

CLIMATE CHANGE AND WATER SCARCITY: ADAPTATION AND MITIGATION STRATEGIES IN PAKISTAN

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ABSTRACT

Climate change and water scarcity are interlinked and pose serious challenges to countries worldwide, especially developing nations like Pakistan. This study critically examines the climate–water nexus in Pakistan through a qualitative methodology combining stakeholder interviews, policy document analysis, and thematic content analysis, grounded in empirical evidence and national-level data. The research identifies systemic gaps in institutional coordination and resource management. It also examines the main impacts of climate change and water scarcity in Pakistan, emphasizes the importance of international cooperation, and explores effective strategies for addressing the challenges to adaptation and mitigation. Findings reveal intensifying climate variability, accelerated glacial melt, declining river flows, and severe groundwater depletion, especially in Balochistan, Tharparkar, and southern Punjab. Despite the policies like National Water Policy (2018) and Climate Change Policy (2021), governance fragmentation, inefficient irrigation, and policy inertia persist. This paper offers practical, evidence-based reforms, including climate-adaptive agriculture, equitable water pricing, decentralized governance, and integrated planning. By combining empirical depth with policy critique and actionable recommendations, the study contributes novel insights into Pakistan's climate–water crisis and presents a strategic framework for a resilient and sustainable future.

Keywords: Climate Change, Global Warming, Glacial Melting, Hydrological Stress, Water Scarcity, Pakistan, Mitigation and Adaptation Strategies, International Cooperation, Climate Resilience.

INTRODUCTION

The phenomenon of climate change has been widely researched and discussed over the past few decades. It refers to long term shifts in weather patterns and temperatures. These shifts may stem from natural sources or from anthropogenic origins (United Nations, What is Climate Change). Climate Change has emerged as one of the most pressing global challenges of the twenty-first century, with both natural and anthropogenic drivers contributing to long-term alterations in weather patterns and climatic

conditions. While volcanic activity, solar variability, and oceanic cycles can influence climate systems, contemporary scientific consensus attributes the accelerated pace and unprecedented scale of change primarily to human activity (IPCC, 2021). Fossil fuel combustion, industrial processes, rapid deforestation, and intensive agricultural practices have raised atmospheric concentrations of greenhouse gases such as carbon dioxide (CO₂), methane CH₄, and

nitrous oxide (N₂O), intensifying the greenhouse effect and contributing to global warming. For Pakistan, the consequences of these dynamics are particularly acute. Situated at the intersection of South Asia's glacial ecosystems and arid zones, the country is exposed to a spectrum of climate-induced hazards—glacial retreat, floods, droughts, and heatwaves—that interact with its fragile socio-economic fabric. Pakistan's dependence on the Indus Basin for food and energy, combined with low adaptive capacity, high poverty levels, and rapid urbanization, magnifies its vulnerability (Eckstein, Künzel, & Schäfer, 2021).

Climate change is intensifying Pakistan's water scarcity crisis, with per capita availability now below 1,000m³, well beneath the international water-stress threshold. Water is the bedrock of socioeconomic development, public health, and ecological integrity, particularly in agrarian societies like Pakistan. However, Pakistan now faces an acute water scarcity crisis, with per capita water availability plummeting from approximately 5,600 cubic meters in 1951 to less than 1,000 cubic meters in 2021 (Ashraf, 2016), marking its transition from water-stressed to water-scarce.

Climate change has emerged as a force multiplier exacerbating this crisis. Rising temperatures, erratic monsoon patterns, accelerated glacial melting in the Hindu Kush-Karakoram-Himalaya (HKH) region, and an increasing frequency of extreme weather events such as floods and droughts have placed unsustainable pressure on Pakistan's already fragile water economy (Immerzeel, van Beek, & Bierkens, 2010). Alarming, over 60% of Pakistan's river flows are dependent on glacial and snow melt (Lutz, Immerzeel, Shrestha, & Bierkens, 2014), making it highly susceptible to any climate-induced hydrological variations. The 2022 floods, which submerged nearly one-third of the country, and prolonged droughts in Balochistan and southern Sindh, provide stark reminders of the growing water-related vulnerabilities facing Pakistan.

Furthermore, Pakistan is on the brink of a water-induced socio-environmental catastrophe, driven by the twin forces of climate change and mismanaged water resources. The critical challenge lies not merely in the absolute scarcity of water but in its temporal and spatial variability, inefficient utilization, and poor

governance. Agriculture, which consumes nearly 90% of freshwater withdrawals (Siyal, Gerbens-Leenes, & Vaca-Jiménez, 2023), is highly water-intensive and inefficient, with low crop-per-drop ratios and outdated irrigation practices. Urbanization, population growth, and industrialization further exacerbate the demand-supply imbalance, while groundwater resources are depleting rapidly and often remain unregulated (FAO, 2022). The current research problem is compounded by a notable gap in interdisciplinary, empirical studies that integrate climate science, water economics, and policy evaluation across different ecological zones of Pakistan. Most existing literature either treats climate change or water scarcity in isolation, or restricts analysis to provincial or sectoral domains, thus failing to offer a holistic understanding of the national picture. Consequently, there is an urgent need for a rigorous, data-driven inquiry into the multi-scalar dimensions of climate-induced water stress and its socio-economic ramifications.

In response to the climate change and water scarcity, there is a range of strategies and policies for both adaptation and mitigation. Adaptation involves managing the unavoidable impacts of climate change and water scarcity to minimize damage and ensure the resilience of communities, ecosystems, and infrastructure. For Pakistan, this means addressing water scarcity through improved irrigation, developing disaster-resilient infrastructure, and early warning systems, promoting climate-smart agriculture and diversifying livelihoods to reduce dependence on vulnerable resources, and strengthening healthcare systems to cope with heatwaves in disease outbreaks. It is also necessary for a comprehensive approach addressing this issue. However, mitigation focuses on reducing the causes of climate change, particularly GHG emissions and enable sustainable development. Pakistan, despite contributing less than 1% of global emissions, has a significant role to play in mitigation through more energy-efficient technologies and transportation, renewable energy transitions, afforestation campaigns, (e.g., the 10 Billion Tree Tsunami Project), improving agricultural practices, and sustainable urban development. The mitigation also involves aligning with international commitments, such as the Paris

Agreement, to achieve low-carbon development pathways.

In terms of addressing the issues, Pakistan has developed National Adaptation Plan for the Climate Change, National Climate Change Policy (NCCP), and National Water Policy (2018), which collectively aim to increase the resilience of communities and ecosystems towards the climate change and water scarcity's impacts. These policies involve a wide range of measures, such as improving water management, promoting climate-smart agriculture practices, improving public health infrastructure, and enhancing the early warning systems (National Climate Change Policy of Pakistan, 2012; Government of Pakistan, 2019). Overall, Pakistan has implemented different plans and policies to enhance energy efficiency and curb emissions from the transportation sector, a major contributor to country's overall emissions (Pakistan's Second National Communication on Climate Change, 2019).

Although national strategies, including the Climate Change Policy (2021) and the National Water Policy (2018), acknowledge these risks, their implementation is undermined by fragmented mandates, insufficient technical expertise, and limited fiscal resources (Ministry of Climate Change, 2021). Moreover, there is another problem which is the lack of sensibility in understanding among people about water scarcity, climate change, and their effects, which makes it tough to mobilize support for adaptation and mitigation measures. The absence of disaggregated, region-specific data constrains the development of localized solutions, leaving marginal communities, such as those in Tharparkar or Gilgit-Baltistan, particularly exposed. This policy-practice gap underscores the urgent need for coherent, evidence-based interventions that integrate climate resilience into Pakistan's developmental planning.

Therefore, this study offers a comprehensive, policy-relevant, and empirically grounded understanding of how climate change exacerbates water scarcity in Pakistan, and what can be done to address it. By integrating climatic trends, hydrological data, and socio-economic indicators, the research aspires to inform evidence-based policy formulation in water governance and climate adaptation, address a critical research gap by adopting a holistic,

interdisciplinary, and nationally scoped approach, and contribute original empirical insights on vulnerable regions and communities. Moreover, the findings are of particular relevance to policymakers, climate resilience planners, development practitioners, and academic scholars engaged in water resource management and climate governance in South Asia.

1. Methodology

This study employs a qualitative research design, consistent with the descriptive and analytical nature of the research objectives, incorporating both cross-sectional and longitudinal elements. Given the multi-dimensional character of climate change and water scarcity, entwining ecological, institutional, and socio-economic dimensions, a qualitative approach allows for in-depth insights into local perceptions, policy dynamics, and lived experiences that are often underrepresented in quantitative data.

