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Climate Change in Pakistan: Emerging Challenges and Sustainable Solutions

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ABSTRACT

Climate change has become a multidimensional human-security challenge in Pakistan, affecting water availability, food systems, livelihoods, public health, economic stability, infrastructure and population displacement. This study investigates Pakistan's major climate-related challenges, underlying socioeconomic vulnerabilities and potential pathways towards climate resilience and sustainable development. A quantitative secondary-data design was employed using annual national-level indicators obtained from FAOSTAT, the World Bank's World Development Indicators, the World Bank/IDMC disaster-displacement database and the Pakistan Floods 2022 Post-Disaster Needs Assessment. Depending on data availability, the analysis covered 2000–2025. Descriptive statistics, ordinary least-squares trend analysis, period-mean comparisons and Pearson correlations in levels and annual first differences were applied. The results revealed a statistically significant increase in temperature anomaly of approximately 0.026°C annually. Urban population, water stress and per-capita carbon dioxide emissions also increased significantly, whereas forest area and the renewable-energy share declined. Although food production and life expectancy improved and undernourishment decreased over the longer period, these gains coexisted with rising unemployment, limited improvement in safely managed drinking-water coverage and continuing dependence on climate-sensitive agriculture. The 2022 floods demonstrated the scale of Pakistan's vulnerability, affecting approximately 33 million people, displacing more than eight million and causing combined damage and economic losses exceeding US$30 billion. Several correlations observed in indicator levels became insignificant after first differencing, demonstrating that common time trends should not be interpreted as causal relationships. The study concludes that climate change in Pakistan is not solely an environmental problem but an interconnected development and human-security crisis. Strengthening resilience requires integrated water governance, climate-smart agriculture, renewable energy, ecosystem restoration, resilient infrastructure, early-warning systems, shock-responsive social protection and transparent climate financing.

Keywords: *climate change; human security; climate vulnerability; disaster displacement; water stress; food security; climate resilience; sustainable development; Pakistan*

INTRODUCTION

Climate change has emerged as one of the defining environmental and developmental challenges of the twenty-first century. Concentrations of greenhouse gasses in the atmosphere have risen and the global climate system has also changed as a result of human activities, especially fossil-fuel combustion, deforestation, industrial production or other unsustainable uses of the land. The impacts are an increase in temperature, changes in precipitation, sea-level rise, loss of glaciers, and an increase in the likelihood of compound extreme events. Losses and damages to natural and human systems are already increasing across the globe and are particularly acute for countries with high poverty rates, climate-exposed livelihoods and low adaptive capacity (IPCC, 2023).

Pakistan is a special case as its geographical diversity makes the country vulnerable to various climate hazards which are compounded. The country encompasses the Hindu Kush-Karakoram-Himalaya glacier-fed mountain regions, the Indus River Basin, dry and semi-dry regions, urban areas with high population density, and a long coastline along the Arabian Sea. These geographic contexts make various regions susceptible to glacial lake outburst flood, riverine and flash flood, drought, heat wave, water scarcity, sea-level rise, coastal erosion and saltwater intrusion. There has been significant spatial and seasonal variability in precipitation found by observational research, with contrasting trends across the climatic regions of Pakistan, which makes water-resource and disaster planning more difficult (Hussain et al., 2022). Rapid population growth, poverty, unplanned urbanisation, environmental degradation and reliance on climate sensitive agriculture increases exposure and limits the capacity of households and institutions to adapt (Adnan et al., 2024).

The 2022 catastrophic floods highlighted the importance of the interplay between climatic and socio-economic factors in creating a national hazard. The floods impacted about 33 million people, and resulted in over 1,730 deaths and over 8 million people being forcibly displaced. Physical damages of more than US$14.9 billion, economic losses of about US$15.2 billion and resilient reconstruction needs of at least US$16.3 billion were officially estimated. The most severely impacted industries included housing, agriculture and livestock, and transportation (Government of Pakistan et al., 2022). The disaster was a result of extreme monsoon rainfall, pre-saturn soils, rapid snowmelt, terrain exposure and communities living in exposed areas. This evidence shows that climate hazards are not distinct from land-use, infrastructure quality, poverty and governance (Arshad et al., 2025).

Climate change also threatens the water, food, energy and economic security of Pakistan, in the long term. The Indus Basin is utilized for irrigated farming, hydroelectric power, industrial and domestic water. But with rising temperatures, unpredictable rainfall, glacier and snow changes, inefficient irrigation, groundwater depletion and the ever-growing demand, this system is under a lot of stress (Adnan et al., 2022). Climate variability is detrimental for the productivity of agriculture and the four dimensions of food security, namely availability, accessibility, utilisation and stability. The recent national level analysis revealed that climate variability and population growth have huge negative consequences for food security in Pakistan (Abbas et al., 2025). By 2050, under the worst climate scenarios, in a country like Pakistan, the impacts of heat, water insecurity, flooding, declines in labour productivity, agricultural and infrastructure losses may result in a gross domestic product (GDP) reduction of around 7–9% compared to the projected baseline (World Bank, 2022).

