel dissemination through SMS, television, radio, mobile applications, social media and community sirens should ensure last-mile connectivity. Communication strategies should also consider vulnerable groups, local languages and gender-sensitive approaches.

Policy Recommendations

For NDMA: develop national guidance on impact-based forecasting, strengthen national coordination and establish common warning protocols.

For PDMAs and District Administrations: prepare evacuation maps, conduct community drills and strengthen last-mile warning systems.

For PMD, SUPARCO and line departments: integrate meteorological, GIS and remote sensing data into unified decision-support platforms.

Innovation: employ AI for impact forecasting, GIS for hazard mapping, drones for rapid damage assessment, remote sensing for flood monitoring and Big Data dashboards for real-time situational awareness.

Conclusion

The Germany Floods (2021) demonstrate that technology alone cannot prevent disaster losses. Successful early warning systems require accurate forecasting, effective communication, institutional coordination and informed public action. Operationally, these findings support anticipatory action through earlier evacuations, preparedness through training, efficient emergency response and long-term resilience-building. Pakistan can significantly reduce disaster losses by combining policy reforms with innovative technologies and community-Centerd disaster risk management.

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STUDENT RESEARCH PAPER

Japan's Earthquake Preparedness Model: Best Practices for Developing Countries

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Executive Summary

This report examines Japan's earthquake preparedness model and identifies lessons that can be adapted by developing countries, especially Pakistan. Japan combines strong laws, earthquake-resistant infrastructure, advanced early warning systems, community awareness and coordinated emergency response. The report recommends strengthening disaster governance, enforcing building codes, expanding public education and integrating modern technologies such as AI, GIS, remote sensing, drones and big data into disaster management.

- Regional Context & Hazard Profile

Japan lies on the Pacific Ring of Fire where four tectonic plates meet, making it one of the world's most earthquake-prone countries. Hazard refers to the earthquake itself, exposure includes people and infrastructure in affected areas, vulnerability reflects weak buildings and limited preparedness, and risk is the expected loss resulting from these factors. The 2011 Great East Japan Earthquake demonstrated that even highly prepared countries face severe impacts, yet preparedness greatly reduces casualties and economic losses. For Pakistan, active faults including the Main Boundary Thrust and Chaman Fault create similar risks, making Japan's experience highly relevant.

- Risk & Vulnerability Assessment

Earthquakes disrupt lives, damage infrastructure, interrupt livelihoods and affect food security and essential services. Women, children, older persons and persons with disabilities are often the most vulnerable. Prepared communities and resilient infrastructure significantly reduce disaster impacts.

- Community Resilience Factors

Japan promotes disaster education from school level, conducts annual drills and encourages community volunteer groups. Local knowledge, hazard mapping and emergency kits help citizens respond quickly and calmly during emergencies.

- Scientific & Institutional Gaps

Many developing countries face weak enforcement of building codes, limited seismic monitoring, fragmented institutional coordination and insufficient public awareness. There is also limited adoption of AI, GIS, remote sensing and big data for risk assessment. The novelty of this study is that it links Japan's proven preparedness model with practical and affordable solutions that Pakistan can gradually implement through existing institutions.

- Mitigation Strategies & Best Practices

Structural measures include earthquake-resistant construction, retrofitting schools and hospitals and enforcing building regulations. Non-structural measures include awareness campaigns, regular drills, capacity building, emergency planning and volunteer training.

- Risk Communication & Early Warning

Multi-channel early warning through mobile phones, television, radio and public sirens should be strengthened. Communication strategies must be simple, timely and inclusive, ensuring women, rural communities and vulnerable groups receive warnings.

- Policy Recommendations

• NDMA should expand nationwide disaster education and simulation exercises.• PDMAs should strengthen district-level preparedness plans and community volunteer programmes.• District Administrations should update hazard maps, conduct evacuation drills and identifysafe shelters.• Relevant ministries should strictly enforce the Building Code of Pakistan and invest in resilient public infrastructure.• AI, GIS, drones, remote sensing and big data should be integrated into hazard mapping, rapid damage assessment and decision-making.Operational Linkage: These recommendations support anticipatory action through early warning, improve preparedness through training, strengthen

emergency response through better coordination, accelerate recovery using rapid assessments and enhance long-term resilience.