Triangulation of data sources and methods was used to enhance validity and reliability. This included policy content analysis, semi-structured interviews, and secondary data triangulated through official records from credible institutions such as the Pakistan Meteorological Department (PMD), Ministry of Climate Change, Pakistan Council of Research in Water Resources (PCRWR), WAPDA, FAO, and relevant UN agencies. This multi-method strategy ensures robust cross-verification and a comprehensive understanding of the research problem. The study draws on both primary and secondary data sources.

Primary Data: A total of 14 semi-structured interviews were conducted with key stakeholders, including climate experts (from PMD and academic institutions; $n=3$), farmers and local community members (from Punjab, Sindh, Balochistan, and Gilgit-Baltistan; $n=8$), and representatives of NGOs; $n=3$. The interviews provided valuable insights into the challenges, opportunities, and gaps in mitigation and adaptation strategies.

Moreover, the interviews followed a flexible guide covering four thematic areas: climate perceptions, water access and management, institutional effectiveness, and policy recommendations. All participants provided informed consent. Anonymity was maintained, especially for rural participants who could be at

risk for disclosing criticisms of local governance. Data security protocols were strictly followed. A purposive sampling strategy was employed to ensure representation across diverse ecological zones and governance levels. Snowball sampling was also used to access hard-to-reach rural communities, particularly in Balochistan and GB, where water insecurity is acute but under-documented.

Secondary Data: A thorough literature review has been conducted to compile existing knowledge and perspectives on climate change and water scarcity in Pakistan. Peer-reviewed journal articles, institutional reports, policy documents (e.g., National Water Policy 2018, Climate Change Policy 2021), relevant books, and datasets from FAO AQUASTAT (for water use statistics), PMD (for climate data and variability), and UNDP and IPCC (for vulnerability assessments and adaptation frameworks), have been reviewed to identify key trends, challenges, and best practices in water scarcity and climate change's adaptation and mitigation.

Data Analysis: Thematic analysis was the principal analytical technique used. The process followed Braun and Clarke's (2006) six-phase method for transcribing, coding, and categorizing into major patterns and themes. The codes were both inductive (emerging from the data) and deductive (derived from prior frameworks such as IWRM). This hybrid coding ensured that theoretical constructs were empirically grounded in the narratives of stakeholders. Themes such as "perceived climate variability," "institutional fragmentation," "local adaptation strategies," and "governance gaps" were identified and interpreted in relation to the broader literature and policy frameworks. Policy content analysis involved systematic review of over a dozen national and provincial documents. These were evaluated based on criteria such as coherence, measurability, institutional clarity, and implementation capacity. While the study adopts a rich qualitative design, some limitations are acknowledged. The findings are not statistically generalizable, although they provide deep contextual validity. Data collection in remote regions (e.g., Chagai and Diamer) was limited by security constraints. However, efforts were made to ensure that the selected sample remains diverse and representative. Nevertheless, triangulation and methodological

rigor offer valuable insights, strong reliability, and relevance.

2. Literature Review

Climate change is a worldwide pressing issue that has significant implications for all countries particularly developing countries like Pakistan (Wang, Cui, Zhang, Wu, & Xie, 2020). Wang, et al. emphasize the significance of adapting to climate change for developing countries like Pakistan, which experience a range of climate related events such as flooding, glacial melting, heatwaves, and droughts. These climate related disasters had resulted in severe economic, social, and environmental consequences. Studies indicate that Pakistan's ability to manage the climate change impacts is relatively low (IPCC, 2018). The IPCC also confirms that it is due to resource limitations, institutional capacity gaps, technical expertise deficiencies, and a high dependence on natural resources for economic growth.

Pakistan ranks consistently among the 10 most climate-vulnerable countries globally, as documented in the Global Climate Risk Index (Eckstein, Künzel, & Schäfer, 2021). Consequently, it is essential to formulate effective strategies for both adaptation and mitigation to tackle these challenges. In response, the Pakistani government has initiated various policies and strategies to address and adapt to the climate change's induced challenges. The literature also suggests that the effective strategies for the climate change adaptation and mitigation require a holistic approach that involves the coordination of multiple sectors and stakeholders (Abid, Scheffean, Schbeider, & Ashfaq, 2015). This is particularly relevant for Pakistan, where different regions are affected by various climate-related hazards.

The literature also highlights the role of non-state actors. Entities like civil society organizations and the private sector of Pakistan have the potential to significantly contribute to efforts aimed at adapting and mitigating to climate change (Bulkeley, Castán Broto, Edwards, & Fuller, 2014). In addition, there are examples of successful initiatives in Pakistan led by non-state actors, such as community-based adaptation projects and private sector investment in renewable energy. However, it is crucial to assess the effectiveness of these

initiatives and identify ways to scale them up in mainstream them into national policies and strategies.

One approach that has gained attention in recent years is the regime theory. This theory argues that international cooperation is necessary to solve global environmental problems, including climate change (Young, 2010). Regimes provide a framework for countries to cooperate and coordinate their actions, and they can facilitate the implementation of effective policies and strategies. Several studies have applied the regime theory to climate change and have highlighted the significance of international cooperation for enhancing adaptation and mitigation (Betsill & Corell, 2008). Despite the potential benefits of regimes, there are also challenges to their implementation. For instance, there may be differing interests among countries, and the effectiveness of regimes may be limited by issues such as weak enforcement mechanisms and lack of political will (Keohane & Victor, 2011). In Pakistan's case, there is a need to evaluate the potential of international cooperation to support the intended adaptation and mitigation. This requires an analysis of Pakistan's engagement with the international regimes for climate change and water scarcity and the effectiveness of these regimes in promoting action at the local or national level.

As a lower-middle-income country with over 240 million people (World Bank, World Development Indicators: Pakistan, 2023), Pakistan relies heavily on its water resources—over 90% of which originate from the Indus River Basin and are primarily used for irrigation (Qureshi, McCornick, Sarwar, & Sharma, 2010). The Intergovernmental Panel on Climate Change: Sixth Assessment Report warns that South Asia faces a high risk of reduced water availability from snow and glacier melt (IPCC, Sixth Assessment Report: Impacts, Adaptation and Vulnerability, 2022). Water scarcity in the context of climate change is not a new phenomenon, yet its manifestations in South Asia, particularly in Pakistan, are increasingly acute and under-examined. The theoretical frameworks provide a lens to understand how climate-induced water stress interacts with governance, socio-economic inequality, and agricultural dependence in developing countries. Pakistan's particular vulnerability

arises from both environmental and institutional fragility, a duality that most scholarly work has only partially addressed. The HKH region, which feeds the Indus Basin, is warming at a rate higher than the global average (Wester, Mishra, Mukherji, & Shrestha, 2019). According to Immerzeel et al. (2010), the Indus River is the most vulnerable river system in Asia due to its heavy reliance on glacial melt and its importance to downstream agriculture and human settlements. These global insights set the stage for country-specific analyses that explore how such changes intersect with local institutional, social, and political dynamics.

Pakistan-specific literature has expanded over the last two decades, with significant contributions from both local and international scholars. Qureshi et al. (2010) emphasize the inefficiency of irrigation practices and outdated canal systems that result in nearly 50% conveyance losses. Siyal et al. (2023) highlight governance challenges, identifying a mismatch between climate policy formulation and ground-level implementation. The National Water Policy (2018) and Pakistan's revised Climate Change Policy (2021) outline broad strategic goals but lack measurable targets, coordination frameworks, or funding mechanisms (Ministry of Climate Change, UPDATED NATIONALLY DETERMINED CONTRIBUTIONS, 2021; Government of Pakistan, 2018). Empirical work by Lutz et al. (2014) has modelled glacial retreat scenarios, predicting up to 60% reduction in glacial mass in some HKH regions by 2100, which will drastically impact the flow regimes of the Indus River. The deltaic region of Sindh, once a fertile zone, now suffers from saltwater intrusion due to reduced downstream flows, an issue documented by Mustafa et al. (2000), who attributes the crisis to both climatic variability and political mismanagement of the Indus Water Accord.