Public health, urban settlements, coastal ecosystems and socially marginalised groups are also at risk. Heatwaves can lead to heat exhaustion and heatstroke, and waterborne and vector-borne diseases can be spread during both floods and warmer weather, along with cardiovascular stress and risks for the occupation. Pakistan has already witnessed the increase in the burden of dengue due to climatic and environmental factors (Abid & Abid, 2023). Sea-level rise, saltwater intrusion, erosion, and ecosystem degradation is a problem for coastal communities, while rapid urbanization exacerbates surface urban heat islands and flood exposure (Rizvi et al., 2021; Weeks et al., 2023). Women, children, low income households, small farmers, informal workers, displaced populations and persons with disabilities are often at higher risk and have less access to financial, institutional and technological resources to recover.

Pakistan has reacted by introducing its National Climate Change Policy, revised National Determined Contribution, National Adaptation Plan, institutions for disaster-management, afforestation programmes, renewables policies and programmes for climate-resilient development. Yet, the policy making to implementation interface continues to have a gap. Some significant barriers are: lack of local participation, fragmented institutional responsibilities, limited climate finance, weak monitoring, inconsistent policy coordination, and limited technical capacity (Masud & Khan, 2024). Recent assessment also indicates that current flood-risk planning is infrastructure-centric, with a need to focus more on NbS, rural resilience, community engagement, local knowledge, and non-structural approaches (Zhu et al., 2026).

Given this background, the purpose of this study is to critically investigate the new challenges that are posed by climate change in Pakistan and identify sustainable approaches that can build environmental, social, and economic resilience. The specific objectives of this are to: first, review recent climatic trends and major climate hazards in Pakistan; second, analyse the implications of these climatic hazards for water, agriculture, food security, health, ecosystems, infrastructure, livelihoods and vulnerable groups; third, assess the current state of adaptation, mitigation and resilience building measures; and fourth, develop and propose an integrated package of sustainable and contextually appropriate solutions for national, provincial, local and community-level applications.

LITERATURE REVIEW

Changing Climate Patterns and Extreme Events

Climate change in Pakistan can be seen in various forms in recent literature, such as increased temperature, erratic rainfall, extended dry periods, heat waves and sudden bursts of rainfall. Hussain et al. (2022) have found a significant spatial and temporal variability in the changes of precipitation, indicating that the national average trends might mask the opposing regional trends. This variability makes the operation of the reservoirs, agricultural planning, drought monitoring and flood forecasting difficult. Climate-model projections indicate that the temperature and precipitation extremes will increase in the twenty-first century, with the magnitude of change being different among the climatic zones of Pakistan such as arid, monsoon, coastal and mountainous (Hussain et al., 2022).

The science of floods has shifted from their consideration as the isolated natural phenomena to the study of the compound climatic and anthropogenic drivers. The exceptional multiday precipitation associated with the 2022 flood was identified by Nanditha et al. (2023) and the large-scale atmospheric circulation and simultaneous heatwave condition over the Eurasia was linked by Hong et al. (2023). In a more recent analysis, heavy pre-monsoon rainfall was found to have led to an increase in soil moisture prior to the onset of extraordinarily high monsoon rainfall, and warmer conditions were found to have helped drive upstream snowmelt. Further human manipulation of floodplain and drainage system compounded the disaster effect (Nanditha et al., 2023; Hong et al., 2023; Arshad et al., 2025). These results suggest that the disaster risk is influenced by atmospheric hazards, hydrological conditions, land use, infrastructure, exposure and social vulnerability.

Water, Glaciers and Coastal Ecosystems

The Indus Basin is also at the heart of the water, food and energy security of Pakistan, yet has a high climate change vulnerability due to its reliance on snow and glacier melt. A modelling study of the Gilgit River Basin for 1981–2020 determined that glacier melt accounted for about 46%, snow melt for 25%, base flow for 24%, and direct rainfall runoff for 5% of the streamflow in the basin. The study also found that there were upward trends in the runoff components, but with significant differences between the elevations and the season (Adnan et al., 2022). Glacier melt can cause increased flows and flood risks with accelerated melt, potentially, although glacier loss may eventually lead to a decrease in dependable dry season flows.

Efficient irrigation, over-extraction of groundwater, pollution, limited storage space and rising amounts of domestic and industrial demand exacerbate these uncertainties.

As a result, the water scarcity faced by the country is not just a result of reduced physical availability but rather the interplay among climate change, demographic stress, the inefficiency of water management, unequal water distribution and institutional weakness. Baocheng et al., (2024) concluded that water scarcity in Pakistan is increasing as a result of climate-related changes and will need integrated management, conservation, upgrade of infrastructure and better policy coordination. The coastal region is further affected by sea-level rise, coastal erosion, diminished sediment supply, subsidence, saltwater inundation, contamination and mangroves loss. The low-lying Indus Delta is highly vulnerable and long-term consistent coastal data for coastal planning is still limited (Baocheng et al., 2024; Weeks et al., 2023). This makes coastal monitoring, mangrove restoration, protection of environmental flows and risk-sensitive development crucial components of national climate adaptation.