- Conclusion

Japan demonstrates that disasters cannot always be prevented, but their impacts can be greatly reduced through preparedness, science, strong institutions and public participation. Pakistan can improve resilience by adapting these best practices according to local conditions while investing in technology, governance and community engagement.

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STUDENT RESEARCH PAPER

Flash Flood Hazards in Mountainous Regions: Risk Assessment and Mitigation

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1. Research Concept and Regional Context

1.1. The Vulnerability Profile of Pakistan

Pakistan represents a profound case of climate injustice, maintaining a negligible global carbon footprint while enduring disproportionately severe environmental consequences 1. The nation currently holds the 8th position in the global climate risk ranking and is identified as the 7th most vulnerable country to climate-induced disasters 1. Historical data regarding extreme hydrological events confirms this high-risk profile through the following impacts 1:

2010 Super Floods: This catastrophic event claimed 1,985 lives, affected 200 million people, and resulted in documented tangible economic losses of USD 9.7 billion 1.

2022 Monsoon Floods: These floods resulted in at least 1,033 deaths, affected 33 million individuals, and displaced 5.4 million people 1. The 2022 event led to 72 districts being declared 'calamity hit,' destroying 2 million homes and 2 million acres of crops and orchards 1.

1.2. Defining Flood Risk in High-Altitude Terrains

Establishing resilient socio-economic outcomes in mountainous and riverine regions necessitates a precise conceptual framework to define the intersection of hydrological hazards and human exposure 2. Within this technical framework, 'Flood Hazard' is defined as the specific flood event characterised by its probability of occurrence 2. 'Flood Exposure' encompasses the lives, properties, and assets situated within the flood path and thus susceptible to impact 2. 'Flood Vulnerability' refers to the inherent lack of resistance to damaging flood waves, often exacerbated by the absence or failure of structural protection measures 2. Finally, 'Flood Risk' is mathematically understood as the product of the hazard and its subsequent socio-economic consequences 2.

1.3. Climatic Trends and Hydro-Meteorological Extremes

Climate change is directly driving an increase in the frequency, severity, and duration of flash and riverine floods across the Pakistani landscape 1. To rigorously analyse these trends, this policy recommends the adoption of the "Noah and Joseph Effect" methodology, a framework successfully utilised in regional South Asian case studies like the Krishna River Basin, to distinguish between long-term persistence and extreme standalone events 2. The Noah Effect describes the phenomenon where precipitation extremes are exceptionally intense, while the Joseph Effect indicates that periods of high or low precipitation can persist over extensive durations 2. While these findings are a regional precedent from Indian hydrological records, the presence of "Erratic Noah and Joseph" elements in medium and large-scale floods suggests this methodology is a vital transferrable tool for Pakistan's mountainous terrain 2.

2. Thematic Analysis of Risk and Vulnerability

2.1. Socio-Economic Impacts and Livelihood

The following table delineates the multidimensional impacts of flooding on communal stability and nutritional security within Pakistan.| Impact Category | Direct Tangible Impacts | Indirect and Systemic Impacts || ------ | ------ | ------ || **Agriculture** | Immediate destruction of millions of acres of cropped area and orchards 1. | Long-term disruption of agricultural production and communal well-being 1. || **Food Security** | Instantaneous loss of productive mediums and livestock assets 1. | Malnourishment, supply chain fragmentation, and hyper-inflation of food prices 1. || **Economic** | Multi-billion dollar tangible losses and the widespread destruction of residential structures 1. | Systemic socio-economic vulnerability rooted in unaffordable sustenance and lack of institutional justice 1. |

2.2. The Gendered Lens in Disaster Management

Women in Pakistan possess a unique vulnerability profile during flood events, largely dictated by restrictive social norms and severe limitations on physical mobility 1. These individuals often lack the decisional power and technical training required for effective responses to rapid-onset disasters 1. Crucially, the National Disaster Management Authority (NDMA) and the Pakistan Meteorological Department (PMD) are currently the only national departments with gender-integrated early warning system (EWS) initiatives, yet even these efforts remain limited in scope 1. Despite the significant potential for women to enhance communal adaptive capacities, they are frequently treated as a "last mile" group in risk communication and remain largely excluded from formal participation due to sociocultural traditions 1.