In Balochistan, several studies (Akhtar, et al., 2021; van Steenberg, Kaisarani, Khan, & Gohar, 2015) have revealed a severe depletion of groundwater tables, over 60% of tube wells operate below sustainable thresholds. This overexploitation is compounded by reduced rainfall, leading to a desertification trajectory that has already displaced communities in districts like Chagai and Kharan. In Gilgit-Baltistan, glacial lake outburst floods (GLOFs) have increased in frequency, threatening lives

and infrastructure, a trend reported by Bajracharya et al. (2009) using satellite-based risk mapping.

Urban water stress is another growing challenge. Karachi and Lahore, cities with populations exceeding 15 million, suffer from aging infrastructure, leakages, and inequitable access. Janjua et al. (2021) document that 40% of water in Karachi is lost due to leakages and illegal connections. In addition, informal settlements rely on contaminated groundwater, exacerbating public health risks. From a public health perspective, limited access to clean water disproportionately affects marginalized groups, particularly women and children. Murtaza et al. (2021) found that in rural Sindh, waterborne diseases account for over 60% of reported illnesses among children under five. This empirical insight illustrates the interconnectedness of water scarcity, poverty, and health, an area largely underexplored in the dominant climate-water literature. Agriculture accounts for 90% of water withdrawals in Pakistan, yet remains one of the least efficient sectors (FAO, 2022). Studies by Ashraf (2016) note that four water-intensive crops (wheat, rice, sugarcane, and cotton) consume disproportionate volumes of irrigation water, leading to regional imbalances in water allocation. The situation is most critical in southern Punjab and Sindh, where declining water tables are directly linked to cropping patterns promoted by subsidized water pricing. Pakistan's institutional architecture for water management is fragmented. The 18th Amendment to the Constitution devolved environmental and water-related responsibilities to provinces, but without building the institutional capacity to implement such responsibilities (Siyal, Gerbens-Leenes, & Vaca-Jiménez, 2023). Consequently, inter-provincial water disputes, such as those between Punjab and Sindh, remain unresolved, and data transparency is often compromised. The Water and Power Development Authority (WAPDA), Indus River System Authority (IRSA), and the Pakistan Council of Research in Water Resources (PCRWR) all function in silos, leading to overlapping mandates. A recent report by UNDP (2022) criticizes the absence of an integrated national water information system, which impedes decision-making and disaster preparedness.

Despite a rich body of research, several gaps persist. Firstly, there is a lack of interdisciplinary studies that integrate climate modeling with socio-economic vulnerability assessments. Most existing work either focuses on physical water availability (hydrological studies) or on governance issues, rarely combining the two. Secondly, regional disparities are underexplored; most studies generalize findings without disaggregating them across eco-zones or socio-political contexts. Finally, few studies evaluate the effectiveness of existing adaptation policies using measurable indicators, leading to a normative rather than analytical discourse.

This research addresses these gaps by offering a nationally scoped, interdisciplinary assessment of how climate change aggravates water scarcity in Pakistan. It combines climatic data, hydrological models, socio-economic indicators, and policy analysis to present a comprehensive narrative. It also integrates region-specific case studies, from glacial retreat in Gilgit-Baltistan to aquifer depletion in Balochistan and salinity in Sindh, thereby ensuring geographic specificity and empirical depth. By doing so, the paper contributes both to academic discourse and to policy-making by offering actionable, evidence-based recommendations.

3. Theoretical Framework

Climate change is a complex and global issue which requires a global solution. Water scarcity is also a complex, worldwide concern that requires regional & international cooperation to effectively address. Theoretically, this research is anchored in three interrelated theoretical perspectives: Complex Interdependence, Integrated Water Resources Management (IWRM), and Regime Theory. Together, these frameworks provide a lens through which to analyze Pakistan's climate-water nexus at both domestic and international levels (Bazilian, et al., 2011). Keohane and Nye's (1977) concept of complex interdependence highlights that state behavior is increasingly shaped by transnational actors, non-state stakeholders, and issue-linkages that transcend traditional borders. Climate change epitomizes this condition: its effects are not confined within political boundaries, and responses require engagement across governments, civil society, and the private sector (Bulkeley, Castán Broto, Edwards, & Fuller, 2014). In Pakistan, local communities and

NGOs have pioneered adaptation projects, such as community-managed water harvesting in arid zones, underscoring the importance of inclusive policy design.

Similarly, the IWRM approach emphasizes coordinated development and management of water, land, and related resources to maximize economic and social welfare without compromising ecosystems (Gain & Giupponi, 2015). Given Pakistan's overreliance on the Indus Basin, IWRM provides a critical framework to address inefficient irrigation practices, inequitable distribution, and unregulated groundwater extraction. Whereas, 'Regime Theory' further contextualizes Pakistan's position in global climate governance. Krasner defines regimes as collections of implicit or explicit principles, norms, rules, and decision-making processes that shape actors' expectations within a specific domain of international relations. International frameworks such as the UNFCCC and Paris Agreement create norms and mechanisms for collective action, but their effectiveness hinges on domestic enforcement and political will (Young, 2010). Pakistan's conditional pledge to reduce emissions by 20% by 2030 illustrates both the opportunities and constraints of regime participation, as access to climate finance and technology transfer remains limited.

Nonetheless, regime theory and IWRM framework also recognize that there can be challenges in implementation and enforcement. Some states may have different interests or priorities, and may be reluctant to make the necessary commitments to minimize emissions or adopt to climate change impacts. In addition, regimes may be subject to political and economic pressures that can affect their effectiveness and durability. Therefore, a critical analysis of the UNFCCC and Paris Agreement, and their implementation in Pakistan, through an approach of regime-based theoretical framework could help to identify opportunities for strengthening and expanding existing regimes or creating new ones to address gaps in climate governance.

4. Climate Change and Water Scarcity in Pakistan

Pakistan ranks consistently among the most climate-vulnerable countries globally, as documented in Global Climate Risk Index. In the 2021 report, Pakistan was listed as the 8th most affected country over a 20-year period (2000 to 2019), facing 173 extreme weather events that cause economic losses amounting to approximately \$3.8 billion annually (Eckstein, Künzel, & Schäfer, 2021). Furthermore, Pakistan's unique vulnerabilities include its geographic location, socioeconomic challenges, urbanization and environmental degradation, etc.

Pakistan houses the world's largest collection of glaciers outside the polar regions, which are melting at an unprecedented rate due to rising temperatures. The Indus River system, fed by these glaciers is a lifeline for the country, making water scarcity a critical concern. Erratic monsoon patterns further aggravate the water crisis, leading to severe floods or prolonged droughts. With a population of over 240 million, Pakistan faces high levels of poverty and inequality. Many communities lack access to adequate resources, making them ill-equipped to cope with climate shocks. The country's dependence on agriculture, contributing about 23% to GDP and employing nearly 37% of the workforce, makes it especially vulnerable to erratic weather conditions. Agriculture uses nearly 90% of Pakistan's water withdrawals (FAO, 2022). Four crops consume nearly three-quarters of irrigation water.

Current water availability per capita has declined sharply. Official records show:

- Historic Level: 5,260 m³/person/year in 1951.
- Current Level: 1,017 m³/person/year in 2021 (Ashraf, 2016).
- Water Stress Threshold: Below 1,700 m³ – water stress; Below 1,000 m³ – water scarcity (UNDP, 2019).

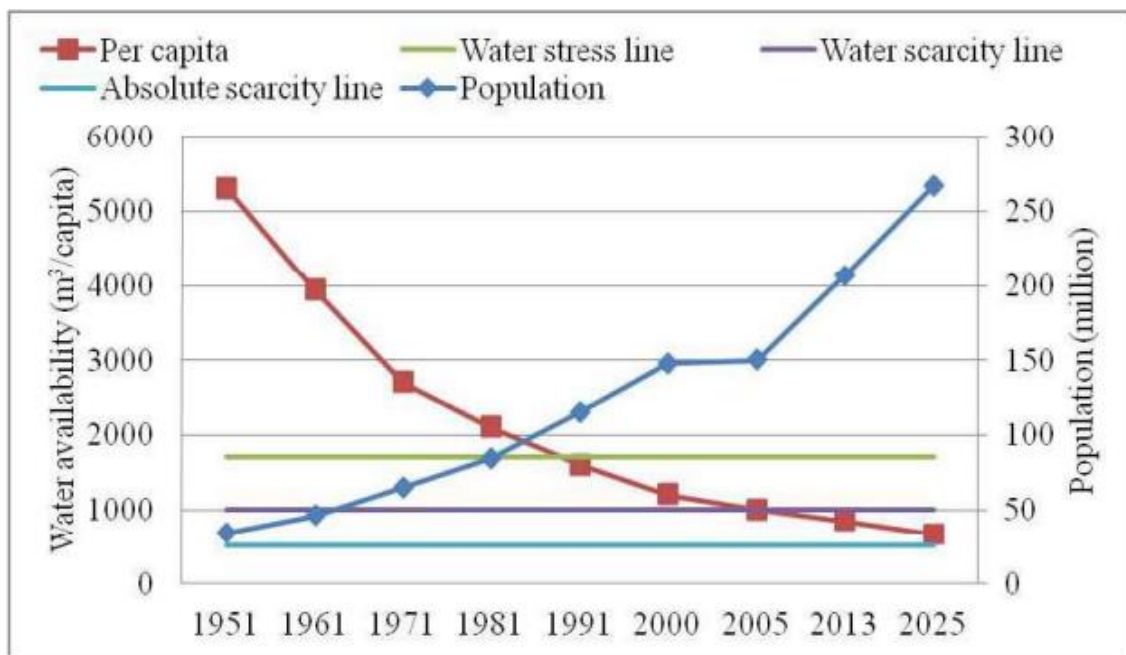


Figure 1. Decline in Per Capita Water Availability (1951–2021) (Ashraf, 2016).

