Artificial Intelligence for Climate Resilience: The Case of Pakistan

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Abstract

Pakistan is among the global leaders in exposure to climate. Its integration of Artificial Intelligence (AI) into climate adaptation policy is still in its initial stages. This study initiates a systematic review of policy from 2010 to 2025 to evaluate the means by which AI can enhance national resilience to three of the most critical climate risks: floods, heatwaves, and sea-level rise. From multilateral data, peer-reviewed research, and government reports, the analysis examines Pakistan's existing policy instruments, including the National Climate Change Policy (2012; revised 2021), National Adaptation Plan (2017), and National AI Policy (2025). The analysis identifies central policy and institutional weaknesses: poor inter-agency coordination, ineffectual procurement mechanisms, weak data management, and poor financing systems. Findings show that despite the immense potential of AI in augmenting early warning systems, heatwave health triage, and coastal surveillance, and its adoption is constrained by capacity and structural reasons. An integrated 'AI-for-Resilience Framework' is suggested in the research, one that harmonises sectoral uses with cross-cutting pillars of data governance, MLOps/procurement, capacity-building, and financing. Policy proposals focus on creating a national AI–Climate Taskforce, integrating AI into upcoming climate planning, and sequencing pilot studies in high-vulnerability provinces. Integrating AI into Pakistan's climate governance has the potential to turn around reactive disaster response to proactive building of

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resilience, bringing quantifiable gains in forecasting precision, institutional effectiveness, and community safeguarding.

Keywords: Artificial Intelligence, Climate Resilience, Policy Review, Pakistan, Climate Adaptation.

Introduction

Pakistan contributes less than one percent of global greenhouse gas emissions, yet it remains among the most climate-vulnerable countries in the world.[1] In the past two decades, the country has experienced more than 80 significant climate-induced disasters, including catastrophic floods, recurrent heatwaves, and accelerated coastal erosion.[2] The 2010 floods affected over 20 million people, while the 2022 floods displaced nearly 8 million individuals and caused economic damages exceeding US$30 billion.[3] Heatwaves, such as in Karachi in 2015, which resulted in more than 1,200 fatalities, demonstrate the acute vulnerability of urban centres with limited adaptive capacity.[4] Coastal communities in Karachi, Keti Bunder, and Gwadar face growing risks from relative sea-level rise, intensified by land subsidence in the Indus Delta.[5]

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[1] Lina Adil, David Eckstein, Vera Künzel, and Laura Schäfer, *Climate Risk Index 2025: Who Suffers Most from Extreme Weather Events?* (Bonn: Germanwatch e.V., February 12, 2025).

[2] National Disaster Management Authority (NDMA), *Annual Report 2022* (Islamabad: Government of Pakistan, 2022).

[3] Government of Pakistan, Asian Development Bank (ADB), European Union (EU), United Nations (UN), and World Bank, *Pakistan Floods 2022: Post-Disaster Needs Assessment (PDNA) Main Report* (Islamabad: Government of Pakistan, 2022).

[4] Muhammad Ali Lakhan, Ambreen Afzal, Samreen Riaz Ahmed, and Altaf Hussain Lahori, "*Assessment of Karachi as an Urban Heat Island Threat through Remote Sensing and GIS Techniques*," *Proceedings of the Pakistan Academy of Sciences: B. Life and Environmental Sciences* 60, no. 3 (August 2023), https://doi.org/10.53560/PPASB(60-3)848

[5] Space & Upper Atmosphere Research Commission (SUPARCO), "Home," *Space & Upper Atmosphere Research Commission (SUPARCO)*, accessed September 2, 2025, https://suparco.gov.pk/

Pakistan's policy documents, i.e., the National Climate Change Policy[6] (NCCP) and the National Adaptation Plan (NAP), recognise these increasing climate threats but yet fall short of systematic incorporation of digital as well as analytical means, especially Artificial Intelligence (AI). This deficit reveals underlying institutional problems, i.e., a broken data framework, inadequate technical capacity, and provincial-federal coordination failures, that hinder evidence-informed decision-making. Vulnerabilities are of the same kind. AI proves effective at forecasting floods, modelling heat wave impacts, and monitoring coastal erosion, demonstrating its promise as an anticipatory governance device. For Pakistan, the adoption of such technologies has the potential to transform climate resilience from a crisis management system with a predominantly post-disaster response focus to a forward-looking system that perceives, prepares, and responds to the threats before they accumulate. Yet, these possibilities are not actualised in the climate governing apparatus of Pakistan.

This paper uses a systematic review policy analysis framework in examining the role of AI in the climate resilience framework of Pakistan. This paper is a critical analysis of policy pronouncements, institutional records, and multilateral data between 2010 and 2025, in which the question of how national policies are responding to floods, heatwaves, and sea-level rise is addressed. Based on comparative policy mapping and thematic analysis, the study identifies areas of governance gaps, institutional constraints, and windows of opportunity to integrate AI. This review-based strategy enables the structured synthesis of existing evidence as opposed to primary data collection, making the paper a complete policy analysis that links technological innovation with practical adaptation

[6] Government of Pakistan, Ministry of Climate Change and Environmental Coordination, *Final updated and revised National Climate Change Policy 2021* (Islamabad: Ministry of Climate Change and Environmental Coordination, March 18, 2022), accessed September 2, 2025, https://mocc.gov.pk/SiteImage/Policy/NCCP%202021.pdf

Despite a proliferation of climate adaptation documents, little empirical analysis exists on *how* AI can be operationalised within Pakistan's climate governance framework. Existing research focuses primarily on physical adaptation and financing, with minimal attention to data-driven decision-making or AI-enabled systems by the help of data identification, screening (inclusion and exclusion) and manual thematic analysis.

Table 1. Summary of Methodological Design

Stage	Description	Output
Dataset Identification	Screening of national and multilateral documents (2010–2025)	52 documents shortlisted
Inclusion & Exclusion	Applied policy relevance and data quality criteria	Pakistan-specific, AI-related sources retained
Thematic Coding	Grounded theory–based manual coding	Four major themes: Data governance, procurement, funding, capacity

Source: *Developed by Authors*

Climate Change Risks in Pakistan

Floods, heatwaves, and sea level rise are three climate threats facing Pakistan that are deeply linked in terms of their impacts or potential effects on the policy. Such risks have increased in terms of frequency and intensity since 2010, placing a lot of burden on communities, infrastructures, and institutions of governance.

