

RESEARCH ARTICLE

## Vulnerability of Water Resources and Sanitation Infrastructure to Climate Change in Rural Pakistan: Implications for Achieving the Sustainable Development Goals

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**Abstract:** Climate change poses unprecedented threats, including rising temperatures, altered precipitation patterns, and increased extreme weather events, disproportionately affecting marginalized communities and perpetuating poverty, gender inequality, and social injustice. This qualitative study assesses the climate vulnerability of water resources and sanitation infrastructure in rural Punjab, Pakistan, and its implications for sustainable development. Using an explanatory sequential mixed-methods design, this research commences with qualitative data collection and analysis to contextualize findings. The study examines hydro-climatic trends, socio-economic disparities, and gender inequities exacerbated by climate change. Key findings include severe groundwater depletion (0.7 m/year), sanitation failures, and systemic neglect of marginalized communities. The research highlights how climate stressors undermine progress toward Sustainable Development Goals (SDGs) 6 (Clean Water) and 13 (Climate Action) while perpetuating poverty (SDG 1) and gender inequality (SDG 5). To address these challenges, the study recommends integrated water governance, climate-resilient sanitation, and community-led adaptation strategies. This research informs policy and practice aimed at enhancing climate resilience and achieving sustainable development in rural Pakistan.

**Keywords:** Climate Vulnerability, Water Scarcity, Sanitation Infrastructure, Sustainable Development Goals (SDGs)

### Introduction

With a population of more than 220 million (Eckstein et al., 2021), Pakistan ranks among the top 10 most vulnerable nations globally for climate-related catastrophes. These issues are especially pressing in Punjab, the social and demographic center of the country. With 53% of Pakistan's GDP and 60% of the nation's population housed in Punjab, the most populous province in Pakistan, this vital component of the economy is absolutely vital (Pakistan Bureau of Statistics, 2023). Public health, livelihoods, and socioeconomic stability are intricately linked to the region's water sources and sanitary facilities. Climate change is endangering Punjab's fragile equilibrium of ecology by changing precipitation patterns, temperature swings, and increasing frequency of violent storms. The advancement of Pakistan toward sustainable development is hampered; poverty is aggravated, and the welfare of millions of people is in jeopardy (WHO, 2023).

Previously a pillar of developmental success, Punjab's water resources and sanitation systems are now at risk of failing amid the dangerous mix of fast population increase and climate change (Mustafa et al., 2021). The combination of climate change and fast population increase poses a threat to the basic framework of rural communities, therefore affecting the well-being of people, groups, and societies. Decades of

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painstakingly acquired improvements in public health, quality of life, livelihoods, and socioeconomic stability could thus be reversed (Qureshi, [2020](#)). Particularly in regard to the Sustainable Development Goals (SDGs), the effects of climate change on the vulnerabilities of water and sanitation infrastructure become increasingly important. Examining the important interrelations between SDG 6 (Clean Water and Sanitation), SDG 13 (Climate Action), SDG 1 (No Poverty), SDG 3 (Good Health and Well-Being), and SDG 5 (Gender Equality) shows how climate change stresses affect the advancement of these linked objectives, so endangering sustainable development and well-being (UNICEF, [2022](#)).

### **Climate Change and Drinking Water Scarcity**

The escalating crisis of drinking water scarcity, particularly in a developing world like Pakistan, exacerbated by climate change, poses a significant threat to human life and well-being. As the impacts of climate change continue to intensify, the scarcity of drinking water is becoming an increasingly pressing issue, and water resources are dwindling at an alarming rate, threatening the livelihoods of millions of people (Qureshi, [2020](#)). The province's groundwater, once a reliable source of drinking water, is being depleted at a rate of 1.5 meters per annum, but the rapid transformation in climate fabric in the region has disrupted hydrological cycles, exacerbating water scarcity. The Intergovernmental Panel on Climate Change (IPCC, [2023](#)) projects a 1.5 to 2.5°C temperature rise in South Asia by 2050, accelerating glacial melt in the Himalayas, the source of 80% of the Indus River's flow. By 2050, the Indus Basin is expected to lose 30% of its water supply and have a vulnerable impact on the underground water table in Punjab and allied areas (World Bank, [2022](#)).

Concurrently, erratic monsoon patterns have increased rainfall variability, with pre-monsoon precipitation declining by 12% over the past two decades (PMD, 2023). These shifts have forced us to overexploit groundwater, which now meets 90% of Punjab's sweet water needs (PCRWR, [2022](#)). Groundwater levels are plummeting by 0.5 to 0.7 meters annually, with aquifers in arid zones like Bahawalpur and DG Khan depleted to depths of 45 meters (Qureshi et al., [2021](#)). Compounding these challenges is water quality degradation as a survey conducted in 2022 by the Pakistan Council of Research in Water Resources (PCRWR) found that 58% of Punjab's groundwater samples were contaminated with arsenic, nitrates, or pesticides, rendering them unsafe for consumption. Saline intrusion driven by excessive pumping has affected 32% of wells in southern Punjab, reducing crop yields by up to 40% (Ali et al., [2021](#)). These trends threaten food security for 65 million rural residents and amplify health risks, as 85% of households rely on groundwater for drinking (UNICEF, [2022](#)).