5. Impacts of Climate Change and Water Scarcity in Pakistan

Climate change has profound and multifaceted impacts on Pakistan due to its unique geographic and socioeconomic vulnerabilities. The critical areas where climate change has disrupted the country's natural and humid systems include, water resources, agriculture and food security, health and human well-being, natural disasters, urban and coastal challenges, economic costs, etc. The results reveal that Pakistan has entered a critical phase of water stress, with per capita availability declining from 5,260 m³ in 1951 to approximately 1,017 m³ in 2021. The data confirm that Pakistan crossed the "water scarcity" threshold of 1,000 m³ per capita in 2022 (PCRWR, 2022), with projections indicating a further fall to around 860 m³ by 2030 if current trends persist (World Bank, World Development Indicators: Pakistan, 2023).

Pakistan's water resources are under significant stress due to climate-induced changes in river flows, glacial melt, and shifting precipitation patterns. The country is heavily dependent on the Indus River system, which provides water for agriculture, industry, and domestic use. Pakistan hosts over 7,000 glaciers in the Hindu-Kush Himalayan region, which are melting at an

unprecedented rate due to rising global temperatures. Research shows that glacial retreat threatens to increase river flows in the short term, causing floods, and subsequently reduce flows as glaciers diminish, leading to water scarcity (ADB, 2010). The resultant variability in river discharge disrupts agricultural cycles and water availability. The erratic and intense monsoon rains have replaced historically predictable patterns. These changes increase the likelihood of both floods and droughts, impacting water storage and distribution. For instance, the 2022 monsoon rains were 175% higher than the 30-year average, causing devastating floods that submerged one-third of the country (World Bank, 2022). Prolonged droughts, inefficient irrigation practices, and over-extraction of groundwater exacerbate the crisis threatening water security for millions (Munir, Ahmad, Hopmans, Belgacem, & Baig, 2021).

Agriculture remains the backbone of Pakistan's economy, contributing nearly 23% to GDP and employing about 37% of the workforce (Munir, Ahmad, Hopmans, Belgacem, & Baig, 2021), yet climate variability has severely undermined its productivity, disrupted food supply chains, and threatened rural livelihoods. Rising temperatures, erratic rainfall, and water scarcity

are reducing yields of major crops such as wheat, rice, and cotton, with studies indicating that a 1°C increase in temperature could lower wheat output in the Indus Basin by 6–9%. Livestock is equally vulnerable, as heat stress diminishes milk production and reproduction rates, while droughts and degraded grazing lands raise feeding costs, pushing small farmers into financial distress. The situation is particularly dire in provinces like Balochistan and Sindh, where prolonged droughts have devastated farming communities, triggered food shortages, and forced migration to urban centers. At the same time, rapid urbanization and coastal exposure have created unique climate challenges for cities such as Karachi, where reduced green cover and extensive concrete surfaces intensify heatwaves, making urban temperatures several degrees higher than surrounding rural areas. Poorly planned infrastructure compounds the risks, as seen during the 2022 monsoon when drainage failures inundated roads and homes, while rising sea levels and coastal erosion threaten millions of livelihoods in Sindh's coastal belt, where even a 10 cm rise could inundate vast tracts of land. Beyond agriculture and urban systems, climate change is directly and indirectly affecting public health, disproportionately impacting vulnerable groups such as children, women, and the elderly. Cities like Karachi and Lahore now face frequent and prolonged heatwaves, with the 2015 Karachi heatwave alone claiming over 1,200 lives due to inadequate preparedness and healthcare access (Chaudhry, Mamood, Rasul, & Afzaal, 2009). Shifting rainfall patterns and rising temperatures have expanded mosquito habitats, increasing the prevalence of malaria and dengue, while the 2022 floods triggered widespread outbreaks of waterborne diseases in Sindh and Punjab (WHO, 2022). These climate-induced disruptions have deepened food insecurity, worsened malnutrition, and further strained access to safe drinking water, which is increasingly threatened by flooding, contamination, and over-extraction of groundwater, thereby compounding Pakistan's public health and socio-economic challenges. The frequency and severity of climate-induced natural disasters have escalated, leaving lasting

socioeconomic scars on Pakistan. Pakistan has faced several catastrophic floods including the 2010 super-floods, which affected 20 million people and caused \$10 billion in economic damages (ADB, 2011). Similarly, the 2022 floods displaced over 33 million people, destroying homes, infrastructure, and agricultural lands. However, the prolonged heatwaves in urban areas strain energy resources, increase mortality rates, and reduce labor productivity. These events are projected to intensify in the coming decades. Furthermore, Pakistan has over 3,000 glacial lakes, of which 33 are at risk of sudden outbursts. GLOFs can devastate downstream communities, as seen in the 2020 GLOF in the Hunza Valley, which displaced thousands and disrupted livelihoods. In terms of economic costs, climate change has inflicted significant economic losses on Pakistan, undermining growth and development prospects. Climate-induced disasters cost Pakistan an average of \$3.8 billion annually, equivalent to 1.3% of its GDP (Eckstein, Künzel, & Schäfer, 2021). The economic toll of the 2022 floods alone was estimated at \$30 billion, covering damages to housing, agriculture, and infrastructure (World Bank, 2022). Recurrent disasters disproportionately affect the poor, pushing millions into extreme poverty. Women and marginalized communities are particularly vulnerable because they have fewer resources to adapt or recover. Heatwaves and floods reduce agricultural output, disrupt supply chains, and lead to energy shortages, further straining Pakistan's fragile economy. This reduction is not evenly distributed across regions; instead, socio-economic consequences vary significantly between provinces and sectors.

Punjab (Agriculture Dependency and Productivity Losses): Punjab, which contributes nearly 70% of Pakistan's total agricultural output, faces severe stress on irrigation due to altered river flows and groundwater depletion. Findings indicate that almost 60% of tube wells in central Punjab extract water with declining water tables, with salinity detected in 26% of surveyed districts (Siyal, Gerbens-Leenes, & Vaca-Jiménez, 2023). Farmers reported yield reductions of 15–20% for water-intensive crops

like sugarcane and rice. Thematic analysis of interviews suggests increased input costs for groundwater pumping, contributing to rural indebtedness. Smallholders particularly highlighted the trade-off between allocating scarce water to cash crops versus food staples, directly affecting household food security.

Sindh (Salinity, Livelihood Erosion, and Deltaic Collapse): Sindh is disproportionately affected due to its reliance on Indus tail-end flows. Findings show that reduced freshwater availability has allowed seawater intrusion to affect nearly 2.2 million acres of agricultural land in lower Sindh (IUCN, 2003). The coastal communities in Badin and Thatta reported declining fish catches and agricultural failures, leading to livelihood erosion. Discourse analysis of stakeholder testimonies reveals a sense of dispossession, with migration to Karachi emerging as a coping mechanism. Health surveys also recorded higher incidences of diarrheal diseases due to contaminated drinking water supplies, affecting labor productivity and increasing health expenditures.

Balochistan (Chronic Drought and Pastoralist Distress): The findings confirm Balochistan as the most water-insecure province. Rainfall variability and absence of perennial rivers have created recurrent droughts. Between 2016–2020, approximately 60% of karezes (traditional water channels) in districts such as Mastung and Chagai were reported to have dried up (PCRWR, 2022). The pastoralist economy, heavily dependent on livestock, suffered herd losses of up to 40%, undermining food security and household incomes. Testimonies from respondents emphasized increasing outmigration of youth to Quetta and Karachi in search of work. Water scarcity has thus emerged

as a structural driver of rural poverty in Balochistan.