Floods

The 2010 floods in Pakistan were one of the worst, impacting close to 20 million people and destroying livelihoods by razing crops covering 17 million acres of cultivable land. The floods not only disturbed agricultural production but also destroyed vital infrastructure, such as thousands of schools, hospitals, and road transport systems.[7] Earlier, in 2022, the floods

[7] Asian Development Bank, *Pakistan Floods 2010: Preliminary Damage and Needs Assessment*, 2010, 2, 12–13.

were even more devastating in terms of scale, flooding nearly a third of the country's land, displacing over 8 million people, and causing economic damages that totalled more than US$30 billion.[8] Such regular disasters underscore the structural vulnerability of Pakistan's society and economy to hydrological shocks. They also remind us that unless there is a consistent investment in early warning mechanisms, adaptive governance, and resilient infrastructure, then these disasters will keep demolishing decades of development gains within weeks.

The drivers of these floods are complex and multi-layered. Pakistan faces erratic monsoons, accelerated glacial melt in the Himalaya–Karakoram–Hindukush ranges, and weak water management practices, all of which converge to amplify flood risks. With more than 7,000 glaciers, the country is exceptionally vulnerable to Glacial Lake Outburst Floods (GLOFs), which can unleash sudden and destructive surges of water downstream.[9] However, accurate classification of hazards remains a challenge in risk governance. For instance, the creation of Attabad Lake in 2010 was initially conflated with a GLOF, but in reality, it was a landslide-dammed lake, formed when a massive landslide blocked the Hunza River.[10] Misclassification of such events can lead to flawed planning, misallocation of resources, and ineffective disaster preparedness. Developing a clearer and more context-specific understanding of different hydrological hazards, such as distinguishing Glacial Lake Outburst Floods (GLOFs) from riverine flooding and landslide-dammed lake incidents, is essential for improving the accuracy of risk mapping and the effectiveness of adaptation planning. This clarity also allows policymakers and disaster managers to rank early warning tools as priorities and assign resources better, particularly when integrating monitoring systems supported by AI.

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[8] Government of Pakistan et al., *Pakistan Floods 2022: PDNA.*

[9] "Why is Pakistan so vulnerable to deadly flooding?", *Al Jazeera*, July 17, 2025. https://www.aljazeera.com/news/2025/7/17/why-is-pakistan-so-vulnerable-to-deadly-flooding

[10] NDMA, *Annual Report 2022.*

Table 2. Major Floods in Pakistan: 2010 vs 2022[11]

Indicator	2010 Flood	2022 Flood
Number of deaths	~1,980	~1,739
Population affected (million)	~20	~33
Displaced population (million)	~7.5	~7.8
Houses damaged or destroyed (millions)	~1.6	~2.1
Economic damage & loss (billion USD)	~10	~30

Source: *Developed by Authors*

Table 2 shows that the 2022 floods resulted in slightly fewer fatalities than the 2010 floods, but they impacted many more people, displaced many more individuals, destroyed more homes, and caused nearly three times greater economic losses, both indicating enhanced emergency response as well as increasing climate-induced vulnerabilities.

Heatwaves

Over the past three decades, Pakistan has witnessed a nearly fivefold increase in the frequency of heatwaves, signaling an alarming trend in climate extremes.[12] Cities such as Jacobabad, which recorded a staggering 51°C in 2022, are now ranked among the hottest inhabited places on Earth.[13] The scale of risk became tragically evident during the 2015 Karachi

[11] Data and insights are adapted from *Addressing Foundational Issues for Effective Flood Risk Governance in Pakistan, Water Policy*, IWA Publishing, 2025, https://iwaponline.com/wp/article/doi/10.2166/wp.2025.236/107138; *Pakistan's 2022 Floods: Climate Extremes and Compounding Vulnerabilities*, *Earth's Future*, AGU Publications, 2022, https://agupubs.onlinelibrary.wiley.com/doi/10.1029/2022EF003230

[12] Government of Pakistan, Pakistan Meteorological Department, Climate Data Processing Centre, *State of Pakistan's Climate in 2022* (Karachi: Pakistan Meteorological Department, February 24, 2023), accessed September 2, 2025, https://cdpc.pmd.gov.pk/Pakistan_Climate_2022.pdf

[13] "The unforgiving heat," *The Express Tribune*, June 23 2024, https://tribune.com.pk/story/2473159/the-unforgiving-heat.

heatwave, which claimed more than 1,200 lives within a matter of days.[14] Fatality rates were provoked not only by the extreme temperatures but also by compounding factors such as prolonged electricity outages, insufficient water availability, and weak ambulance response systems.[15] Such events expose the intersection of climatic stress with systemic governance weaknesses, where insufficient investment in emergency response infrastructure amplifies the human toll. Without proactive adaptation measures, heatwaves will continue to translate into recurrent public health disasters that strain both hospitals and communities.

The further deterioration of the natural dangers is also caused by the urban heat island (UHI) effect in the fast-growing urban centres like Karachi, Lahore, and Islamabad. Shallow vegetation cover, construction of buildings with concrete, and the growing motor emissions create microclimates that are several degrees warmer than the surrounding countryside habitat. This does not only expose them to heat related diseases, but it also leads to extreme shortages of energy, because the air conditioning requirement is the highest during hot summer seasons. Existence of increasing base-level temperatures and UHI processes implies that millions of urban dwellers are likely to be subjected to high conditions with higher frequencies that exceed the human tolerance range.[16] The problem is not restricted to direct mortality but has implications such as straining health systems in the long term, reduced productivity of workers, and energy grid interruptions. The design of green infrastructure and buildings that are resistant to climate change, as well as digital innovations that can make cities more prepared, should be combined into a multi-pronged approach to addressing the challenge of such issues. AI tools, in particular, can assist health services

[14] Mansoor Khan, "Deaths 1,200 as Karachi Wilts Under Heat," *The Nation*, June 24, 2015.
[15] Adil et al., *Climate Risk Index 2025.*
[16] Muhammad Ali Lakhan et al., "Assessment of Karachi as an Urban Heat Island Threat through Remote Sensing and GIS Techniques," *Proceedings of the Pakistan Academy of Sciences: B. Life and Environmental Sciences* 60, no. 3 (2023): 463–475, https://doi.org/10.53560/PPASB(60-3)848.

and energy managers in anticipating and mitigating the impacts of severe heatwaves.

