



CLIMATE RISK AND VULNERABILITY ASSESSMENT OF PAKISTAN

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Pakistan is among the countries most vulnerable to the potential impacts of climate change. The country's complex geography, ranging from coastal plains and fertile riverine basins to arid deserts and glacier-fed high mountains, when combined with deep socioeconomic inadequacies, makes it a mosaic of exposure and vulnerabilities in which climate risks are amplified. Over the last two decades, Pakistan has witnessed an increase in the level of floods, heatwaves, droughts, GLOFs and coastal hazards. Understanding Pakistan's vulnerability to climate-related hazards requires an understanding of physical hazard with drivers and dynamics, differential exposure of people and assets, underlying socioeconomic vulnerabilities and evidence-based tools (risk mapping and modeling) used to translate those elements into actionable risk information to ensure planning and adaptation.

HAZARD DRIVERS AND CLIMATIC TRENDS

Situated at the juncture of various physical drivers that amplify climate risks, Pakistan receives most of its summer rainfall from a highly variable and erratic South Asian monsoon. This leads to flashier, more intense rainfall events when storms do occur and longer dry spells between them. At the same time, rising temperatures increase the capacity of the atmosphere to hold moisture, which further intensifies extreme precipitation. The high HKH region faces unprecedented heat and warming, which is accelerating glacier melt and may increase the natural hazards of glacial lake formation and sudden breaches, generating floods downstream. On one end, sea level rise and storm surges threaten

the low-lying Indus delta and urbanized coastal zones, including Sindh and southern Balochistan; on the other end, the arid south and sections of central Pakistan face worsening heatwaves and droughts. Overall, such climatic shifts are in line with global and regional assessments that show South Asia as a climate hotspot for high exposure to temperature rise, extreme rainfall, and sea-level change.

Exposures to climate hazards are large and varied in Pakistan. The Indus River system forms the agricultural heartland of the country; major floods in the Indus basin threaten life, crops, infrastructure, and industry. Urbanization is often unplanned and focuses on floodplains, low-lying peri-urban zones, and informal settlements, amplifying exposure to vulnerable populations via both riverine and urban flash flooding. Populations along the coastline in Sindh and southern Balochistan are exposed to sea-level rise, saltwater intrusion, and cyclonic storm surges that damage housing, fisheries, and livelihoods. Rural and mountainous communities in the north face living downstream of glaciers and steep mountain slopes at risk from landslides and GLOFs. Infrastructure has been built or lies within many multi-hazard corridors: roads, bridges, irrigation canals, power grids, and communication lines that keep getting destroyed and raise the costs of recovery while undermining long-term development. The concentration of assets and people in hazard-prone corridors multiplies systemic risk when a shock cascades across multiple systems.

SENSITIVITY AND ADAPTIVE CAPACITY

Sensitivity refers to the degree to which a system is affected by climate stimuli; adaptive capacity is the ability to adjust, cope, and recover. Pakistan exhibits high sensitivity in key sectors, which include agriculture, highly dependent on seasonal water flows and natural irrigation; water resources, where the Indus system and glacier melt are central; and public health, regarding heat stress and vector-borne diseases. Adaptive capacity is uneven: some urban centers and national agencies have technical capacities and resources, while rural smallholders, informal settlements, marginalized social groups, and many local governments lack finance, technology, and institutional reach. Coupled with poverty, food insecurity, gender inequities and limited social safety nets, the current

situation deepens sensitivity and constrains the ability to adapt, thereby increasing vulnerability to climatic shocks that could easily lead to long-term losses. International analyses and country profiles consistently emphasize how Pakistan has disproportionate vulnerability relative to its low contribution to global greenhouse gas emissions.

MAJOR CLIMATE IMPACTS

Pakistan's climate vulnerability cuts across multiple, interconnected sectors, with significant implications for national resilience and sustainable development. Retreating northern glaciers have perturbed seasonal river flows, first caused increased runoff and flood risk but eventually portended long-term summer water unavailability. Intensified monsoon patterns and prolonged dry spells increase flood and drought risks, putting a strain on irrigation systems, hydropower generation, and water governance in the face of growing competition among agricultural, domestic, and industrial users. Highly sensitive to climate variability, the agriculture sector is taking hits in productivity as heat stress shortens crop cycles, erratic rainfall and floods damage fields and erode soils, while sea-level rise pushes salinization on coastal lands. Smallholder farmers, having no access to irrigation, credit, or climate information, are highly vulnerable to income and food insecurity. Human health is increasingly at risk due to more frequent and intense heatwaves, which heighten mortality and disease burdens, while floods spread waterborne diseases and disrupt healthcare delivery. The expansion of vector habitats further exacerbates the risks of diseases such as dengue and malaria. Critical infrastructure and urban systems continue to suffer recurring damage from floods and landslides that destroy roads, bridges, and power lines; poor urban drainage brings along lengthy flooding and service disruptions, especially in remote or mountainous areas, where access and repair are hard. Meanwhile, Pakistan's ecosystems and biodiversity are deteriorating due to the erosion of coastal mangroves, inland saltwater intrusion, and degradation of mountain forests and pastures, weakening natural buffers formerly moderating floods, droughts, and soil erosion. This cumulative ecosystem decline diminishes the nation's adaptive capacity and multiplies the social and economic toll of climate extremes. Taken together, these pressures outline a complex web of vulnerabilities, demanding integrated, cross-sectoral responses that combine improved water governance, climate-smart

agriculture, resilient infrastructure, strengthened health systems, and ecosystem restoration to secure Pakistan's future in an era of accelerated climate change.