Khyber Pakhtunkhwa and Gilgit-Baltistan (Glacier Dependency and Hazards): In northern Pakistan, livelihoods depend on glacier-fed rivers. Findings indicate shifts in seasonal water availability due to earlier snowmelt peaks, corroborating IPCC projections for the Hindu Kush–Karakoram–Himalaya region (IPCC, Sixth Assessment Report: Impacts, Adaptation and Vulnerability, 2022). Communities in Gilgit and Hunza valleys reported both increased risks of glacial lake outburst floods (GLOFs) and reduced late-summer flows critical for agriculture. Content analysis of policy documents revealed that while early warning systems exist, local adaptation remains limited. The socio-economic consequences include damage to infrastructure, land loss, and heightened vulnerability of subsistence farming households.

Urban Centers (Inequality in Water Access): In urban contexts such as Karachi, Lahore, and Quetta, water scarcity manifests as unequal access rather than absolute unavailability. Karachi's population of over 16 million receives only about 50-60% of its daily water demand and over 38% of Karachi's daily demand remains unmet (Janjua, et al., 2021). Survey data show that wealthier households rely on private tankers, paying 15–20 times the official tariff, while poorer communities in Orangi and Korangi spend hours daily fetching unsafe water. This inequity translates into health disparities: water-borne diseases contribute significantly to child mortality in informal settlements. Thus, scarcity aggravates urban social stratification. Stakeholder Quote: "Our supply lines lose as much water as they deliver. There's no accountability", KWSB official, Karachi.

Table 1: Socio-Economic Consequences by Region

Region	Primary Consequences	Evidence/Data
Punjab	Yield decline, groundwater salinity, rural debt	PCRWR (2022)
Sindh	Seawater intrusion, migration, health issues	IUCN (2003)
Balochistan	Drought, pastoralist distress, outmigration	PCRWR (2022)
KP & GB	GLOF risks, altered flows, subsistence vulnerability	IPCC (2022)
Urban Centers	Inequitable access, tanker economy, health disparities	KWSB (2021), WHO (2019)

6. Challenges in Addressing Climate Change and Water Scarcity

Pakistan's struggle with climate change and water scarcity is shaped by a complex interplay of economic, institutional, technological, and social constraints that collectively undermine the country's capacity to adapt and mitigate effectively. Despite being one of the most climate-vulnerable nations in the world, ranked eighth on the Global Climate Risk Index (Eckstein, Künzel, & Schäfer, 2021), Pakistan continues to face systemic barriers that hinder the translation of policy frameworks into tangible outcomes. These challenges are not isolated; rather, they are deeply interconnected, reinforcing cycles of vulnerability that leave the country exposed to recurrent climate shocks and chronic water stress.

Economic Constraints: One of the foremost challenges in addressing climate change and water scarcity in Pakistan is the severe limitation of financial resources. The country's fiscal space is constrained by high external debt, which reached approximately USD 126 billion in 2023, reducing the government's ability to allocate sufficient funds for climate adaptation and mitigation (State Bank of Pakistan, 2023). Although Pakistan has pledged to reduce its greenhouse gas emissions by 20% by 2030 under its Nationally Determined Contributions (NDCs), this commitment is conditional upon receiving an estimated USD 40 billion in international financial support (Ministry of Climate Change, 2021). Accessing such funds, however, has proven difficult due to bureaucratic hurdles, donor fatigue, and global competition for climate finance.

Domestically, climate change receives minimal budgetary attention. In the fiscal year 2022–23, less than 1% of the federal budget was allocated to environmental and climate-related programs (Pakistan Economic Survey, 2022). This chronic underfunding has limited the scaling of renewable energy projects, the modernization of irrigation systems, and the development of disaster-resilient infrastructure. Moreover, the prioritization of short-term economic stabilization over long-term climate planning perpetuates a cycle where immediate fiscal pressures overshadow the urgency of climate

action. The economic challenge is further compounded by the agricultural sector's inefficiencies, which consume over 90% of freshwater resources yet contribute only about 19% to GDP (FAO, 2022). Without significant investment in water-efficient technologies and climate-smart practices, Pakistan risks deepening its economic and ecological vulnerabilities.

Governance and Institutional Weaknesses:

Governance deficits remain a critical impediment to effective climate and water management. The devolution of environmental responsibilities to provinces under the 18th Constitutional Amendment has created fragmentation in policy implementation. While the National Climate Change Policy (2012) and the Pakistan Climate Change Act (2017) provide comprehensive frameworks, their execution at the provincial level has been inconsistent due to limited technical capacity and financial resources (Syed, Awan, & Mumtaz, 2024). Weak coordination between federal and provincial institutions has resulted in overlapping mandates and accountability gaps, undermining policy coherence.

Despite policy recognition of climate risks, Pakistan faces entrenched barriers to effective action. Governance deficits are prominent: corruption, weak enforcement, and fragmented institutional mandates undermine policy delivery. The Ten Billion Tree Tsunami initiative, while ambitious, continues to struggle with illegal logging and inconsistent monitoring (UNEP, 2021). Similarly, inequities in the Indus Basin Irrigation System, where tail-end farmers are systematically deprived of water, reveal persistent governance failures (Qureshi, McCornick, Sarwar, & Sharma, 2010). The absence of robust monitoring and evaluation systems also hampers the ability to track progress on adaptation and mitigation targets, leaving policies aspirational rather than actionable.

Technological and Knowledge Barriers:

Technological limitations compound these governance gaps. The transition to renewable energy, for example, is hindered by limited access to efficient solar panels, wind turbines, and grid integration technologies, which remain costly and dependent on imports. Similarly,

outdated irrigation techniques—particularly flood irrigation, result in nearly 40% conveyance losses before water reaches fields (WAPDA, 2020). Modern systems such as drip and sprinkler irrigation remain underutilized due to high costs and limited extension services. Renewable energy adoption, a key mitigation pathway, is slowed by dependence on imported technologies and inadequate grid integration. Knowledge deficits exacerbate these constraints: the Pakistan Meteorological Department's limited forecasting capacity reduces preparedness for floods, droughts, and heatwaves (Chaudhry, Mamood, Rasul, & Afzaal, 2009). The absence of a centralized climate-water data management system further hampers evidence-based policymaking. Research and development (R&D) on climate-resilient technologies remain underfunded, while climate education and awareness campaigns are insufficient to mobilize community-level action. This technological and knowledge deficit not only delays adaptation but also prevents Pakistan from tailoring solutions to its unique ecological and socio-economic context.

Socioeconomic Inequities: The impacts of climate change and water scarcity are unevenly distributed across Pakistan's population, with marginalized groups bearing the heaviest burdens. Rural communities, which rely heavily on agriculture for their livelihoods, are particularly vulnerable to climate-induced droughts, floods, and erratic rainfall. The 2022 floods displaced over 33 million people, destroyed millions of acres of crops, and pushed rural households into acute food insecurity (World Bank, 2022). With limited access to financial safety nets, these communities struggle to recover from climate shocks, perpetuating cycles of poverty and vulnerability.

Women, in particular, face disproportionate challenges. As primary managers of household water and food resources, women in rural Pakistan are directly affected by water scarcity and food insecurity. Yet, they face structural barriers to land ownership, credit, and decision-making, limiting their adaptive capacity (ADB, 2011). Empowering women through education, microfinance, and inclusion in water governance structures has been shown to

improve community resilience, but such initiatives remain limited in scope.

Urban populations are not immune to these inequities. Low-income and poor communities, particularly in informal settlements of Karachi and Lahore, are disproportionately exposed to water scarcity, flooding, and heat islands due to inadequate infrastructure and municipal neglect. These inequalities highlight the necessity of inclusive adaptation frameworks that address both technical and social dimensions.

The challenges Pakistan faces in addressing climate change and water scarcity are multifaceted. Financial constraints limit the scaling of climate initiatives, while governance weaknesses undermine policy implementation and accountability. Technological and knowledge gaps delay the adoption of innovative solutions, and socioeconomic inequities exacerbate the vulnerability of marginalized groups. Addressing these challenges requires a holistic approach that integrates economic reforms, institutional strengthening, technological innovation, and social inclusion. Without simultaneous reforms in governance, financing, technology, and equity, Pakistan risks remaining locked in cycles of climate vulnerability and water insecurity.