Table 3: Reported heatwave deaths/impact[17]

Year	Location/scope	Reported heatwave deaths/impact (summary)
2015	Karachi / Sindh	**~700+ deaths** during the June 2015 heatwave; extreme temperatures, power outages and overwhelmed hospitals.
2018	Karachi	**~65 deaths** reported during a short May 2018 heat episode in Karachi (media reported additional unconfirmed casualties).
2022	Pakistan (region)	Severe early-spring heat affecting Pakistan & India; **extreme temperatures recorded (e.g., >49°C in parts of Sindh)**; attribution studies highlight climate change influence (mortality counts not centrally compiled).
2023	Pakistan	Heat events with **dozens of reported deaths / hundreds of heat-related hospitalisations** in various months (media & health briefs).
2024	Karachi / Sindh	Reports from rescue/NGO services (Edhi) documented a surge of **hundreds of deaths received by mortuaries** during late-June 2024 heat events; official counts and attribution debates follow.

[17] Data compiled from multiple sources: BBC, "Pakistan Heatwave: Death Toll Crosses 800 People in Sindh," June 23, 2015, https://www.bbc.com/news/world-asia-33236067; Patrick Wintour, "Death Toll Climbs in Karachi Heatwave," *The Guardian*, May 22, 2018, https://www.theguardian.com/world/2018/may/22/death-toll-climbs-in-karachi-heatwave; World Weather Attribution, *Attribution of the March–April 2022 Heatwave in India and Pakistan* (May 2022), https://www.worldweatherattribution.org/wp-content/uploads/India_Pak-Heatwave-scientific-report.pdf; Associated Press, "Hundreds of People Suffer Heatstroke in Pakistan" (2023); Bloomberg, "Karachi Sees a Surge in Deaths as Heat Wave Sears Pakistan," June 27, 2024, https://www.bloomberg.com/news/articles/2024-06-27/karachi-sees-a-surge-in-deaths-as-heat-wave-sears-pakistan; and Pakistan Meteorological Department (PMD), *State of Pakistan Climate in 2022*, https://www.pmd.gov.pk/report_rnd.pdf.

—	Trend (PMD analysis)	**Positive trend in heatwave frequency** over recent decades reported by PMD analyses (increases in frequency and severity in southern Pakistan).

Source: *Developed by Authors*

Table 3 indicates a rising trend of heatwaves in Pakistan, with severe mortality in 2015 and recurring events through 2024, causing hundreds of deaths and hospitalizations. The data highlights increasing frequency and intensity, especially in southern regions, posing serious public health risks.

Sea-Level Rise

Relative sea-level increase along Pakistan's coastal areas has emerged as a rapidly intensifying threat, with Karachi and the Indus Delta witnessing an annual increase of 3.6-4.2 mm, higher than the global rate due to combined land subsidence pressures and over-drafting of groundwater. [18] This process speeds up shoreline erosion, pushes saltwater into agricultural fields, and erodes the natural protective function of mangroves, already critically declining. Societies and communities in Keti Bunder, Badin, and other deltaic societies experience repeated crop failure and displacement, eroding household livelihoods, and exacerbating rural–urban migration.[19] Concurrently, the urban fabric of Karachi is subjected to further strain as saline intrusion pose a risk to aquifer quality and increasing seas put Port Qasim's industrial complex, which has considerable input in national trade, at risk.[20] These trends together show how climate-driven coastal changes

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[18] SUPARCO, "Home," *Space & Upper Atmosphere Research Commission.*

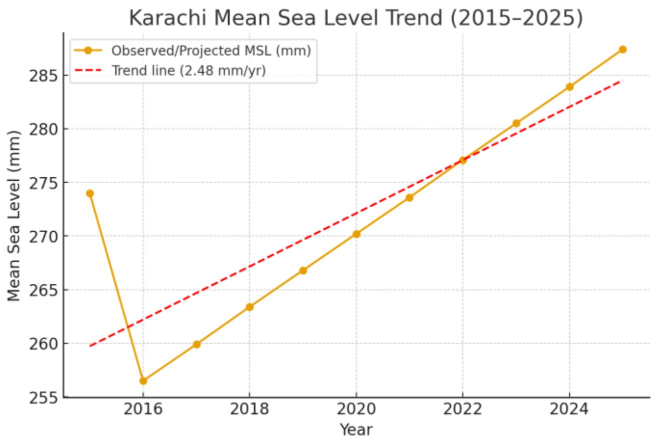
[19] J. H. Weeks et al., *Sea-Level Rise in Pakistan: Recommendations for Strengthening Evidence-Based Coastal Decision-Making* (2023), 7–10; see discussion of saltwater intrusion, aquifer contamination, and coastal land degradation.

[20] Shoaib A. Jagirani, Subhash Guriro, and Muhammad Kamil Lakho, "Economic Effects of Seawater Intrusion on Life of Coastal Communities in Sindh Region of Pakistan," *Global Social Sciences Review* VI, no. I (2021): 448–452; also see "KARACHI: Keti Bunder facing sea intrusion," *Dawn*, June 19, 2008 (Keti Bunder land loss).

can directly compromise food security, water supply, and economic productivity in Pakistan's most heavily populated province.

While these risks are known to be significant, current adaptation policy in Pakistan is still centered mostly on conventional infrastructure responses, including construction of embankments, drainage enhancement, and physical asset rehabilitation, as opposed to the institutionalised application of digital monitoring or AI-driven decision-support systems. While national and provincial climate plans recognise sea-level rise, they rarely include sophisticated forecasting and decision-support systems that may offer dynamic early warnings or simulate potential coastal vulnerabilities under alternative climate futures. Lack of such systems restricts policymakers' capacity to rank order interventions, e.g., targeted restoration of mangroves, enforcement of coastal zoning, or protection infrastructure improvements. Besides, in the absence of AI-monitored platforms, the health system is unprepared to respond to disease outbreaks caused by saline water contamination, and local governments cannot predict the forces of displacement. By introducing AI-based modeling and predictive analytics in coastal management, Pakistan would be able to transition its approach to the responsive reply instead of the proactive risk governance to guarantee that the adaptation strategies are able to protect communities and major economic resources.

Figure 1: Karachi Mean Sea Level trend (2015–2025) Plot[21]



Source: *Developed by Authors*

Figure 1 displays a gradual increase in the average sea level of Karachi between 2015 and 2025, and the overall tendency of rise is about 2.48 mm in a year. Despite the fact that temporal inconstancy is well established, the steady increase indicates that the dangers of coastal flooding, erosion, and saltwater intrusion extend and thus, the proactive adaptation measures of the coastline are urgent.

Floods and AI Applications

Flooding is the most sporadic and detrimental weather threat to Pakistan. AI technology has immense potential to enhance forecasting, emergency management, and long-term water planning by examining large and varied sets of data, e.g., precipitation trends, river flow levels, and glacial melt rates in real time to produce more timely and precise predictions.