2.3. Social Capital as a Mitigation Asset

Social capital serves as a critical, often dormant, resource for post-flood recovery and personal resilience within Pakistani communities 1. This asset is categorised into bonding capital (ties within immediate family), bridging capital (links between diverse communities), and linking capital (connections between citizens and formal institutions) 1. Empirical evidence indicates that flood victims in Pakistan often rely on their social networks rather than formal aid during the immediate aftermath of a disaster 1. A higher density of social capital is directly correlated with a community's ability to "bounce back" through mutual trust and the informal exchange of vital information 1.

3. Identified Gaps and Areas of Novelty

3.1. State of Scientific Knowledge

There is a notable upward trend in scientific publications regarding floods in Pakistan, with over 55% of the total research corpus produced between 2018 and 2022 1. Leading institutions in this field include the National University of Sciences and Technology (NUST), the University of Peshawar, COMSATS University, the University of Agriculture Faisalabad, and international collaborators such as the Chinese Academy of Sciences and Wuhan University 1. While Environmental, Earth, and Social Sciences dominate the discourse, there remains a critical research deficit in the disciplines of Economics, Econometrics, and Finance 1.

3.2. Technological and Institutional Infancy

Despite the growth in general academic interest, several technological and institutional gaps hinder effective disaster risk management 1:

The application of Information and Communication Technology (ICT), Artificial Intelligence (AI), and Machine Learning (ML) in flood studies is currently in its infancy 1.

There is a lack of comprehensive, state-of-the-art studies that synthesise the total knowledge specifically for Pakistan-centric flooding events 1.

Institutional frameworks are hampered by a rigid "top-down" approach that overlooks the nuances of local context and indigenous insights 1.

The integration of Big Data into flood research remains severely limited within the broader computer science and disaster management disciplines 1.

3.3. The Perception-Reality Gap

A significant area of novelty in risk research is the inverse relationship between physical proximity to hazards and psychological risk perception 1. In Pakistan, individuals residing further from flood sources often exhibit more accurate risk perceptions than those in high-risk zones who develop a "false sense of security" over time 1. To bridge this gap, this policy recommends the strategic deployment of AI and Big Data to provide residents in high-risk riverine zones with personalised, evidence-based risk visualisations that counteract psychological complacency 1.

4. Policy Recommendations and Innovative Approaches

4.1. Integrated Governance Frameworks

Mandate a transition toward integrated governance to fortify national resilience against hydrological extremes 1. Execute the formal integration of Climate Change Adaptation (CCA) with Flood Risk Reduction (FRR) strategies at all levels of government 1. Shift administrative models from top-down hierarchies to inclusive frameworks that prioritise the indigenous knowledge of local communities 1. Perform rigorous institutional challenge-mapping to identify and dismantle the social and political barriers that currently impede effective flood management 1.

4.2. Structural and Non-Structural Mitigation

Adopt a dual-track approach to mitigation that balances infrastructure with capacity building 1:

Agricultural R&D: Prioritise the expansion of crop varieties and the promotion of agro-based technology packages to safeguard rural livelihoods 1.

Capacity Building: Implement non-structural policies that focus on community training and skill development rather than relying solely on physical barriers 1.

Floodplain Delineation: Execute the zoning of floodplains based on scientific return-period data, utilizing the Indian Flood Plain Zoning Bill of 1975 as a regional methodological precedent for marking risk zones 2.

4.3. Innovations in Risk Communication

Modernise risk communication to ensure it penetrates the most vulnerable communal segments 1. Redesign early warning systems to be gender-sensitive, ensuring that warning notifications are accessible, culturally appropriate, and actionable for women 1. Furthermore, reduce livelihood vulnerability by promoting passive income opportunities, such as small-scale livestock and poultry management, to diversify the economic base of rural households 1.

5. Conclusion

The escalating intensity of hydrological extremes in Pakistan demands an immediate institutional commitment to the principle of "building back better" 1. This analysis concludes that qualitative assessments of disaster impacts must be meticulously paired with rigorous scientific and quantitative evidence to transition away from perception-based management 2. To achieve the targets of SDG:2 (Zero Hunger) and enhance overall community resilience, the state must undertake systematic institutional challenge-mapping and formally integrate social capital and accurate risk perception into the national disaster framework 1. Moving forward, the pairing of indigenous knowledge with advanced technological tools like AI will be the cornerstone of a flood-resilient Pakistan 1.