7. Results Analysis

The results converge on a clear pattern: climatic variability and intensifying extremes are interacting with structural inefficiencies in Pakistan's water economy, yielding regionally uneven but nationally significant socio-economic impacts. The empirical evidence confirms that climatic variability is intensifying Pakistan's hydrological stress while exposing systemic inefficiencies in water governance. Temperature records from the Pakistan Meteorological Department indicate an increase of approximately 0.57°C per decade since 1960, with projections suggesting a further rise of 2.0–2.8°C in northern Pakistan by mid-century (PMD, 2022; IPCC, 2022). These changes are compressing agricultural cycles, increasing heat stress, and amplifying the risks of both drought and flooding. Hydrological data corroborate this trend: glacial retreat in the Hindu Kush–Karakoram–Himalaya region has shifted peak

flows earlier in the year, complicating irrigation scheduling and reservoir management. Simultaneously, erratic monsoon rainfall, exemplified by the 2022 floods, illustrates the

volatility of precipitation patterns, which threaten both rural livelihoods and national infrastructure (World Bank, 2022).

Figure 1: This graph shows the average temperature in Pakistan from 1961 to 2021 (Pakistan Meteorological Department, 2022).

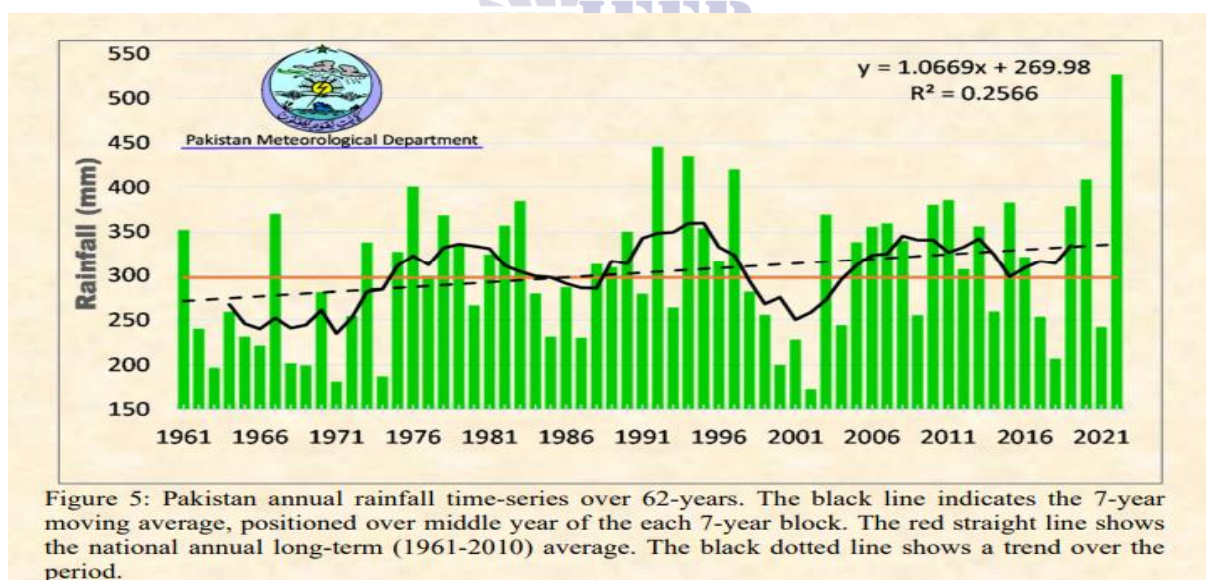
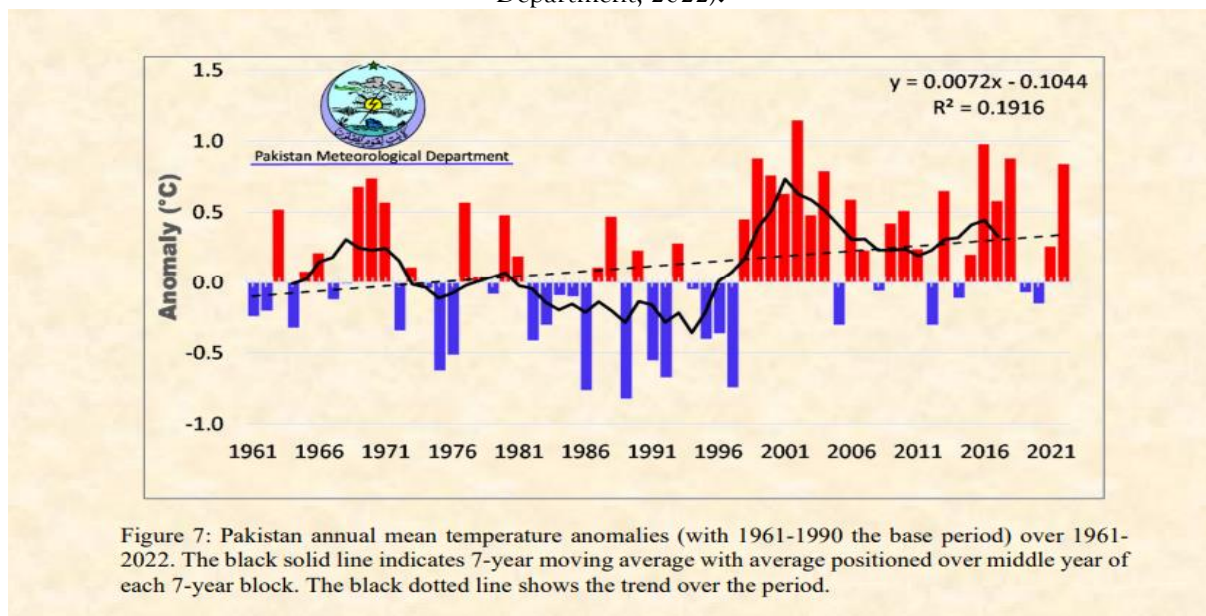


Figure 2: This figure shows the amount of precipitation in Pakistan from 1961 to 2021 (Pakistan Meteorological Department, 2022).

Hydrological signals mirror the thermal trends. The satellite and field evidence documenting losses in major glaciers such as Batura and Siachen; communities in Hunza and adjacent valleys reported increased glacial lake outburst flood (GLOF) risk and flash flooding from newly

formed lakes (Bajracharya & Mool, 2009). Flow timing at Tarbela has advanced by 2-3 weeks compared to the 1980s, consistent with earlier snowmelt peaks and altered runoff regimes, while Kabul River peak shifts of roughly 2.5 weeks indicate basin-wide phenological change.

These changes complicate reservoir operations and downstream irrigation scheduling, particularly in tail-end command areas where

reliability is already compromised by conveyance losses and governance gaps.

Table 2.
Change in Timing of Peak River Flows (1980–2020)

River	1980s Peak Flow	2020 Peak Flow	Shift (Weeks)
Indus (Tarbela)	Mid-July	Late June	-2
Kabul River	Early August	Mid-July	-2.5

Water availability trends underscore the severity of the resource constraint. Per capita renewable water has declined from approximately 5,260 m³/year in 1951 to about 1,017 m³/year in 2021, placing Pakistan at the brink of the international scarcity threshold; the trajectory reflects demographic growth, limited storage, and growing consumptive use (Ashraf, 2016; PCRWR, 2022; UNDP, 2019). PMD and PCRWR analyses, supported by stakeholder accounts, link declining and more variable precipitation with intensified dry spells in arid and semi-arid zones, while the 2022 monsoon anomaly, 175% above the 30-year average, triggered devastating floods affecting one-third of the country and imposing damages near USD 30 billion (World Bank, 2022). The coexistence of pluvial/flood risks and hydrological drought across seasons and regions highlights the volatility and the need for storage and demand management rather than an exclusive focus on supply augmentation.

Sectoral water use patterns accentuate the stress. Agriculture accounts for nearly 90% of withdrawals, with four crops, wheat, rice, sugarcane, and cotton, consuming roughly three-quarters of irrigation water, reflecting entrenched cropping patterns and low water productivity (Rehman, et al., 2015). Interviews and provincial reports reveal that conveyance losses remain high and modern irrigation technologies (drip, sprinkler, HEIS) are adopted on a small fraction of cultivated area, well below policy targets, due to cost, awareness, and institutional barriers (PMD, Climate Data Archive, 2021). This inefficiency interacts with climatic stressors: a 1°C rise can reduce wheat yields by an estimated 6–9% in the Indus Basin, while heat stress depresses livestock productivity, and droughts elevate feed costs, undermining smallholder resilience (IPCC, 2022).