[21] Based on Karachi tide gauge data from the Permanent Service for Mean Sea Level (Station 204, 1916–2016) PSMSL, with extensions by the author's regression to 2025. Note: Karachi record has known data gaps and datum shifts (e.g. gauge relocation) that may affect trend reliability.

Early Warning and Forecasting

AI-enabled hydrological models can improve flood forecast lead times by 6–12 hours over conventional methods.[22] Combining rainfall observations, river gauge measurements, and glacial melt patterns with machine learning techniques offers more precise forecasts. Deep learning on Indus Basin flow data records could enhance real-time flood warning systems in Punjab and Sindh, for example.[23]

IoT and Remote Sensing

IoT sensors installed near rivers and reservoirs, connected to AI platforms, can deliver dynamic, location-based flood risk assessments. Space and Upper Atmosphere Research Commission's (SUPARCO) satellite data, when integrated with AI-driven image classification, can delineate inundated regions at more than 85% accuracy.[24] This would assist National Disaster Management Authority (NDMA) in prioritising evacuation areas and relief planning.

Reservoir Management

WAPDA's existing reservoir operation logs (e.g., Tarbela and Mangla) can be optimised with AI-driven decision-support models that balance water storage for hydropower against flood discharge. Case studies from China's Yangtze Basin demonstrate that AI-optimised operations reduced downstream flood risk by nearly 20%.[25] A similar approach could be adapted for Pakistan.

[22] Pakistan Meteorological Department, *State of Pakistan's Climate in 2022*.

[23] Mehran Khan, Afed Ullah Khan, Basir Ullah, and Sunaid Khan, "Developing a Machine Learning-Based Flood Risk Prediction Model for the Indus Basin in Pakistan," *Water Practice & Technology* 19, no. 6 (2024): 2213-2225.

[24] Space & Upper Atmosphere Research Commission (SUPARCO), "Home," *Space & Upper Atmosphere Research Commission.*

[25] X. Li, Y. Zhang, and H. Chen, "AI-Based Reservoir Operation for Flood Risk Reduction in the Yangtze River Basin," *Water Resources Management* 34, no. 11 (2020): 3415–30, https://doi.org/10.1007/s11269-020-02611-3

Urban Flooding

Rapid urbanisation has intensified drainage failures in Karachi and Lahore.[26] AI-powered smart drainage systems, using sensors and predictive analytics, can automatically redirect excess water to reduce urban inundation. Integration with municipal infrastructure would strengthen city-level resilience.

Policy Relevance

Establishment of AI-based flood forecasting as part of NDMA's disaster management scheme requires a harmonised approach with coordination and sustainability. First, proper inter-agency information sharing between the Pakistan Meteorological Department (PMD), Water and Power Development Authority (WAPDA), SUPARCO, and provincial governments is indispensable to create interoperable data sets that enhance AI models to be precise. Equally important are transparent procurement guidelines for AI systems with explicit provisions for auditing performance in a manner that makes them accountable and trustworthy. Finally, the long-term efficacy of these systems depends on dedicated funding for establishing and sustaining sensor networks and on ensuring regular model update and maintenance.

Proposed KPIs for Flood AI Systems

AI-based flood management performance matrix would include the reduction in lead-time prediction (hours), decrease in false-alarm rate (percentage), the increase in the precision-recall measure of inundation mapping (percentage), and the increase in the efficiency of reservoir management through the reduction in the downstream flood volume. Through institutionalisation of these applications within the disaster management system of Pakistan, the nation can shift towards proactive risk mitigation of reactive relief, which will result in reduced human

[26] "Urban sprawl strains city's aging drainage system," *The Express Tribune*, December 11, 2024; S. Akhtar and M. R. Dhanani, "Surface Water Drainage and Flooding in Karachi City," *Sindh University Research Journal (Science Series)* 44, no. 1 (2012).

displacement and limitation of the scope of economic detriment of future floods.

Heatwaves and AI Applications

Among the most lethal and least organised hazards in the domain of climate are heatwaves in Pakistan. Poor urban planning, power supply shortage, and low standards of preparation of the health system are even worse contributors to their effects.

Health System Preparedness

Together with health statistics, AI can be used to predict medical surges during heat waves based on meteorological predictions. Indicatively, in Karachi, where PMD temperature predictions and ambulance dispatches, and hospitalisation data were combined, AI algorithms could predict the volume of patients daily with a Mean Absolute Error (MAE) of less than 5%. These tools may be deployed to include the distribution of resources as seen in the deployment of ambulances, cooling centres, and surge staffing in the hospitals.[27]

Early Warning and Public Outreach

AI-based predictive models can give targeted warnings for vulnerable populations like outdoor workers, the elderly, and residents in slums. Mobile-based early warning systems, supported by AI triage, could disseminate risk-specific advice, for example, directing high-risk individuals to nearby cooling centres.[28]

[27] *Machine Learning with Environmental Predictors to Forecast Hospital Visits and Admissions: A Systematic Review*, Environmental Systems Research 14, no. 12 (2025).

[28] *Health-Related Hazards of Heatwaves in Pakistan*, *Journal of Medicine, Surgery, and Public Health* 3, no. 5 (2024); *A Journey of Anticipatory Action – Early Response to Heatwaves in Pakistan*, Humanitarian Practice Network, 2024.

Energy Demand Management

Heatwaves strain Pakistan's fragile energy system. National Electric Power Regulatory Authority's (NEPRA) data indicates that hydropower contributes about 25–27% of electricity generation, but capacity falls during low water inflows.[29] AI-enabled smart grids, using historical demand logs and real-time consumption data, could forecast peak demand and optimise load distribution, reducing blackouts during extreme heat periods.[30]

Urban Heat Island (UHI) Mitigation

AI applications in urban planning can identify high-heat zones through satellite imagery and land-surface temperature data. Algorithms can recommend targeted interventions such as tree plantation, and green roofs in Karachi and Lahore, where UHI effects are most severe.[31]

Policy Relevance

Pakistan currently lacks municipal-level heat action plans that integrate AI. NDMA and provincial health departments could jointly pilot AI-supported early warning and surge management systems in heat-prone cities.[32]

Proposed KPIs for Heatwave AI Systems

For heatwave resilience, the most important performance indicators will be decreasing the forecast error margin (MAE) for maximum hospital admissions, ambulance dispatch optimisation to reduce average response times, decreasing excess mortality relative to baseline events, and

[29] National Electric Power Regulatory Authority (NEPRA), *State of Industry Report 2023* (Islamabad: NEPRA, 2023).

[30] *Health-Related Hazards of Heatwaves in Pakistan*, *Journal of Medicine, Surgery, and Public Health* 3, no. 5 (2024); "Hydropower Generation Breaks Records in 2023-24," *The Express Tribune*, July 7, 2024.