Agriculture, Food Security and Rural Livelihoods

Agriculture is one of the most climate sensitive sectors in Pakistan as crop production is very sensitive to temperature, seasonal rainfall, irrigation water, soil conditions and timing of extreme events. Heat stress can cause reduced crop-development times and drought can lead to reduced water availability, and flooding can affect standing crops, livestock, stored inputs, irrigation systems and rural roads. Food security is also indirectly impacted through increased production costs, disruptions in food supply, loss of livelihood, food-price inflation and loss of household purchasing power. A national empirical analysis from 1995 to 2023 revealed that climate variability and population growth had a significant impact on the food-security situation in Pakistan, highlighting the need to consider both production and access, along with stability and utilisation (Abbas et al., 2025).

Adaptation at the farm level is influenced by access to assets, technology, climate information, credit, extension services and social networks. An analysis of 360 farmers in Punjab revealed that factors like machinery, tube-well ownership, transport, education, labour availability, access to credit, farmer organisations, extension services, landownership and climate knowledge impacted the adoption of practices like changing crop varieties, planting dates, conserving soil and water and diversifying production (Mustafa & Alotaibi, 2024). But small farmers, rain-farmers, tenants and women agriculture labourers are less able to avail these inputs. Climate-smart agriculture should therefore not only include technological recommendations, but also rural finance, land rights, market access, farmer education, water governance, storage facilities, and crop insurance and locally appropriate knowledge.

Public Health, Urban Risk and Social Inequality

There are direct and indirect pathways by which climate change impact health. Immediate impacts include death, injury, cardiovascular stress, dehydration, and heatstroke, during heatwaves and disasters. Indirect effects of these impacts involve effects on water quality, food insecurity, malnutrition, air pollution, displacement, mental stress and distribution of disease vectors. Flooding can cause damage to the health facilities and sanitation, and provides conditions that are conducive to diarrhoeal and mosquito-borne diseases. In Pakistan, the rise in dengue cases underscores the need for a linkage between climate surveillance and public-health preparedness (Abid & Abid, 2023). The necessary components for building climate-resilient health systems are: risk registers, heat-health action plans, disease early-warning systems, resilient facilities, emergency supplies, and coordination among meteorological, health, water, and disaster-management authorities (World Bank, 2024).

With rapid urbanisation, climate risks are exacerbated in urban areas, as urban settlement has taken over floodplains, drainage systems are insufficient, green space has been lost, and low income groups live in unsafe houses. The remote-sensing study in coastal cities of Pakistan has found the correlation between urban expansion, land cover, and surface urban heat-island intensity (Rizvi et al., 2021). Climate impacts are also socially differentiated. Women may be hindered from moving freely, have greater care and water-collection duties, have limited access to relief, and experience loss of informal livelihoods. The research on climate induced migration in Pakistan showed that women's vulnerability can be exacerbated by existing social disparities during migration (Ullah et al., 2024). Adaptation therefore needs to be gender responsive, disability inclusive, poverty sensitive and be based on the involvement of the impacted communities.

Adaptation, Mitigation and Climate Governance

In Pakistan, both adaptation to inevitable climate impacts and mitigation to facilitate clean development are needed for a sustainable response. Climate-smart agriculture, efficient irrigation, drought- and heat-tolerant crops, watershed restoration, multi-hazard early-warning systems, resilient infrastructure, heat-action plans, coastal monitoring, social protection and ecosystem-based adaptation are priority adaptation measures mentioned in the literature. Renewable energy, energy efficiency, cleaner transportation, sustainable buildings, forest conservation, methane reduction and better waste management are all appropriate mitigation measures. These activities can generate development co-benefits such as through health, employment, energy security, biodiversity conservation and pollution reduction (Adnan et al., 2024).

The greatest challenge lies in the implementation of policy commitments into coordinated and sustained action. Pakistan's NAP offers a comprehensive whole-of-society approach, including agriculture, water, health, infrastructure, ecosystems, gender, social inclusion and Disaster Risk Management. It, however, identifies the constraints of finance, data, awareness, coordination, participation of the stakeholders and institutional capacity (Government of Pakistan, 2023). Closed consultation, generic policy making and ambiguous links between centralised and devolved administration also can impede implementation as has been found by Masud and Khan (2024). Based on the findings of this study, Zhu et al. (2026) called for improved integration of community knowledge, NbS measures, early-warning systems, rural resilience and measures against maladaptation in Pakistan's flood adaptation. Sustainable climate action should therefore be locally based, scientifically sound, and sufficiently funded, and ensure measurable responsibilities and accountability mechanisms (Masud & Khan, 2024; Zhu et al., 2026).