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STUDENT RESEARCH PAPER

Urban Flooding in Karachi: An Analysis of Causes, Structural Impacts, and Sustainable Mitigation Solutions

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Executive Summary

Urban flooding has become one of the most serious environmental and development challenges facing Karachi. Every year, heavy monsoon rainfall, poor drainage systems, rapid urbanization, and weak waste management lead to severe flooding in different parts of the city. The consequences include damage to roads and buildings, disruption of businesses, spread of diseases, and loss of livelihoods.

This report examines the major causes and impacts of urban flooding in Karachi while highlighting practical and sustainable solutions. It also identifies existing research and institutional gaps and explains how modern technologies such as Artificial Intelligence (AI), Geographic Information Systems (GIS), Remote Sensing, drones, and Big Data can improve flood management. Finally, the report provides policy recommendations for NDMA, PDMA Sindh, Karachi Metropolitan Corporation (KMC), and other relevant institutions to strengthen disaster preparedness and build a more climate-resilient Karachi.

Regional Context & Hazard Profile

Karachi is Pakistan's largest city and its financial and commercial hub. Due to rapid population growth and unplanned urban development, the city's natural drainage system has been significantly altered. At the same time, climate change has increased the intensity of monsoon rainfall, making urban flooding more frequent and severe.

Urban flooding occurs when heavy rainfall exceeds the capacity of drainage systems, causing water to accumulate on roads, residential areas, and commercial centers. In Karachi, this problem is further worsened by blocked stormwater drains, illegal construction on natural waterways, and poor solid waste management.

From a disaster management perspective:

Hazard refers to heavy rainfall and flash flooding.

Exposure includes people, houses, businesses, roads, and public infrastructure located in flood-prone areas.

Vulnerability arises from poor drainage systems, weak urban planning, and inadequate emergency preparedness.

Risk is the likelihood of human, economic, and environmental losses resulting from the interaction of these factors.

Recent flood events have shown that without proper planning, urban flooding will continue to threaten Karachi's economic stability and public safety.

Risk & Vulnerability Assessment

Urban flooding affects almost every aspect of life in Karachi. Roads become impassable, transport services are interrupted, businesses remain closed, and schools and hospitals face operational difficulties.

Floodwater mixed with sewage increases the spread of waterborne diseases such as diarrhea, cholera, dengue, and skin infections. Families living in low-income settlements are particularly vulnerable because they often live near drainage channels with limited access to emergency services.

Women, children, older persons, and persons with disabilities face additional challenges during floods due to limited mobility, healthcare access, and safe shelter facilities. Flooding also causes financial losses for daily wage earners who depend on uninterrupted economic activities.

Community Resilience Factors

Community participation plays an important role in reducing flood risks. Local residents often possess valuable knowledge about flood-prone areas and can contribute to early reporting of blocked drains and illegal dumping.

Public awareness campaigns, volunteer groups, and community-based disaster preparedness programmes can significantly improve emergency response. Schools, universities, civil society organizations, and local governments should work together to educate citizens about waste disposal, emergency planning, and flood safety.

Strengthening community resilience encourages people to become active partners in disaster risk reduction rather than passive victims.

Scientific & Institutional Gaps

Although urban flooding is a recurring problem in Karachi, several important gaps continue to limit effective flood management.

One major challenge is the absence of integrated urban planning. Drainage infrastructure has not expanded at the same pace as urban growth. Coordination among different government departments responsible for drainage, solid waste management, urban planning, and emergency response also remains weak.

Another important limitation is the limited use of modern technologies for flood prediction and monitoring. Flood risk maps are not regularly updated, and real-time data sharing among institutions remains inadequate.

Research Gap

Most previous studies focus mainly on engineering solutions such as improving drainage systems. Less attention has been given to integrating modern technologies, community participation, and climate adaptation into a comprehensive flood management strategy.

Novelty of the Study

This report combines structural improvements with community resilience and emerging technologies. It highlights how AI, GIS, Remote Sensing, drones, and Big Data can support flood forecasting, hazard mapping, emergency response, and long-term urban planning in Karachi.

Mitigation Strategies & Best Practices

Reducing urban flooding requires both structural and non-structural measures.

Structural Measures

Upgrade and expand stormwater drainage systems.

Regular desilting of nullahs before the monsoon season.

Restore natural waterways and wetlands.

Develop green infrastructure such as parks, rain gardens, and permeable pavements using the **Sponge City** concept.

Restrict construction on floodplains and natural drainage channels.