RISK MAPPING: METHODS, DATASETS AND PRODUCTS

Climate risk mapping translates hazard, exposure, and vulnerability data into spatially explicit depictions of risk to inform planning and investments. Core components and methods used in Pakistan include:

Hazard mapping: Historical observations, meteorological reanalysis, and climate model outputs (CMIP6 projections) are considered for characterizing extremes, such as 1-in-100-year river discharge, extreme rainfall intensity, and temperature exceedances, while long-term trends include temperature increases and sea-level rise. Glacier and mountain hazards involve remote sensing-satellite imagery and DEMs, and field surveys focused on mapping glacier extents, moraine dams, and glacial lakes to identify sources that could give rise to GLOFs.

Exposure datasets: population grids, land use/land cover, infrastructure layers including roads, power lines, and hospitals, agricultural areas, in conjunction with economic asset valuations, are combined with the hazard footprint to estimate who and what is exposed.

Vulnerability and sensitivity layers include the spatialization of socio-economic indicators relating to poverty, age structure, and types of housing; sectoral sensitivities on crop types and irrigation dependence; and institutional capacities that define the presence of local disaster management committees and access to early warning.

Integrated risk models: The overlay of hazard, exposure, and vulnerability in GIS will result in multi-hazard risk maps. Probability modeling converts hazards into expected annual damages and scenario-based losses along different warming pathways. Scenario analysis (near-term versus long-term; moderate versus high emission) supports planning over multiple horizons.

The country's agencies - NDMA and provincial DMAs - and international partners have generated

country and provincial risk profiles and hazard atlases using combinations of these methods. National initiatives aim at standardizing hazard layers - flood, landslide, GLOF, drought, cyclone - and maintaining dynamic risk maps fed by meteorological and hydrological monitoring.

CASE STUDIES

Floods: The 2010 floods affected millions and caused billion-dollar losses; 2022 again produced unprecedented inundation across the Indus basin, displacing tens of millions and damaging infrastructure and crops on a massive scale. Recent monsoon seasons have produced intense rainfall events whose severity has been attributed in attribution studies to anthropogenic warming—indicating that climate change is already amplifying Pakistan's flood hazard. The pattern is clear: when extreme rainfall intersects with vulnerable land management (deforestation, encroachment on floodplains), the scale of damage escalates.

Heatwaves: Record temperatures have expanded the frequency and intensity of heatwaves, particularly in the southern parts of Punjab and Sindh. Heatwaves reduce labor productivity, increase mortality among the elderly and infants, and add to drought stress on agriculture. The combined heat and humid conditions also test urban infrastructure and power systems against higher demand for cooling.

INSTITUTIONAL FRAMEWORKS AND EXISTING INITIATIVES

In Pakistan, a variety of policies and institutions address climate and disaster risk, including the National Climate Change Policy of 2012 and successive Nationally Determined Contributions that establish national targets for mitigation and adaptation; the National Disaster Management Authority and provincial DMAs coordinate disaster risk management and early warning; the National Institute of Disaster Management supports research and capacity building; and sectoral agencies in water, agriculture, and energy integrate climate considerations into planning. International finance and technical partners support climate risk assessments, adaptation planning, and investments in resilience, including

flood early warning systems, climate-resilient infrastructure, and community-based adaptation programs. Yet despite these efforts, financing, coordination across scales, and long-term maintenance of monitoring networks remain significant gaps.

LIMITATIONS AND CHALLENGES IN RISK MAPPING

Many regions have a lack of high-resolution, long-term hydrometeorological and glaciological data; socioeconomic and exposure datasets are often outdated or inconsistent across provinces. The institutional fragmentation means that pieces of data and responsibilities are held by multiple agencies; standardized protocols for hazard mapping and risk assessment are lacking, which restricts integrated planning and national aggregation.

The dynamic glaciers, subsidence, and shifting monsoon patterns would also need near real-time monitoring with fresher maps, which is resource-intensive. Map production is an initial task, but maintaining monitoring networks, data management platforms, and early warning dissemination systems over time requires sustained funding and institutional will.

PRIORITY ACTIONS TO STRENGTHEN VULNERABILITY REDUCTION AND RISK MAPPING

A proposed National Multi-Hazard Geospatial Platform will host hazard, exposure, and vulnerability datasets on an open-access basis for planners, researchers, and decision-makers. It should be integrative at the provincial level and updated regularly. Stronger observation networks and remote sensing, with enhanced meteorological, hydrological, and glaciological stations, will advance real-time hazard detection and forecasting. Downscaled climate projections will be developed to inform climate-resilient infrastructure and agriculture, while people-centered vulnerability mapping will integrate social factors and local knowledge. Risk maps must be mandatory in land-use planning and public investment, prioritizing decisions driven by considerations of

resilience. Robust early warning and anticipatory action systems with links to pre-approved financing, prepositioned emergency commodities will enable timely evacuations and supplies. Nature-based solutions, such as the restoration of mangroves, wet lands and watersheds, will protect with low-cost, sustainable solutions. Further capacity building and coordination among institutions and innovative, equity-based climate financing will guarantee just adaptation for vulnerable communities.

CONCLUSION

Pakistan's climate-vulnerable profile is defined by a mix of increasing physical hazards with high levels of socioeconomic exposure and sensitivity. Risk mapping, supported by robust data, multi-hazard models, and people-centered vulnerability indicators, transforms this complex scientific information into tools for practical decision-making, investment prioritization, and the mobilization of anticipatory action. Devastating floods and heat events in recent times have shown that climate change has already caused amplification of risk in the country, and therefore, bridging data, capacity, and financing gaps must be urgent priorities if the country is to transition from reactive recovery to proactive resilience. This is the way to reduce loss and build a safer, climate-resilient Pakistan: strengthening national geospatial platforms, monitoring networks, early warnings, and integrated policy frameworks while keeping the most vulnerable communities at the center.

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