Conceptual Framework

The study is informed by a climate-risk framework where risk is a result of the interplay of climatic hazards, exposure, vulnerability and adaptive capacity. Climatic drivers (increased greenhouse-gas concentration and land-use change) affect hazards (heatwaves, flooding, drought, glacial changes and sea-level rise). Exposure is the population, assets, livelihoods, ecosystems and infrastructure in hazard prone areas. Poverty, inequality, dependence on climate-sensitive resources, weak infrastructure, environmental degradation and limited institutional capacity are all factors affecting vulnerability. Adaptive capacity is the resources, knowledge, technology, finance, governance and social networks that can be mobilized to anticipate, adapt and recover from climatic shocks (IPCC, 2022).

The analytical pathway is hence:

Climate drivers → Climate hazards → Exposure and vulnerability → Sectoral and societal impacts → Adaptation and mitigation responses → Climate resilience and sustainable development

Within this framework, adaptation reduces exposure and vulnerability through resilient infrastructure, early warning, climate-smart agriculture, water management, health preparedness, social protection, and ecosystem restoration. Mitigation - renewable energy, energy efficiency, sustainable transport, waste management and carbon sequestration. Governance, finance, participation, information and institutional coordination are enabling conditions, which influence whether proposed solutions lead to equitable and lasting resilience (Government of Pakistan, 2023).

METHODOLOGY

Research Design

The study adopted a structured integrative-review design combined with secondary-data and policy analysis. This design was chosen because the evidence of climate change in Pakistan includes a wide range of environmental, hydrological, agricultural, economic, health, social, and governance evidence, which is not suitable to be combined using a traditional statistical meta-analysis. The review process was carried out based on the identification, screening, eligibility and inclusion criteria for PRISMA (2020), and the results were narratively summarised and thematically synthesised (Page et al., 2021; Campbell et al., 2020).

Information Sources and Search Strategy

Relevant literature was identified through structured searches of Scopus, Web of Science, ScienceDirect, SpringerLink, Wiley Online Library, Taylor & Francis Online, PubMed, and Google Scholar. Official reports and data sets were sourced from the Government of Pakistan, Pakistan Meteorological Department, National Disaster Management Authority, Ministry of Climate Change and Environmental Coordination, World Bank, Asian Development Bank, IPCC, UNDP, UNEP, FAO, WHO and UNFCCC. The review covered material published between January 2020 and July 2026.

Boolean operators were used for combining search terms. The principal search string was: (“climate change” OR “climate variability” OR “global warming”) AND Pakistan AND (flood OR drought OR heatwave* OR glacier* OR “water security” OR agriculture OR “food security” OR health OR migration OR coastal OR adaptation OR mitigation OR resilience OR “sustainable solutions”)**. Additional searches combined “Pakistan” with sector-specific terms such as “Indus Basin,” “climate finance,” “urban heat,” “sea-level rise,” “climate-smart agriculture,” “climate governance,” and “nature-based solutions.”

Eligibility Criteria

Studies were included when they: were published from 2020 to 2026; directly examined Pakistan or presented South Asian evidence with clear relevance to Pakistan; addressed climate hazards, impacts, vulnerability, adaptation, mitigation, governance, or sustainable development; were written in English; and provided identifiable methods, data sources, or authoritative institutional evidence. Peer-reviewed articles, systematic reviews, empirical studies, official policy documents, national assessments and reports from recognised international organisations were eligible.

Sources were excluded if they were published prior to 2020, except in cases where they were necessary to interpret a recent policy document; contained evidence already identified in other sources; were not relevant to Pakistan; were missing evidence or included unsupported claims; did not have an identifiable author or institutional source; or were dominated by news commentary, blogs, commercial content or non-scholarly opinion. Older studies that were published in recent publications were not used as separate evidence.

Screening and Quality Assessment

Three stages of retrieval review of records were conducted. Studies were first screened for relevance, and then abstracts or executive summaries were evaluated for inclusion. Potentially relevant publications were then reviewed in detail. Copies of publications and sources that did not have necessary methodological or institutional creditability were not included. The selection process will be depicted using a study-selection flow diagram, as outlined in PRISMA 2020 (Page et al., 2021).

Quality assessment considered clarity of objectives, suitability of research design, transparency of data sources, adequacy of analysis, consistency between findings and conclusions, geographical relevance, recency, and publication credibility. The official reports were evaluated based on institutional authority, methodological transparency, and source of data and based on independent peer-reviewed evidence. Only those major statistical assertions were kept where they could be attributed to an original study, an authoritative evaluation or an official data set.

Data Extraction and Synthesis

Structured extraction framework was employed to document authors/institutions, year of publication, study location, research design, timeframe of study, climatic hazard, affected sector, population exposed, key findings, suggested solutions, and implementation constraints. The evidence was organised into the following themes: climatic trends and extreme events; water, glaciers and ecosystems on coasts; agriculture and food security; health, urban risk and social inequality; adaptation, mitigation and climate governance.