Non-Structural Measures

Strengthen urban planning regulations.

Improve municipal solid waste management.

Conduct regular public awareness campaigns.

Organize emergency preparedness drills.

Train community volunteers for flood response.

6. Risk Communication & Early Warning

Effective early warning systems can significantly reduce flood impacts.

Pakistan Meteorological Department (PMD), NDMA, and PDMA Sindh should strengthen weather forecasting and issue timely warnings through mobile phones, television, radio, and social media.

Communication should be simple, easy to understand, and accessible to everyone, including women, elderly people, persons with disabilities, and communities living in informal settlements.

Community participation should also be encouraged through local disaster management committees that can assist with evacuation and emergency communication.

7. Policy Recommendations

To improve flood management in Karachi, the following actions are recommended:

For NDMA

Develop a national framework for urban flood risk management.

Promote the use of AI, GIS, and Remote Sensing for flood forecasting.

Support climate-resilient infrastructure projects.

For PDMA Sindh

Strengthen district-level preparedness plans.

Improve coordination among provincial departments.

Conduct annual flood simulation exercises.

For Karachi Metropolitan Corporation (KMC)

Upgrade drainage systems.

Ensure regular cleaning of nullahs before monsoon seasons.

Strictly prevent illegal construction on drainage channels.

For Karachi Water and Sewerage Corporation (KWSC)

Modernize drainage infrastructure.

Improve maintenance of sewerage and stormwater systems.

For Pakistan Meteorological Department (PMD)

Expand weather radar coverage.

Improve real-time rainfall forecasting.

Strengthen flood warning dissemination

Innovation Section

Modern technology can significantly improve urban flood management.

Artificial Intelligence can predict flood-prone areas using rainfall and drainage data. GIS and Remote Sensing can produce detailed flood hazard maps for better urban planning. Drones can quickly assess flood damage and identify blocked drainage channels after heavy rainfall. IoT-based water level sensors can provide real-time monitoring of stormwater drains, while Big Data can support informed decision-making by combining weather forecasts, satellite imagery, and historical flood records.

Operational Linkage

The recommendations presented in this report directly support Pakistan's disaster management objectives.

Anticipatory Action: AI forecasting, GIS mapping, and early warning systems allow authorities to take preventive action before flooding occurs.

Preparedness: Public awareness campaigns, community training, and regular maintenance of drainage systems improve readiness.

Response: Drones, mobile alerts, and coordinated emergency operations improve rescue and relief activities.

Recovery: Accurate damage assessment supports faster rehabilitation and resource allocation.

Resilience Building: Sustainable urban planning, green infrastructure, and climate adaptation reduce long-term flood risks

8. Conclusion

Urban flooding in Karachi is not only caused by heavy rainfall but also by rapid urbanization, weak infrastructure, poor waste management, and the growing impacts of climate change. Addressing these challenges requires coordinated efforts from government institutions, local communities, and the private sector.

Investing in resilient infrastructure, enforcing urban planning regulations, improving drainage systems, and adopting modern technologies can significantly reduce future flood risks. By combining scientific knowledge, community participation, and effective governance, Karachi can become a safer and more climate-resilient city.

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STUDENT RESEARCH PAPER

Satellite-Based Earth Observation for Disaster Monitoring and Damage Assessment

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1. Concept and Context

Satellite-based Earth Observation (EO) has emerged as one of the most powerful tools in modern disaster management. Pakistan faces multi-hazard threats — riverine and flash floods, earthquakes, cyclones, and wildfires — that demand wide-area, near-real-time situational awareness far beyond what ground teams alone can provide. This research examines how space-borne sensors, specifically Optical, Synthetic Aperture Radar (SAR), and Thermal imagery, can be systematically integrated into Pakistan's disaster management cycle, from early warning through damage assessment to recovery monitoring.

A globally operational fleet of 300+ Earth Observation satellites now delivers continuous temporal coverage, province-scale spatial footprints, and all-weather, day-night imaging via SAR. A typical disaster response draws on approximately 45% optical, 40% SAR, and 15% thermal data, processed through tools such as Google Earth Engine, Python (rasterio, geopandas), QGIS, and automated change-detection algorithms. NDMA's GCOP and NCOP portals already host over 8,000 live geospatial layers, providing an institutional foundation on which expanded EO capabilities can be built.