Table 3. Major Crops and Water Share in Agriculture

Crop	Share of Water Use (%)
Wheat	23
Rice	21
Sugarcane	19
Cotton	14

Regional disaggregation illuminates heterogeneous burdens. In Punjab, where approximately 70% of national agricultural output is concentrated, groundwater tables are declining across central districts, with salinity detected in over a quarter of surveyed locales; farmers reported 15–20% yield reductions in water-intensive crops, rising pumping costs, and growing rural indebtedness, indicating the

macro trend's microeconomic translation (Siyal, Gerbens-Leenes, & Vaca-Jiménez, 2023). Sindh's tail-end canals demonstrate pronounced inequity and vulnerability: seawater intrusion has affected about 2.2 million acres in lower districts, while tail-end farmers receive substantially less than allocated water due to conveyance losses and elite capture; livelihoods in Badin and Thatta have

shifted as fish catches decline and agriculture fails, with migration to Karachi as a coping response (IUCN, 2003; Janjua, et al., 2021). Balochistan exhibits chronic drought and aquifer depletion: approximately 60% of karezes in Mastung and Chagai reportedly dried between 2016 and 2020, pastoralist herds suffered up to 40% losses, and youth outmigration accelerated, underscoring scarcity's role as a structural driver of rural poverty (van Steenberg, Kaisarani, Khan, & Gohar, 2015). In KP and GB, earlier snowmelt peaks and proliferating GLOF risks damage infrastructure and threaten subsistence agriculture; while early warning systems have expanded in selected valleys, local adaptation remains uneven.

Urban centers register scarcity as unequal access rather than absolute absence. In Karachi, an estimated 40% of water is lost to leakages and illegal connections, and over a third of daily demand remains unmet; tanker markets fill the gap at prices many times official tariffs, imposing disproportionate burdens on low-income households in informal settlements (Janjua, et al., 2021). These inequities translate into public health risks, with repeated flood events and intermittent supply aggravating waterborne disease incidence; rural and urban data converge on high exposure among children under five where safe water and sanitation are inadequate (WHO, 2022; Murtaza, Muzaffar, Mustafa, & Anwer, 2021). The 2015 Karachi heatwave, claiming over 1,200 lives, exemplifies compound climate-health hazards in cities with limited preparedness, and anticipates more frequent heat extremes under AR6 scenarios (Chaudhry, Mamood, Rasul, & Afzaal, 2009). Synthesizing these strands, the analysis indicates that climate change is a force multiplier acting on an already inefficient and inequitable water system. Earlier runoff peaks, a warming climate, and erratic monsoon behavior stress infrastructure and institutions designed for relatively stationary hydrology. Simultaneously, irrigation inefficiencies and cropping distortions amplify scarcity, while fragmented governance, post-18th Amendment, complicates basin-scale coordination and data integration across federal and provincial

authorities (Government of Pakistan, 2018). The socio-economic consequences are profound and region-specific: productivity losses and indebtedness in Punjab; deltaic collapse and health burdens in Sindh; pastoralist distress and aquifer decline in Balochistan; and hazard exposure in KP/GB. Urban inequities and tanker economies further stratify risk and cost, entangling water scarcity with poverty and public health.

Importantly, the evidence also points to leverage points. Where high-efficiency irrigation systems have diffused, water savings up to 40% are documented; catchment stabilization through reforestation reduces erosion and improves spring flows; and selected pilot recharge projects report localized aquifer gains during monsoon months (Ishaque, Tanvir, & Mukhtar, 2022). Yet these remain fragmented and underfunded relative to the scale of risk. The results thus argue for a pivot from piecemeal supply-side projects toward integrated demand management, groundwater regulation, storage augmentation (decentralized and nature-based), and equity-centered allocation, embedded in stronger inter-provincial coordination and national data systems. Absent such systemic reforms, warming and hydrological volatility will continue to outpace adaptive capacity, deepening regional disparities and macroeconomic exposure (World Bank, 2022). Pakistan needs to act immediately and the cooperation of the international community, including both state and non-state actors, is required on urgent basis.

8. Adaptation and Mitigation Strategies for Pakistan

Pakistan stands at the frontline of climate change impacts, with water scarcity emerging as the most pressing challenge threatening its socio-economic stability, food security, and ecological sustainability. The country's dependence on the Indus Basin Irrigation System (IBIS) makes it acutely vulnerable to glacial retreat, erratic monsoon patterns, and rising temperatures. The IPCC (2022) has underscored South Asia's vulnerability to intensified hydrological extremes, with Pakistan

particularly exposed due to its geography and governance constraints. To respond effectively, strategies must extend beyond reactive measures, embedding adaptation and mitigation within long-term development frameworks.

must be integrated and equity-centered, ensuring that adaptation and mitigation are pursued in tandem while addressing governance and social justice dimensions. Without such systemic reforms, the widening gap between climate risks and institutional responses will continue to undermine sustainable development.

Adaptation Strategies

Adaptation strategies are essential to minimizing the risks posed by climate variability and extreme weather events. It requires prioritizing water governance reforms, including canal lining, telemetry-based monitoring, and regulation of groundwater abstraction.

Climate-Resilient Water Management:

Adaptation in Pakistan must begin with water governance reforms. The IBIS, though historically one of the largest irrigation systems in the world, suffers from inefficiencies, seepage losses, and inequitable distribution. Estimates suggest that nearly 40% of water is lost before reaching farms due to canal seepage and outdated conveyance systems (PCRWR, 2022). Enhancing climate-smart agriculture through high-efficiency irrigation, crop diversification, and drought-resistant varieties offers dual benefits of water savings and productivity gains (FAO, 2022). Disaster preparedness, particularly early warning systems for floods and glacial lake outburst floods, must be scaled across vulnerable regions. Urban resilience, through green infrastructure and climate-sensitive planning, is equally urgent. Moreover, groundwater extraction, which accounts for nearly 50% of irrigation demand, is largely unregulated, leading to over-extraction and salinity intrusion (Qureshi, McCornick, Sarwar, & Sharma, 2010). Introducing groundwater governance frameworks, including licensing,

metering, and community-based recharge projects, can help restore aquifer sustainability. Water storage capacity is another critical gap. Pakistan's current storage capacity is approximately 30 days of average river flows, compared to the global benchmark of 120 days (ADB, 2010). Expanding small and medium-sized reservoirs, alongside nature-based solutions such as wetland restoration and watershed management in the upper Indus Basin, can enhance resilience to both floods and droughts. Rainwater harvesting in urban and peri-urban areas, particularly in water-stressed cities like Quetta and Karachi, should be mainstreamed through municipal bylaws and incentives.

Climate-Smart Agriculture: Agriculture, which consumes over 90% of freshwater resources, must undergo a structural transformation to adapt to climate variability. Climate-smart agriculture (CSA) practices, including laser land leveling, drip and sprinkler irrigation, and drought-resistant crop varieties, have demonstrated significant water savings and yield improvements in pilot projects across Punjab and Sindh (FAO, 2022). For instance, high-efficiency irrigation systems (HEIS) have shown water savings of up to 60% while increasing crop productivity (Ministry of Water Resources, 2025). However, adoption remains limited due to high upfront costs and lack of farmer awareness. Scaling CSA requires targeted subsidies, credit facilities, and extension services tailored to smallholder farmers, who constitute the majority of Pakistan's agricultural workforce.

Crop diversification is another key adaptation measure. The dominance of water-intensive crops such as rice and sugarcane exacerbates water stress. Shifting towards less water-demanding crops like pulses, oilseeds, and horticultural products can reduce water footprints while enhancing nutritional security (Qureshi, McCornick, Sarwar, & Sharma, 2010). Moreover, integrating agroforestry and conservation agriculture can improve soil health, reduce evapotranspiration, and provide additional income streams for rural households.

Disaster Risk Reduction and Early Warning Systems: Pakistan's vulnerability to floods, droughts, and glacial lake outburst floods (GLOFs) necessitates robust disaster risk reduction (DRR) strategies. The 2022 floods, which affected over 33 million people and caused damages exceeding USD 30 billion, underscored the inadequacy of current preparedness mechanisms (World Bank, 2022). Strengthening early warning systems through real-time hydrometeorological monitoring, community-based disaster preparedness, and integration of satellite data can significantly reduce human and economic losses. The Pakistan Meteorological Department's GLOF early warning initiatives in Gilgit-Baltistan and Chitral provide a promising model that should be scaled nationwide (PMD, 2021).