Because the included evidence differed in methods, indicators, spatial scales, and outcomes, statistical pooling was inappropriate. Therefore, a synthesis without meta-analysis was performed by comparing direction, consistency, context and strength of findings across studies. Descriptive statistics were used for quantitative evidence, and thematic analysis for qualitative and policy evidence. Findings from peer-reviewed studies were triangulated with national and international assessments to reduce dependence on any single source (Campbell et al., 2020).

Ethical Considerations and Methodological Limitations

The study relied exclusively on published literature, publicly accessible reports, and secondary data; therefore, no human participants were recruited and institutional ethical approval was not required. However, all sources were cited, statistical statements were tracked to their sources and conflicting information was included, if applicable. The expected limitations are publication bias, climate indicators vary, geographical coverage is unequal, limited district level evidence, and institutional data quality varies. These limitations were overcome by source triangulation, clarity of eligibility criteria and careful interpretation.

RESULTS

Data Coverage and Analytical Approach

The analysis used annual secondary data for Pakistan covering 2000–2025, although coverage varied among indicators because the original data providers used different reporting schedules. Climate, environmental, demographic, economic, food-security, water, health and displacement indicators were obtained from the World Bank's World Development Indicators, FAOSTAT temperature-change statistics and the World Bank/IDMC disaster-displacement database. The consequences of the 2022 floods were examined using the official Pakistan Floods 2022 Post-Disaster Needs Assessment (PDNA).

Missing observations were retained as missing and were neither replaced with zeros nor interpolated. Descriptive statistics were calculated for each indicator. Ordinary least-squares linear trends were estimated using year as the independent variable. The study also compared the average values for 2000–2010 with those for 2011 to the latest available year. Pearson correlations were calculated as exploratory associations. Because trending time-series variables may produce misleading correlations, correlations were also estimated using annual first differences. These results indicate statistical association rather than causation.

Descriptive Profile of Climate and Human-Security Indicators

Table 1. Descriptive statistics for selected indicators

Indicator	Period	N	Mean	SD	Minimum	Maximum
Temperature anomaly (°C)	2000–2025	26	0.887	0.407	0.214	1.581
CO_2 emissions per capita (metric tons)	2000–2024	25	0.820	0.082	0.694	0.966
Urban population (%)	2000–2025	26	35.70	1.95	33.00	39.53
Forest area (%)	2000–2023	24	5.26	0.36	4.67	5.85
Renewable-energy consumption (%)	2000–2021	22	46.67	2.84	41.60	51.50
Water stress (%)	2000–2022	23	112.93	4.99	105.86	122.67
Prevalence of undernourishment (%)	2001–2023	23	15.49	2.70	10.90	21.00
Food-production index	2000–2022	23	87.93	20.69	59.13	122.43

Agriculture value added (% of GDP)	2000–2025	26	22.48	1.29	19.94	25.39
Disaster-displacement cases	2008–2023	16	1,592,856	3,214,555	1,800	11,060,000
Safely managed drinking water (%)	2000–2024	25	43.89	0.78	42.58	44.97
Unemployment (%)	2000–2025	26	2.58	2.15	0.40	6.34
GDP growth (%)	2000–2025	26	3.96	2.15	−1.27	7.83
Life expectancy at birth (years)	2000–2024	25	64.82	1.74	61.90	67.80

Note: SD = standard deviation. Authors' calculations from FAOSTAT and World Bank data.

Table 1 demonstrates that Pakistan experienced simultaneous climatic, environmental and socioeconomic pressures. The mean temperature anomaly was approximately 0.89°C, while the maximum reached 1.58°C. Water stress averaged 112.93%, indicating that freshwater withdrawals consistently exceeded the level normally considered environmentally sustainable. Forests accounted for only about 5.26% of the country's land area. Displacement was the most volatile human-security indicator. Its standard deviation was approximately twice its mean, reflecting the concentration of displacement in catastrophic years rather than a stable annual pattern. Agriculture continued to represent an average of 22.48% of GDP, demonstrating the economy's continuing exposure to temperature variation, floods, droughts and water shortages. Improvements were visible in life expectancy, food production and drinking-water services, but undernourishment remained substantial and safely managed water coverage averaged below 45%.

Long-Run Trends

Table 2. Linear trends in selected indicators

Indicator	First value	Latest value	Observed change	Annual trend	R^2	p-value
Temperature anomaly (°C)	0.656	1.581	+0.925	+0.0257°C	0.234	0.012
CO_2 per capita	0.722	0.812	+0.089	+0.0083 tons	0.558	<0.001
Urban population (%)	33.00	39.53	+6.52 pp	+0.2508 pp	0.968	<0.001
Forest area (%)	5.85	4.67	−1.18 pp	−0.0503 pp	0.999	<0.001
Renewable-energy consumption (%)	51.00	41.60	−9.40 pp	−0.3759 pp	0.740	<0.001