[31] Muhammad Ali Lakhan et al., "Assessment of Karachi as an Urban Heat Island Threat through Remote Sensing and GIS Techniques," *Proceedings of the Pakistan Academy of Sciences: B. Life and Environmental Sciences* 60, no. 3 (2023): 463-475. https://doi.org/10.53560/PPASB(60-3)848.

[32] "Floods, Rains and Heatwaves in Pakistan: Over 300 m Early Warnings Issued Digitally," *Business Recorder*, September 20, 2025.

enhancing peak energy demand forecasting accuracy. By implementing AI-based tools for health triage, energy forecasting, and city cooling measures, Pakistan can significantly decrease preventable mortality and soften the economic shocks related to repeated heatwaves.

Sea-Level Rise and Coastal Management

Pakistan's coastline, particularly Karachi, Keti Bunder, Badin, and Gwadar, faces accelerating risks from sea-level rise, coastal erosion, and saltwater intrusion. Unlike global averages, local relative sea-level rise in the Indus Delta is higher, estimated at 3.6-4.2 mm annually, due to land subsidence, groundwater extraction, and reduced sediment deposition.[33] These dynamics intensify flooding, erode agricultural lands, and threaten critical infrastructure such as Port Qasim and Gwadar Port.

Mangrove Degradation and Encroachment

Previously, the Indus Delta had 600,000 hectares of mangroves, but there is less than a half now.[34] Key causes are encroachment, uncontrolled development and industrial pollution. Remote sensing AI can identify the mangrove loss with over 90% classification accuracy and aid the targeted restoration initiatives.[35]

Urban and Industrial Risks

Saltwater is polluting fresh water aquifers and driving up the risk of urban flooding in Karachi. The tidal surges damage infrastructure in industrial hubs along Port Qasim. The use of AI-supported zoning enforcement based on satellite imagery and anomaly detection can be used to assist the authorities to track illegal coastal developments and implement land-use regulations.

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[33] Space & Upper Atmosphere Research Commission (SUPARCO), "Home," *Space & Upper Atmosphere Research Commission.*

[34] International Union for Conservation of Nature (IUCN) Pakistan, *Mangrove Ecosystem Status in the Indus Delta,* (Karachi: IUCN, 2022).

[35] "Trouble downstream: 'Indus Delta's ecology is being harmed by reduced flows'," *The Express Tribune*, August 2023.

Predictive Coastal Surveillance

AI-enhanced satellite monitoring can detect shoreline retreat and storm surge pathways in near real-time. Based on tidal records and wind patterns, predictive modelling could be used to guide the evacuation plans of vulnerable fishing communities like Pasni and Omara.

Policy Relevance

Effective adaptation requires coordinated action across the Ministry of Maritime Affairs, provincial coastal authorities, and SUPARCO. Current coastal policies emphasise ecosystem restoration but lack enforceable zoning and digital monitoring mechanisms.[36] Integrating AI-based surveillance and zoning enforcement would provide actionable governance tools.

Proposed KPIs for Coastal AI Systems

To achieve coastal resilience, performance should be measured by increased precision of shoreline change recognition (percentage), pace of zoning enforcement measures undertaken every year, and total number of hectares of recovered or preserved mangroves. They use the models of international coastal monitoring systems, including the ones being implemented in Bangladesh and Indonesia, where AI-powered satellite imagery has enhanced the accuracy of detecting shoreline and restored ecosystems. Also, the decrease of the number of households exposed as described by post-event surveys was a measure of adaptive efficacy that would be critical. By using AI to monitor the coastline and product zoning, Pakistan will be able to enhance protection of the shoreline, protect sensitive port facilities, and mitigate the pressure of displacement of the vulnerable fishery populations.

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[36] *Improving Coastal and Marine Resources Management through a Co-management Approach: A Case Study of Pakistan*, IOP Publishing (2023); *Pakistan's Coastal National Coordinating Body Urges Attention to Depleting Coastal Resources*, IUCN (2023).

Data Governance, Procurement, and AI Policy Integration

The launch of Pakistan's National AI Policy 2025 presents an opportunity to embed AI in climate governance.[37] However, effective deployment requires reforms in data governance, procurement, cybersecurity, and funding frameworks.

Data Governance

Pakistan lacks a unified legal framework for climate-related data sharing. At present, datasets are fragmented across the Pakistan Meteorological Department (PMA), NDMA, WAPDA, and SUPARCO, as well as provincial agencies.[38] Establishing a national climate data-sharing protocol, with clear privacy safeguards and classification standards for sensitive sensor networks, is essential.

Procurement and MLOps

AI adoption in the public sector requires transparent procurement guidelines. These should cover:

- **Model lifecycle management (MLOps):** ensuring algorithms are updated with new data, retrained regularly, and audited for bias or performance drift.
- **Continuity planning:** protocols to maintain AI systems during crises, avoiding reliance on single vendors.
- **Audit mechanisms:** periodic review of model outputs against ground realities, e.g., comparing AI flood forecasts with observed inundation maps.

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[37] "Cabinet approves National AI Policy 2025 to build robust AI ecosystem," *Aaj English TV*, July 30, 2025. https://english.aaj.tv/news/330427165/cabinet-approves-national-ai-policy-2025-to-build-robust-ai-ecosystem

[38] *New Data Regime to Help Build Climate Resilience*, *Dawn*, December 11, 2023. https://www.dawn.com/news/1796876/new-data-regime-to-help-build-climate-resilience

Cybersecurity and Ethics

AI models that integrate real-time sensor data from rivers, power grids, or coastal zones must be secured against cyber threats.[39] Ethical standards must prevent discriminatory outcomes in early warning dissemination (e.g., ensuring alerts reach marginalised communities).

Funding

Deployment will require blended finance. Potential sources include:

- Federal and provincial development budgets.
- Green Climate Fund (GCF) and Adaptation Fund projects.
- Asian Development Bank (ADB) and World Bank climate financing lines.
- Public–private partnerships with Pakistan's growing ICT sector.

Proposed KPIs for Governance and Procurement

Some of the key indicators to be used in governance and procurement would be the proportion of interoperable datasets effectively shared across agencies, quantity of audited AI models each year to determine accuracy and fairness, and the total amount of mobilised fund to be used in AI-enabled resilience projects. Moreover, it will be necessary to monitor the score of cybersecurity compliance of vital sensor networks to protect the integrity of data and reliability of the system. Therefore, It would be relevant to include these governance reforms in the National AI Policy 2025,[40] and tie them together in the NCCP (2021 revision) and NAP (2017) to establish an establishment-wide institutional route-way toward climate resilience.