Urban resilience must also be prioritized. Cities like Karachi and Lahore face compounded risks from heatwaves, flooding, and poor drainage infrastructure. Climate-adaptive urban planning, including green belts, permeable pavements, and stormwater management systems, can mitigate these risks. Public health preparedness, particularly heatwave response plans and vector control programs, must be integrated into municipal governance.

Social and Institutional Adaptation: Adaptation is not merely technical but also institutional and social. Strengthening the capacity of local water user associations, farmer cooperatives, and community-based organizations can ensure participatory governance and equitable resource distribution. Gender-sensitive adaptation is particularly critical, as women in rural Pakistan bear disproportionate burdens in water collection, agricultural labor, and household food security (ADB, 2011). Policies must therefore integrate women's voices in decision-making and provide targeted support for female farmers and entrepreneurs.

Case study Gilgit-Baltistan Community-Based DRM Program: The Gilgit-Baltistan Community-Based DRM Program implemented by the International Center for Integrated Mountain Development

(ICOMOD), is a successful example of climate adaptation. The program focuses on empowering local communities to manage their risks of GLOFs and other disasters. This program has significantly reduced disaster-related casualties and economic losses in the region.

Key components include:

- Installation of early warning systems in high-risk valleys.
- Training local volunteers in search-and-rescue operations.
- Constructing small-scale flood defenses to protect villages.

Mitigation Strategies

Pakistan, though contributing less than 1% to global greenhouse gas (GHG) emissions, faces disproportionate impacts of climate change and has an essential role in global mitigation efforts. The country's mitigation strategies aim to address its reliance on fossil fuels, reduce emissions from key sectors, and transition to a low-carbon economy while adhering to its international commitments. Below are the key mitigation strategies for Pakistan.

Renewable Energy Transition:

Pakistan's energy sector is both a contributor to and a victim of climate change. The country's reliance on fossil fuels not only exacerbates greenhouse gas (GHG) emissions but also increases vulnerability to global oil price volatility. Transitioning towards renewable energy sources, solar, wind, and hydropower, offers a dual benefit of reducing emissions and alleviating water stress. Thermal power plants consume significant amounts of water for cooling, whereas solar and wind energy are virtually water-free technologies. Pakistan's Alternative and Renewable Energy Policy (2019) aims to achieve 30% renewable energy by 2030, but implementation remains slow. Accelerating investment in decentralized solar systems, particularly for rural electrification and agricultural pumping, can reduce both emissions and groundwater depletion.

Forestry and Ecosystem Restoration: Forests play a critical role in carbon sequestration, watershed protection, and microclimate

regulation. Pakistan's forest cover, however, is alarmingly low at around 5% of total land area. Initiatives such as the Billion Tree Tsunami and the Ten Billion Tree Tsunami Program have made progress in afforestation and ecosystem restoration, with over 1.5 billion trees planted by 2021 (UNEP, 2021). While these programs have garnered international recognition, concerns remain regarding survival rates, species selection, and long-term monitoring. A shift towards community-managed forestry, integration of indigenous species, and transparent monitoring mechanisms can enhance the effectiveness of afforestation as a mitigation strategy.

Industrial Efficiency and Waste Management:

Industrial emissions and urban waste contribute significantly to Pakistan's GHG profile. Improving energy efficiency in industries, particularly textiles, cement, and fertilizer, can reduce both emissions and water consumption. Adoption of cleaner production technologies, waste heat recovery, and circular economy practices should be incentivized through fiscal and regulatory frameworks. Solid waste management, particularly methane capture from landfills, offers another mitigation opportunity. Cities like Lahore and Islamabad can benefit from waste-to-energy projects that simultaneously reduce emissions and provide renewable energy.

Transport Sector Reforms: The transport sector, responsible for nearly 25% of Pakistan's energy-related emissions, requires urgent reforms (World Bank, 2023). Promoting mass transit systems, electric vehicles (EVs), and non-motorized transport can significantly reduce emissions while improving urban air quality. The National Electric Vehicle Policy (2020) sets ambitious targets for EV adoption, but infrastructure development, including charging stations and grid integration, must be accelerated. Moreover, shifting freight transport from road to rail can reduce both emissions and fuel costs.

Integrating Adaptation and Mitigation: The Nexus Approach

A critical insight from global climate governance is that adaptation and mitigation

cannot be pursued in isolation. In Pakistan, water, energy, and agriculture are deeply interconnected, necessitating a nexus approach. For instance, promoting solar-powered irrigation reduces emissions, alleviates groundwater stress, and enhances farmer resilience. Similarly, afforestation not only sequesters carbon but also improves watershed health and reduces flood risks. Therefore, ensuring synergy between adaptation and mitigation efforts, avoiding fragmented strategies, and maximizing resource efficiency is highly required for an integrated approach. Integrated Water Resources Management (IWRM), combined with the Regimes Theory framework, provides a holistic lens for designing policies that maximize synergies and minimize trade-offs.

Developing city-level climate action plans that combine adaptation measures (e.g., flood defenses) with mitigation strategies (e.g., sustainable transportation and energy-efficient buildings) is also very efficient. Using mangroves along coastal areas to protect against rising sea levels and storms while sequestering carbon and wetlands restoration can improve water storage and biodiversity. Involving marginalized groups, particularly women and rural communities, in decision-making processes improves the overall adaptation and mitigation to climate change and water scarcity. Their local knowledge and active participation can enhance the effectiveness of adaptive and preventive measures.

Effective implementation of adaptation and mitigation strategies requires robust governance, financing, and institutional coordination. Therefore, trained policymakers and government officials can play a more effective role in integrated climate action to ensure informed decision-making and efficient resource allocation. The fragmentation of responsibilities across federal and provincial levels, particularly after the 18th Constitutional Amendment, has created overlaps and gaps in climate and water governance (Mustafa, Akhter, & Nasralla, 2013). Establishing a federal-provincial coordination mechanism, such as a strengthened Water and Climate Council, can ensure policy coherence. Climate finance is

another critical enabler. Pakistan's access to global climate finance remains limited; developing bankable projects and transparent monitoring systems is essential to mobilize resources through mechanisms such as the Green Climate Fund.

Conclusion

This research has demonstrated that climate change and water scarcity in Pakistan constitute interdependent crises that reinforce one another and pose existential risks to the country's socio-economic stability, ecological balance, and political resilience. Evidence indicates that Pakistan has already crossed the internationally recognized water scarcity threshold, with per capita availability falling to nearly 1,000 m³ in 2021 and projected to decline further amid rising demographic pressures. Concurrently, mean annual temperatures have increased by 0.57°C per decade since 1960, while erratic monsoon variability, accelerated glacial retreat in the Hindu Kush–Karakoram–Himalaya region, and the proliferation of extreme events such as the 2010, 2022, and 2025 floods underscore the intensifying volatility of Pakistan's hydrological regime.

Findings reveal that the challenge is not confined to physical scarcity but is compounded by governance deficits, inequitable distribution, inefficient irrigation, and weak institutional coordination. The evidence highlights pronounced regional disparities: groundwater salinity and indebtedness in Punjab; seawater intrusion and deltaic collapse in Sindh; chronic drought and pastoralist distress in Balochistan; and glacial hazards in Gilgit-Baltistan. Urban centers such as Karachi and Lahore illustrate the inequities of access, where tanker economies and crumbling infrastructure deepen socio-economic stratification and public health risks. Taken together, the policy frameworks developed, such as the National Water Policy (2018) and Climate Change Policy (2021), provide a foundation but remain hampered by fragmented mandates, limited financing, and inadequate enforcement. Effective adaptation requires moving from supply-driven approaches

to integrated water resource management, emphasizing efficiency, demand management, and equity. Climate-smart agriculture, decentralized storage, renewable energy transitions, and community-based governance provide viable pathways, but only if anchored in coherent institutions, robust financing, and inclusive participation.

Ultimately, Pakistan's pathway to resilience lies in bridging science, policy, and society. Strengthening federal–provincial coordination, embedding equity into allocation frameworks, and mainstreaming climate considerations into economic planning are imperative. Without such systemic reforms, Pakistan risks remaining locked in a cycle of vulnerability. With them, however, the country has the potential to transform its climate and water crises into an opportunity for sustainable development and regional leadership in resilience.

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