Water stress (%)	105.86	109.99	+4.13 pp	+0.4481 pp	0.370	0.002
Undernourishment (%)	20.40	16.50	−3.90 pp	−0.2541 pp	0.408	0.001
Food-production index	59.13	122.43	+63.30	+3.0332 points	0.989	<0.001
Agriculture value added (%)	25.39	23.02	−2.37 pp	+0.0027 pp	<0.001	0.937
Safely managed drinking water (%)	42.58	44.97	+2.39 pp	+0.1054 pp	0.996	<0.001
Unemployment (%)	0.61	5.42	+4.81 pp	+0.2554 pp	0.828	<0.001
GDP growth (%)	4.26	3.70	−0.56 pp	−0.0747 pp	0.071	0.190
Life expectancy (years)	61.90	67.80	+5.90	+0.2308 years	0.952	<0.001

Note: "pp" means percentage points. Latest years vary according to source availability. The annual trend is the estimated OLS slope.

Pakistan's temperature anomaly increased by an estimated 0.0257°C per year, and the trend was statistically significant. The country also experienced increasing CO_2 emissions per capita, population concentration in urban areas and water stress. Urbanisation had one of the strongest trends, rising by approximately 0.25 percentage points annually. This indicates increasing exposure of people, housing, infrastructure and essential services to urban heat, flooding and water shortages. Environmental resilience indicators moved in an unfavourable direction. Forest area declined by approximately 0.05 percentage points annually, while the share of renewable energy in total final energy consumption decreased by 0.38 percentage points annually. These patterns imply reduced ecosystem protection and an energy transition that has not kept pace with growing demand.

Some human-development indicators improved. The food-production index more than doubled, life expectancy increased by almost six years and undernourishment declined over the complete study period. Nevertheless, unemployment increased significantly, safely managed drinking-water coverage improved by only 2.39 percentage points, and GDP growth remained volatile without a statistically significant long-run trend. Agriculture's contribution to GDP also showed no significant linear trend, confirming its continued structural importance.

Comparison Between the Earlier and Recent Periods

Table 3. Mean values before and after 2010

Indicator	2000–2010 mean	2011–latest mean	Difference
Temperature anomaly (°C)	0.766	0.976	+0.210
CO_2 per capita	0.771	0.859	+0.087

Urban population (%)	33.92	37.00	+3.08 pp
Forest area (%)	5.58	4.98	−0.60 pp
Renewable-energy consumption (%)	48.38	44.96	−3.42 pp
Water stress (%)	109.80	115.80	+6.01 pp
Undernourishment (%)	17.36	14.05	−3.31 pp
Food-production index	69.41	104.91	+35.50
Safely managed drinking water (%)	43.14	44.47	+1.33 pp
Life expectancy (years)	63.19	66.10	+2.91

Note: "Latest" refers to the most recent observation available for each indicator.

The comparison confirms that the recent period was warmer, more urbanised and more water-stressed. The average temperature anomaly increased by approximately 0.21°C, while average water stress rose by 6.01 percentage points. At the same time, forest cover and renewable-energy consumption decreased.

The results also reveal an important development paradox. Food production and life expectancy improved, and average undernourishment declined. However, these gains occurred alongside deteriorating environmental conditions and only limited improvement in safely managed drinking water. Consequently, national development has increased some dimensions of human welfare without removing the environmental vulnerability that threatens their long-term sustainability.

Exploratory Relationships Among Climate and Human-Security Indicators

Table 4. Pearson correlations in levels and annual first differences

Variable pair	N	Levels: r	Levels: p	First difference: r	First difference: p
Temperature–displacement rate	16	0.313	0.238	0.274	0.323
Temperature–food-production index	23	0.306	0.156	0.136	0.545
Displacement rate–GDP growth	16	−0.167	0.536	−0.119	0.673
Renewable energy–CO_2 per capita	22	−0.965	<0.001	−0.894	<0.001
Forest area–CO_2 per capita	24	−0.804	<0.001	−0.019	0.932
Food production–undernourishment	22	−0.679	<0.001	0.349	0.121

Safe water–undernourishment	23	−0.656	<0.001	−0.057	0.802

Temperature had a positive but statistically insignificant association with disaster displacement. This does not mean temperature is irrelevant to displacement. Displacement is generated by particular floods, storms and droughts and is therefore episodic, whereas national temperature anomalies change more gradually. Renewable-energy consumption had a strong negative relationship with CO_2 emissions in both levels and first differences. The association remained statistically significant after the common time trend was reduced, making it the most robust relationship in the analysis. However, it should still not be interpreted as a causal estimate because energy demand, fuel prices, economic activity and energy policies were not controlled.

Forest area was strongly negatively associated with CO_2 emissions in levels, but the relationship disappeared in first differences. Similarly, higher food production and drinking-water coverage were related to lower undernourishment in levels, but these associations became insignificant after differencing. This indicates that the original correlations were partly driven by long-term trends. The results illustrate why simple time-series correlations should not be presented as evidence of causality.