The 2022 Pakistan floods serve as the primary applied case study. NDMA leveraged Sentinel-1 radar imagery to map standing water across Sindh, Balochistan, and southern Punjab under heavy monsoon cloud cover — producing inundation extents within days rather than weeks. This directly supported relief planning for 33 million affected people at a point when an estimated one-third of Pakistan's landmass was underwater. The case illustrates both the proven value and the current ceiling of EO integration in Pakistan's disaster response architecture.

2. Research Gaps and Novelty Areas Identified

Despite demonstrated value, four critical gaps constrain the operational effectiveness of satellite EO in Pakistan's disaster management context:

Revisit Time Constraints: Most public satellites revisit the same area every 5–16 days. In fast-evolving events such as flash floods or landslides, this latency can render imagery operationally irrelevant before it is received. Pakistan lacks systematic access to high-revisit commercial constellations.

Data Processing Bottlenecks: The volume of EO data generated during major disasters exceeds current in-house processing capacity. Workflows remain largely manual, delaying actionable outputs. Automated machine learning pipelines for near-real-time change detection are underdeveloped institutionally.

Ground Validation Deficits: EO-derived damage maps must be verified against field reports for operational reliability. The accuracy gap is largest in remote or inaccessible areas — precisely where satellite data is most critical and ground teams are slowest to arrive.

Cost and Access Barriers: Sub-1m very-high-resolution commercial imagery, required for building-level damage assessment, remains expensive and procured ad hoc. Free public missions (Sentinel, Landsat) partially substitute but do not cover all operational needs.

The principal novelty identified is the integration of deep learning models — specifically convolutional neural networks and semantic segmentation architectures (e.g., U-Net) — with multi-temporal SAR and optical image stacks to automate the generation of classified damage maps in near real time. This approach would shift NDMA's EO capability from expert-dependent descriptive analysis to scalable, near-instantaneous machine-assisted assessment, and represents a largely underexplored frontier within Pakistan's institutional context.

3. Policy Recommendations

For NDMA:

• Establish a dedicated Satellite Intelligence Cell within NDMA's Geospatial Unit, mandated to activate EO tasking within six hours of a declared emergency, with pre-cleared data access agreements in place.

• Negotiate standing emergency imagery access with the Copernicus Emergency Management Service (CEMS), UNOSAT, and Planet Labs to ensure sub-daily revisit coverage during national disasters — eliminating dependence on ad hoc humanitarian requests.

• Integrate AI-based change detection pipelines into GCOP/NCOP portals for automated, near-real-time flood extent mapping and structural damage classification.

For PDMAs and District Administrations:

• Train provincial and district focal persons to interpret and operationalize satellite-derived damage maps, embedding EO outputs into Standard Operating Procedures (SOPs) for resource pre-positioning and relief deployment.

• Establish structured field verification feedback loops — ground reports returned to NDMA's geospatial teams — to continuously improve model accuracy and build confidence in EO-derived products.

For Federal Ministries (MoCC, MoS&T, NCC):

• Develop a National Earth Observation Strategy under the Space Programme earmarking EO capacity specifically for disaster risk reduction, aligned with Pakistan's Sendai Framework commitments and National DRR Policy 2013.

• Facilitate Pakistan's formal onboarding to CEMS on a standing basis, enabling rapid EO activation as a treaty-level entitlement rather than a one-off humanitarian request.

4. Innovative Approaches and Emerging Technologies

AI and Machine Learning: Deploy semantic segmentation models (U-Net, DeepLabV3+) trained on Pakistan-specific multi-hazard satellite datasets to automatically classify flood inundation, collapsed structures, and burn scars. This reduces time-to-damage-map from 2–3 days to under four hours with minimal analyst intervention.

InSAR for Earthquake Response: Interferometric SAR (InSAR) coherence analysis enables detection of ground deformation and surface displacement within hours of a seismic event, supporting rapid impact zoning before field teams can safely access the affected area.

UAV Integration for Last-Mile Validation: Autonomous UAVs deployed within hours of an event can acquire sub-decimeter imagery for building-level damage classification, bridging the resolution gap between satellite observation and human ground assessment — particularly in areas inaccessible to response teams.

Cloud-Based Big Data Processing: Migrating EO workflows to cloud platforms (Google Earth Engine, AWS, Azure Planetary Computer) enables parallel processing of large image stacks, making province-scale flood mapping achievable in under four hours using open-source toolchains within Pakistan's current technical reach.