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[39] "AI-Powered Cyber Threats in Pakistan's Critical Infrastructure," Pakistan House, accessed September 26, 2025, https://pakistanhouse.net/ai-powered-cyber-threats-in-pakistans-critical-infrastructure/

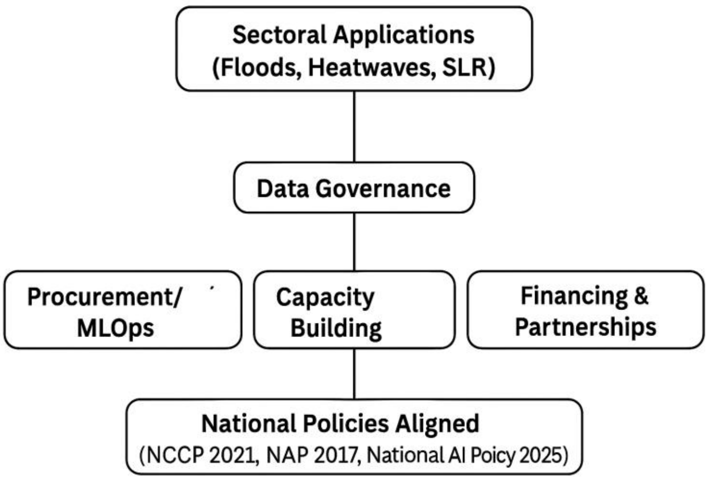
[40] Ministry of Information Technology and Telecommunication (MoITT), *National Artificial Intelligence Policy Consultation Draft V1* (Islamabad: Government of Pakistan, 2022), https://moitt.gov.pk/SiteImage/Misc/files/National%20AI%20Policy%20Consultation%20Draft%20V1.pdf

AI-based-Resilience Framework of Pakistan

Pakistan needs an AI-for-Resilience Framework, which is more inclusive and aligns the digital innovation to institutional mandates, budgets, and performance indicators to leave behind fragmented pilot projects. The framework suggested here is made up of three sectoral applications that are reinforced by four cross cutting pillars.

A schematic flow chart connecting sectoral applications: floods, heatwaves, and coastal management, with cross-cutting pillars: data governance, procurement/MLOps, capacity-building, and financing. The framework also displays alignment with national policies: NCCP 2021, NAP 2017, and National AI Policy 2025.

Figure II Proposed AI-for-Resilience Framework for Pakistan



Source: *By Author*

Sectoral Applications

Flood resilience calls for the implementation of AI-facilitated hydrological forecasting systems that incorporate IoT sensors, satellite imagery, and machine learning algorithms, in conjunction with decision-support tools for the optimisation of dam operations at Tarbela and Mangla. The success of these applications can be quantified in terms of forecast lead time enhancements, decreases in false-alarm rates, and improved precision-recall scores in inundation mapping. Heatwave resilience, on the other hand, relies on combining meteorological predictions with hospital and ambulance data to forecast patient surges and enhance emergency response. NEPRA and distribution company demand forecasting using AI can also assist in the management of peak loads, with the progress monitored by hospital surge prediction accuracy, ambulance response time, excess mortality reductions, and enhanced energy demand forecasting accuracy. Coastal resilience is supported by AI-facilitated satellite monitoring to identify shoreline change, map mangroves, and apply zoning regulations, with predictive models of storm surge being able to enhance Karachi, Badin, and Gwadar's protection. Indicators for coastal resilience are shoreline change accuracy detection, hectares of restored mangroves per year, and the number of enforcement actions triggered due to zoning.

Cross-Cutting Pillars

Four cross-cutting pillars are needed to strengthen climate resilience with AI. First, the data governance has to be enhanced through the formulation of a national climate data-sharing procedure within PMD, NDMA, WAPDA, SUPARCO, and provincial authorities, while maintaining effective privacy protection and classification regimes for sensitive networks. Second, the procurement and MLOps have to be strengthened through effective AI procurement procedures addressing lifecycle management, periodic retraining, auditing, and vendor continuity. Third, capacity development is needed, including the education of government personnel, disaster managers, and health experts to be able to read the outputs of AI so as to make informed decisions, with the support of Pakistani universities and IT companies to localise the tools. Last, financing and collaborations need to be activated through tapping federal development budgets, the Green Climate Fund, and partnerships with telecom and tech industries. All these pillars together give the institutional foundation to mainstream AI in climate governance.

Governance Pathway

The envisioned framework interlinks AI-driven climate resilience with Pakistan's current policy framework. The National Climate Change Policy (2021 update) needs to incorporate AI in water management, health, and coastal adaptation, and the National Adaptation Plan (2017) needs to be changed to reflect the presence of digital and AI-driven risk reduction strategies. Moreover, climate resilience is another priority area of application identified by the National AI Policy (2025) that has clearly allocated funding lines. This alignment can be institutionalised to enable Pakistan to cease the disjointed and reactionary efforts in favour of a unified and technology-enabled resilience plan.

Policy Challenges and Opportunities

There is hope for AI for climate resilience, but Pakistan is affected by long-standing institutional and structural impediments that render successful uptake challenging. However, new opportunities provide an opening for a quick leap forward if reforms are cleverly staged.

Challenges

Fragmented Institutional Coordination

Pakistan's climate management remains characterised by redundant mandates and interagency coordination problems between government departments such as the Pakistan Meteorological Department (PMD), NDMA, WAPDA, and SUPARCO. These agencies operate in parallel, leading to redundancy of efforts and inefficiencies in disaster response. For instance, PMD issues weather forecasts, but data do not always get harmonised with NDMA's early warning systems or provincial governments' preparedness mechanisms. This is a result of horizontal integration failure that makes it difficult to build interoperable datasets required for AI-based systems, which delays the adoption of nextgeneration modelling tools.[41] Without institutional harmonisation, AI uptake may be siloed and underperform.

Resource Constraints

Public investment in digital infrastructure for disaster risk management remains insufficient. The NDMA's 2022 flood response highlighted structural weaknesses, with situational reporting delays exceeding 30% due to reliance on manual data collection methods. These constraints are linked to broader fiscal limitations, as Pakistan allocates less than 1% of its GDP to climate adaptation and disaster risk reduction.[42] The absence of a stable financing framework prevents the scaling of AI-based pilots into national systems. Studies emphasise that low- and middle-income countries like Pakistan struggle to maintain real-time monitoring systems without consistent funding for maintenance and human resource training.[43] Consequently, even when donor-funded AI projects are piloted, they often fail to transition into sustainable government programmes.