The 2022 Flood Shock and Human Security

Table 5. Climate and human-security indicators surrounding the 2022 floods

Year	Temperature anomaly (°C)	Disaster displacements	Displacements per 100,000	GDP growth (%)	Undernourishment (%)	Agriculture (% GDP)	Unemployment (%)
2020	0.441	829,000	352.76	−1.27	13.4	21.85	5.99
2021	1.133	70,000	29.23	6.51	16.4	22.66	6.34
2022	1.390	8,168,000	3,351.65	4.78	16.7	22.33	5.29
2023	1.088	732,000	295.75	−0.41	16.5	23.43	5.24
2024	1.526	—	—	3.08	—	23.73	5.49

Note: A dash indicates that an observation was unavailable, not zero.

Disaster displacement increased from 70,000 cases in 2021 to 8.168 million in 2022—an increase of more than one hundred times. Displacement remained elevated at 732,000 cases in 2023. GDP growth fell to −0.41% in 2023, while agriculture's share of GDP increased. The increased agricultural share should not be interpreted as improved agricultural performance because it may partly reflect weaker growth in other sectors and changes in relative prices.

Table 6. Human and economic consequences of the 2022 floods

Impact category	PDNA estimate
Population affected	Approximately 33 million
Recorded deaths	More than 1,730
Population displaced	More than 8 million
Direct physical damage	US$14.9 billion
Economic losses	US$15.2 billion
Recovery and reconstruction needs	At least US$16.3 billion
Housing damage	US$5.6 billion
Agriculture and livestock damage	US$3.7 billion
Transport and communication damage	US$3.3 billion
Projected increase in poverty rate	3.7–4.0 percentage points
Additional people at risk of poverty	8.4–9.1 million
Estimated GDP loss	2.2% of FY2022 GDP

The 2022 floods transformed a climatic hazard into a multidimensional human-security emergency. The destruction of homes weakened physical security, losses of agricultural produce posed a risk to livelihood and food security, the means of transport were destroyed, and the large scale displacement affected education, and community networks. The estimated increase in poverty indicates that the effects of disasters went way beyond death and damage to infrastructure. The event corroborates the study's conceptual approach: hazard events are caused by climatic triggers; exposure and vulnerability decide the magnitude of social impacts. However, the severity of the flood was exacerbated by settlement on flood-prone lands, poor housing conditions, reliance on the agricultural sector, absence of drainage and poor household capacity to recover from the flood.

DISCUSSION

The findings demonstrate that climate change is increasingly interacting with Pakistan’s demographic, environmental and institutional vulnerabilities. This substantial temperature rise of ~0.026 °C per year is also in line with studies that have shown an increasing trend in hydroclimatic extremes and heat in Pakistan and the Indus Basin. The impacts of these changes are on crop calendar, irrigation demand, labour productivity and public health. As the urban population grows, so do the number of people and assets at risk from heatwaves and urban flooding, especially when drainage infrastructure is not expanding at the same rate as urbanization, and housing and land-use regulations are not adapted (Adnan et al., 2024; Carrera Heureux et al., 2022).

Water is especially a link between climate change and human security. The average water stress was above 100% and the safely managed drinking-water coverage barely increased. As temperatures rise, so does the rate of evaporation and agricultural demand for water, and water supplies are unpredictable due to changing glaciers, droughts and floods. Previous studies also highlight population growth, poor irrigation practices, inadequate storage infrastructure, groundwater depletion, and weak governance in Pakistan as major factors contributing to water insecurity (Ishaque et al., 2022; He et al., 2024). Climate change thus exacerbates an existing issue of resource-management instead of its own effects.

The increasing food-production index and decreasing long-run undernourishment rate are signs of vital progress, but not a sign that the food system in Pakistan is climate-resilient. Despite a growing production index, the number of undernourished people grew from 2020 to 2022. Moreover, the negative level correlation between production and undernourishment disappeared after first differencing. Apart from national production, household income, food prices, distribution, nutrition and food storage and market access are also crucial factors that influence food security. Rural income losses can result from agricultural losses in a changing climate, and can lead to higher prices even if national production overall is comparatively high. This is in line with the research that shows that climate variability, population growth and economic pressures are interlinked threats for food security in Pakistan (Syed et al., 2022; Abbas et al., 2025).

The displacement results illustrate the importance of understanding how the impacts of extreme events can be hidden in average annual relationships. However, the correlation between temperature and displacement was not significant as displacement was focused in exceptional flood years. More than eight million people were displaced in the 2022 floods compared to 70,000 in 2021. Spatial analyses of the disaster also show that exposure was different depending on the flood depth and settlement pattern and vulnerability in the area concerned (Iqbal et al., 2024; Kam et al., 2025). Hence the lack of a large annual national correlation cannot be construed as the absence of climatic influence.