Digital Twin and Predictive Modelling: Linking satellite-derived DEMs and land-cover layers with national hydrological models (e.g., FFEWS) enables predictive inundation scenario modelling 48–72 hours ahead of peak flood events — the foundational step toward anticipatory action rather than reactive response.

5. Operational Linkage to Disaster Management Framework

The findings directly support all phases of Pakistan's disaster management cycle under the National Disaster Management Act 2010 and the DRR Policy:

Preparedness: Baseline EO mapping of flood-prone zones, seismic fault proximity areas, and wildfire-risk landscapes enables evidence-based pre-positioning of resources and community-level evacuation planning ahead of seasonal hazard windows.

Anticipatory Action: Cloud-processed satellite data integrated into FFEWS and NCOP enables district administrations to trigger pre-emptive evacuation orders and release contingency funds hours before peak flood arrival, shifting the paradigm from reactive to anticipatory.

Response: Near-real-time EO damage maps reduce multi-hazard situational assessment from weeks to days, allowing NDMA and PDMAs to prioritize relief to the most severely affected union councils with empirical precision.

Recovery: Multi-temporal EO tracks structural repair progress, agricultural recovery, and displacement patterns over months, providing the evidence base for donor reporting, recovery planning, and equitable resource allocation.

Resilience-Building: Long-term systematic EO monitoring of expanding flood plains, deforested hillslopes, growing urban heat islands, and glacial dynamics provides the empirical foundation for climate-sensitive land-use planning and long-term DRR investment by federal and provincial governments.

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Batch Photograph

List of Course Participants C2DM P-07/26 Assigned Topic

S. No	Student Name	Research Topic
1	Abdul Ghani Shaikh	Germany Flood (2021) Regional Hazard Profile, Vulnerability Assessment and Early Warning System Reform
2	Ahmad Faraz	Climate Change Impacts on Food Security and Agricultural Systems in Pakistan
3	Aqsa Batool	Anticipatory Action for Heatwaves in Pakistan: Current Interventions and Future Enhancements
4	Atiqa Hashmi	Climate Change Impacts on Food Security and Agricultural Systems: A Pakistan Perspective
5	Attiya Batool	Climate Change Impacts on Food Security and Agricultural Systems
6	Gatluak Ngueny Tot	Climate Change as the Driver of Key Disasters Hazard Profile and Climate Risk Analysis of Jonglei State
7	Hafsa Faizan	Industrial and Technological Disasters Triggered by Natural Disasters (NaTech Disasters)
8	Ifrah Mubushar	Flash Floods and Landslides in Mountainous Regions
9	Joseph Kamau Gitau	The Role of Local Governments in Strengthening Disaster Risk Reduction
10	Khlieeq Ul Zaman	Ecological Risk Assessment of Human-Impacted Coastal Zones: A Framework for the Karachi Coast, Pakistan
11	Khuda Bakhsh	Comparative Analysis of GLOF Management in Pakistan, Nepal, and Bhutan
12	Laiba Hameed	Climate-Disaster Supply Chain Resilience in Pakistan: Vulnerabilities, Community Resilience, and Policy Pathways for Flood-Prone Supply Chains
13	Laiba Shehzadi	Development of the Dynamic Readiness Assessment and Resource Optimization Framework (DRAROF): A System Dynamics Approach for Relief Warehouse Readiness and Resource Allocation in NDMA Pakistan
14	Maha Haroon	Anticipatory Action for Urban Flood Risk Management in Karachi
15	Maham Asif	Earth Observation for Disaster Monitoring & Damage Assessment
16	Mahreen Abro	Internet of Things (IoT)-Based Systems for Disaster Monitoring and Early Warning
17	Mudessar Iqbal	Germany Floods (2021): Early Warning System and Public Response Analysis
18	Muhammad Baqir	Japan's Earthquake Preparedness Model: Best Practices for Developing Countries
19	Nimrah Nasir	Flash Flood Hazards in Mountainous Regions: Risk Assessment and Mitigation
20	Sana Baloch	Urban Flooding in Karachi: An Analysis of Causes, Structural Impacts, and Sustainable Mitigation Solutions
21	Syed Imtenan Raza	Satellite-Based Earth Observation for Disaster Monitoring and Damage Assessment