Capacity Deficits

A critical bottleneck is the lack of AI expertise in government institutions. Most technical expertise in machine learning, predictive modelling, and data analytics resides in the private ICT sector and universities, leaving ministries and disaster management agencies underprepared to implement advanced systems.[44] This creates a gap between available technological innovations and their application in public policy. For example, while Pakistani start-ups have developed AI solutions for agriculture and urban

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[41] M. Abid, J. Scheffran, U. A. Schneider, and M. Ashfaq, "Farmers' Perceptions of Climate Change, Observed Trends and Adaptation of Agriculture in Pakistan," *Environmental Management* 63, no. 1 (2020): 110–123.

[42] World Bank, *Pakistan Country Climate and Development Report* (Washington, DC: World Bank, 2023).

[43] M. Jahangir, M. Ahmad, and S. Nawaz, "Financing Disaster Risk Reduction in Developing Countries: The Case of Pakistan," *Natural Hazards* 106, no. 1 (2021): 567–585.

[44] Z. Rehman and A. Shah, "Artificial Intelligence and Public Sector Reform in Pakistan: Capacity Challenges and Opportunities," *Public Administration and Development* 41, no. 3 (2021): 215–227.

planning, there are a few institutional mechanisms to scale these solutions into NDMA's operational frameworks. Similar findings in South Asia indicate that without targeted training programmes for civil servants, AI adoption remains superficial and donor-driven. Building institutional capacity is therefore essential to avoid reliance on external consultants and ensure local ownership of AI systems.

Outdated Legal Frameworks

Pakistan's current legal and regulatory systems fail to comprehensively address data governance, privacy, or AI ethics. The existing law, including the Pakistan Telecommunication (Re-organisation) Act 1996 and Prevention of Electronic Crimes Act 2016, offers some coverage of digital governance but no climate and disaster provisions.[45] Without updated laws, agencies face difficulties in sharing sensitive datasets, such as satellite imagery, river flow data, or hospital admission records, which are critical for AI-enabled forecasting. Comparative studies suggest that countries with clear legal frameworks for data sharing and ethical AI, such as India's draft Personal Data Protection Bill, are better positioned to deploy AI in disaster management.[46] In Pakistan, the absence of such frameworks risks misuse of data, undercuts public trust, and creates barriers for international funding, as donors increasingly demand evidence of data security and ethical safeguards.

Technology Dependence

Pakistan's AI adoption is highly dependent on imported hardware, software, and expertise, creating risks of vendor lock-in and long-term sustainability challenges. Many pilot projects rely on foreign platforms for geospatial modelling, cloud storage, and predictive analytics, which may

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[45] Z. Mahmood, "Cybersecurity and Digital Governance in Pakistan: Challenges and Opportunities," *Information & Computer Security* 29, no. 5 (2021): 701–716.
[46] P. Arora and A. Ranjan, "Data Protection and AI Ethics in South Asia: Emerging Challenges," *Asian Journal of Comparative Law* 16, no. 2 (2021): 215–233.

not align with local data needs or budgetary capacities.[47] Over-reliance on foreign vendors limits the country's bargaining power and exposes critical climate resilience infrastructure to cybersecurity vulnerabilities. Studies show that developing nations relying heavily on imported technologies face difficulties in sustaining AI applications once donor support ends, as maintenance contracts and retraining costs are prohibitively high.[48] Localisation of AI tools and investment in indigenous innovation ecosystems are therefore essential to reduce dependency and ensure resilience in the long run.

Opportunities

Policy Windows

The endorsement of the National AI Policy 2025, provides an unusual institutional opportunity to officially incorporate AI into Pakistan's climate-governance structure. The policy lays down national goals for the take-up of AI across government services, but climate resilience is not an immediate priority. Incorporating climate resilience as a high-priority area in the AI policy would be consistent with the National Climate Change Policy (NCCP, 2021 revision) and the National Adaptation Plan (NAP, 2017) so that technological innovation and environmental adaptation are aligned (Government of Pakistan, 2021).[49] Policy integration is particularly urgent since fragmented policymaking has long contributed to implementation deficits in Pakistan. [50] There is a global evidence that integrating AI in climate strategies at the policy design level enhances budgeting, inter-agency coordination, and donor confidence.[51]

[47] H. Khan, A. Ullah, and M. Rafiq, "Artificial Intelligence Adoption in Developing Countries: Barriers and Enablers," *Journal of Technology in Society* 68 (2022): 101911.

[48] F. Sultana and C. E. Haque, "Dependency and Resilience: Technology Adoption in Disaster Management in South Asia," *Progress in Disaster Science* 7 (2020): 100111.

[49] Government of Pakistan et al., *Pakistan Floods 2022: PDNA.*

[50] Abid et al., "Farmers' Perceptions of Climate Change," 112.

[51] Shrestha and Bhandari, "Artificial Intelligence in Disaster Risk Reduction," 570.

Growing ICT Sector

Pakistan's local ICT sector has expanded considerably, generating more than 1% of GDP and top-tier export revenues in the services sector.[52] Geospatial analytics, health-tech, and predictive modelling start-ups already have AI-led applications being tested for relevance to resilience, such as platforms tracking air pollution in Lahore or predicting agricultural harvests in Punjab. Mobilising this ecosystem for climate resilience co-development would reduce reliance on foreign vendors and create localised, cost-effective solutions.[53] Research indicates that public–private innovation partnerships in the ICT sector can accelerate AI adoption in disaster risk reduction by combining state authority with entrepreneurial agility.

International Finance

Pakistan is also qualified to receive concessional funding from multilateral organisations, such as the Green Climate Fund (GCF), the Asian Development Bank (ADB), and the World Bank, which have invested in resilience programmes in South Asia. Bangladesh, for example, tapped GCF funds to finance AI-based flood early warning systems, while Nepal utilised ADB funds to set up satellite-based disaster tracking. Pakistan can also place AI-powered pilots in floods, heatwaves, and coastal planning under donor-financed adaptation initiatives. There is an evidence that connecting AI initiatives with existing international financing frameworks facilitates durability because regular expenses (sustenance, retraining, and audit) can be folded into multi-year financing arrangements.[54]

Regional Collaboration

Pakistan's geographical proximity to South Asian and East Asian centers of innovation offers a chance to pick up lessons from regional experience.

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[52] State Bank of Pakistan, *Annual Report: The State of Pakistan's Economy* (Karachi: SBP, 2023).

[53] Z. Rehman and A. Shah, "Artificial Intelligence and Public Sector Reform in Pakistan: Capacity Challenges and Opportunities," *Public Administration and Development* 41, no. 3 (2021): 215–227.