The energy and environmental outcomes depict the major challenges for sustainable mitigation. Consumption of renewable-energy decreased and per-capita CO_2 emissions increased. They had a strong negative association that persisted after first differencing, indicating a close association between changes in the energy mix and changes in emissions. The lost forest land also diminishes forest's ability to sequester carbon, provide watershed protection, and provide biodiversity and local protection from erosion and flooding. The forest–emissions correlation vanished, though, after differencing, meaning that their strong level relationship was driven mostly by opposing time trends. This distinction is significant for two reasons: first, it does not imply that there is a causal connection where there is not; second, it helps prevent the misinterpretation of statistical association as causal evidence.

As a result, vulnerabilities have not been eradicated by human-development improvements. There is an increase in unemployment and volatility of growth, poverty exposure and dependence on agriculture along with a longer life expectancy and modest improvements in drinking-water services. The 2022 flood uniquely highlighted how a disaster event can setback development gains, resulting in loss of lives and livelihoods, disease, displacement and infrastructure destruction. Thus, water and climate issues in Pakistan are not just environmental but also issues of human security and governance (Ishaque et al., 2023).

Lastly, the results should be considered in the light of the national secondary data which are used. Some variables had reporting periods that varied, some displacement data referred to events and not to persons, and national averages masked provincial and district disparities. Inflation, conflict, policies, international prices and socioeconomic differences were not accounted for in the analysis. However, the trend statistics, event evidence and recent research all point to the same central fact: Sustainable development in Pakistan needs to be achieved concurrently on all four fronts - adaptation, mitigation, poverty reduction and institutional capacity.

CONCLUSION

This study examined Pakistan's emerging climate challenges and their implications for environmental sustainability, livelihoods, food, water, health, economic stability and population displacement. Secondary data analysis revealed that in Pakistan, the temperature anomalies have been significantly rising in the period 2000-2025. This warming was accompanied by the growth of exposure to urban areas, water stress and per-capita CO_2 emissions. There was a loss of forest area and the share of renewable energy, which means that environmental and mitigation capacity has not increased as quickly as needed to face growing climate risks. Results, however, show discernible progress in development. An increase in food production and life expectancy, and a decrease of the long-run prevalence of undernourishment. Such enhancements should not be seen as evidence of climate resilience, however. Safefely managed drinking-water coverage increased at a slow rate, unemployment increased, growth was still volatile and agriculture still contributed about 20 percent of the national economic activity. Growth benefits are thus vulnerable to climate and economic shocks.

The 2022 floods are the latest example of this vulnerability. Some 33 million people were impacted, over 8 million people were displaced and damage and loss costs combined were over US$30 billion. It had repercussions in housing, agriculture, transport, health, education, poverty and security of the community. The event illustrates that besides the physical hazard, poverty, settlement characteristics, infrastructure quality, livelihood dependence, and institutional readiness are also important factors in determining the scale of a climate disaster. Additional exploratory correlations also revealed that it is important to interpret the national time-series relationships with care. For some of the apparently strong relationships, the relationships that they created between the variables were lost after being transformed into annual changes, which means that they are somehow similar. The analysis thus reinforces a vulnerability-based interpretation, and does not make a claim about a direct relation between a climate variable and a specific social outcome.

Climate Change in Pakistan is a problem of the environment, development and human security all together. Practical adaptation, resilient infrastructure, water reform, climate-smart agriculture, ecosystem restoration and social protection must be integrated into effective responses, along with emissions reduction. How climate is incorporated into budgeting, urban planning, agriculture policy, energy investment and disaster governance will determine the country's future resilience. It will be challenging to achieve sustainable development without putting the population and areas most vulnerable to exposure at the heart of policy design and resource allocation.

RECOMMENDATIONS

1. Forecasts should be translated into local-language, impact-based warnings connected to evacuation plans, shelters, emergency health services and district disaster-management authorities.

2. Pakistan should expand water metering, groundwater regulation, canal maintenance, rainwater harvesting, wastewater reuse and high-efficiency irrigation while protecting minimum environmental flows.

3. Government support should prioritise drought-, heat- and flood-tolerant seeds, crop diversification, weather-indexed insurance, climate advisory services, improved storage and efficient irrigation for small farmers.

4. Solar, wind, distributed generation, electricity-storage and energy-efficiency programmes should be expanded while protecting low-income households and workers affected by changes in the energy system.

5. Forest restoration, mangrove protection, wetland rehabilitation, watershed management and community forestry should be independently monitored to ensure ecological survival rather than counting plantation targets alone.

6. Land-use regulations should restrict unsafe development in floodplains, while drainage, housing, schools, hospitals, roads, bridges and electricity systems should be designed according to updated climate-risk standards.

7. Existing social-protection systems should use disaster triggers to provide rapid cash assistance, nutrition support, temporary housing, healthcare and livelihood recovery to displaced and vulnerable households.

8. Pakistan should establish transparent climate-budget tagging, provincial and district resilience targets, public project evaluations and stronger access to international adaptation and loss-and-damage finance.

9. District-level data on temperature, water, crop losses, health, poverty and displacement should be openly available and disaggregated by gender, age, disability and income. Future research should use spatial and causal methods rather than relying exclusively on national correlations.

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