[54] Jahangir, Ahmad, and Nawaz, "Financing Disaster Risk Reduction in Developing Countries," 570.

India has tested AI-supported heatwave early warning systems, correlating health surveillance with meteorological forecasts. China has shown AI-optimised dam control on the Yangtze River, incorporating predictive algorithms into hydropower regulation.[55] Transferring these pilot studies to Pakistan's institutional and resource environment could hasten application while preventing expensive trial-and-error methods. Experts posit that regional knowledge-sharing in disaster risk reduction cuts down on duplication, consolidates collective bargaining power for donor funds, and increases the scalability of innovations.[56]

Public–Private Partnerships (PPPs)

Engaging Pakistan's telecom operators and technology firms offers a scalable pathway for expanding AI-enabled disaster communication systems. Telecom firms already maintain extensive outreach, with mobile penetration exceeding 80% of the population.[57] Leveraging these platforms for AI-enhanced mobile early warning systems could ensure last-mile delivery of targeted alerts to vulnerable communities during floods and heatwaves. PPPs also enable governments to share financial and technical risks while incentivising private-sector innovation. Evidence from South Asia suggests that PPPs in ICT-driven resilience initiatives improve efficiency, expand coverage, and enhance community trust compared to government-only systems.[58]

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[55] "India Is Using AI and Satellites to Map Urban Heat Vulnerability Down to the Building Level," *Wired*, June 23, 2025; "Three Gorges Dam: a model of China's infrastructure construction featuring smarter, greener and more creative," *Global Times*, July 26, 2024.

[56] *Chapter 10: Regional Support and National Enabling Environments for Integrated Risk Reduction*, *Global Assessment Report (GAR)*, United Nations Office for Disaster Risk Reduction, 2022, https://gar.undrr.org/chapters/chapter-10-regional-support-and-national-enabling-environments-integrated-risk-reduction

[57] Pakistan Telecommunication Authority (PTA), *Annual Report 2023* (Islamabad: PTA, 2023).

[58] *Are Public-Private Partnerships Fit for Purpose? Evidence from the South Asian Region*, Rajshahi University Journal of Social Science and Business Studies 27, no. 1 (2025).

Way Forward: Policy Leverage

To seize such opportunities and overcome such obstacles, Pakistan should use a proactive and consistent strategy, which will ensure that national priorities are aligned with technology innovation.

Mainstream AI into Climate Policy

Climate resilience cannot be kept on the periphery of Pakistan's AI agenda. Future updates of the NAP and provincial adaptation plans should officially incorporate AI applications, with programmatic areas including flood early warning, urban heat management, and coastal monitoring. By incorporating AI in policy documents, line ministries will be compelled to invest resources and build institutional capacity to actualise these pledges.[59]

Establish a National AI–Climate Taskforce

The Ministry of Climate Change, NDMA, PMD, WAPDA, SUPARCO, health departments, and provincial authorities need to be united in a high-level and inter-agency taskforce. Such a platform would be a hub of central control and the data flows would be interoperable, duplication will be minimised and pilot projects can be brought to national systems. In addition to coordination, the taskforce would serve as a policy innovation unit, which identifies gaps, establishes standards in the use of AI, and monitors the ethical and security protection.

Prioritise Pilot Projects in High-Risk Areas

Pilot projects ought to be focused on the regions that are the most vulnerable to climate risks and where the deployment of AI tools can produce measurable benefits in terms of forecasting accuracy, responding to the emergency, or managing the resources. In the Punjab and Sindh regions of Pakistan, AI-based flood predictions can be used to improve dispersed reservoir systems and early warning systems at the community level. Health triage based on AI aided prediction of patient surge in hospitals during heatwave can help reduce mortality during heatwave in Karachi and

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[59] Government of Pakistan, Ministry of Climate Change & Environmental Coordination, *Pakistan National Adaptation Plan, 2023.*

Lahore. AI is applicable to track the shoreline in the coastal belt, or Karachi, Badin, and Gwadar, to restore mangroves and enforce zoning. These pilots would serve as proof-of-concept demonstrations, providing a demonstration of scalability and long-term investment.

Through this three-faceted approach, policy mainstreaming, institutional coordination, and pilot targeting, Pakistan can transition away from broad declarations of aspiration to a unified, operational framework. By this double emphasis on reducing challenges as much as it harvests opportunities, AI is ensured to become an operational tool of climate resilience instead of being a rhetorical goal. It also sets the stage for the provision of a system of government in which technology, policy, and community interests melt into a more robust future.

Policy Implementation Roadmap

For these recommendations to translate into action, implementation should be sequenced along three timelines:

- **Short-term (1–2 years):** Establish a national AI–Climate Taskforce and initiate pilot projects in Sindh and Punjab focusing on AI-based flood forecasting and heatwave triage.
- **Medium-term (3–5 years):** Develop interoperable climate data platforms and harmonise legal frameworks for data sharing and AI ethics.
- **Long-term (5+ years):** Scale up successful pilots across the country, embed AI governance modules in civil service training, and institutionalise performance-budgeting for AI-facilitated resilience programmes.

This action plan is a progressive roadmap that will ensure that the climate adaptation agenda in Pakistan moves to the practical stages with measurable outcomes.

Conclusion

Rise in the exposure to flood, heatwave and rise in sea level in Pakistan requires innovation in climate governance. National-level frameworks of adaptation exist, however, they have not been organised and coordinated in relation to AI as yet. There is still poor data governance, decentralisation of institutional coordination, and insufficiency of resources that underlie resilience development.

AI applications can bring quantifiable gains in case they were institutionalised. AI can be used in flood management to add time to forecasts, reduce false alarms, and make the operation of a reservoir more practical. AI has the potential to increase health system preparedness, reduce deaths, and energy demand forecasting in heatwaves by promoting resilience. In the coastal area, AI can be used to monitor the mangroves, provide shoreline surveillance, and carry out zoning.

The AI-based Resilience Framework as presented in this study provides a methodical roadmap that facilitates digital innovation integration in the climate policy-making process in Pakistan. It unites sector uses with cross-cutting information management reforms, acquiring reforms, capacity building reforms and investment reforms. With these reforms connected to the national policy, AI can be shifted out of being an ambiguous agenda and into a concrete resilience plan.

Incorporating AI into climate governance is no longer an option but a necessity. Without technological adjustment, catastrophes will continue taking control of institutions, reducing infrastructure, and displacing millions of people. Using AI-enhanced resilience, Pakistan will be able to fortify the early warning systems, protect the vulnerable communities, and transition towards a more sustainable and secure future amidst the increased climate threats.■