The repercussions of the escalating water crisis are far-reaching and devastating. As the availability of clean drinking water dwindles, water-borne diseases such as cholera, typhoid, and diarrhea are surging, claiming lives and debilitating communities. Moreover, the agricultural sector, the backbone of rural economies, is suffering greatly, with crop yields declining precipitously due to inadequate water supplies. The very fabric of rural communities is beginning to fray as the scarcity of water erodes livelihoods, exacerbates poverty, and fuels migration to urban centers. As the effects of climate change continue to intensify, the situation will only deteriorate further unless concerted efforts are made to address the root causes of this crisis and develop sustainable solutions to ensure the long-term availability of clean water (Halvorson et al., [2021](#)).

### **Sanitation Infrastructure: A Climate-Sensitive Crisis**

Though most people talk about water scarcity, Punjab has a sanitation crisis that seriously compromises the health, dignity, and well-being of people living in rural areas. According to the Pakistan Bureau of Statistics (2023), 72% lack access to contemporary sanitation facilities, while 41% of rural families participate in open defecation. Extreme weather makes an already insufficient sewage system even more strained. This increases the situation's fragility. In areas prone to floods, the devastating floods of 2010 and 2014 destroyed practically

60% of pit latrines. Outbreaks of waterborne infections, including cholera, hepatitis, and diarrhea (Mustafa et al., 2021), sprang from this contaminated water supply. Numerous effects of the sanitation dilemma include ongoing poverty, injustice, and environmental damage, therefore sustaining a circle of inequality. Empirical studies show that people trying to rebuild after a tragedy sometimes overlook hygiene, which is absolutely important for building community resilience. As a result, communities remain susceptible to later calamities since rebuilding homes is the first priority (Halvorson et al., 2021). Since women and girls use water and sanitation facilities most of the time, inadequate systems affect them disproportionately.

Women and children are driven to spend too much time in water collecting, often under dangerous conditions because safe and dependable sanitary facilities are inaccessible. Participating in this Sisyphean labor for four to six hours every day greatly reduces their time and energy for education, work, or other activities meant to improve their general health or financial situation. Their inability to access basic water and sanitation services (IPCC, 2023) keeps a great number of people vulnerable, thus limiting their potential and aspirations. Fast urbanization in Pakistan is changing the demographic scene and aggravating the already complex relationship between sewage treatment and climate change. Drought and agricultural failures are forcing rural residents to relocate, leading to urban hubs like Lahore and Faisalabad confronting issues, including crowded slums, inadequate sewage systems, and stretched municipal services (Qureshi, 2020). Sanitation facilities have been underappreciated for years in rural Punjab, which accounts for an amazing 65% of Pakistan's population and forms the country's economic base, hence extending poverty and inequality. Insufficient investment in rural sanitation has led to contaminated water supplies, poor waste management, and inadequate operating toilets, therefore compromising public health, education, economic productivity, and long-term development (World Bank, 2022).

### **Implications for Sustainable Development**

Particularly SDG 6, which calls for universal access to clean water and sanitation facilities by 2030, Punjab's degraded water and sewage infrastructure impedes the UN's Sustainable Development Goals (SDGs) attainment. Punjab still lags far from reaching this goal, even with progress in several spheres. For health, welfare, and continuous development, this is an alarming sign. Forty-five million people in Punjab lack access to hygienic toilets, and twenty-two million are deprived of safe drinking water—an incredible statistic. This fuels waterborne infections, hunger, and poverty. "Decent Work and Economic Growth" is Goal 8. Twelve is "Sustainable Consumption and Production." Goal 13 is "Climate Action"; Goal 1 is "No Poverty." Lack of water reduces agricultural income and forces 35% of rural homes into debt. Good Health, SDG 3: 128,000 children die from diarrhea brought on by polluted water annually. Gender Equality, SDG 5: The requirement of gathering water without pay prevents women from fully participating in the economy. The economy is underperforming according to SDG 8: Decent Work and Economic Growth. According to SDG 12, Responsible Consumption and Production, the deterioration of water supplies compromises Sustainable Consumption and Production. According to SDG 13, Climate Action, the effects of climate change on water sources aggravate the vulnerability of rural areas. Despite the complex links among water, sanitation, and climate change, the policy solutions in Punjab are scattered and insufficient, therefore impeding advancement towards the Sustainable Development Goals (SDGs).

The Punjab Water Policy 2020 falls short in stressing community-based adaptation techniques meant to improve the climate resilience of the Punjab. Rather, it supports large-scale infrastructure projects, including dam building. In the same vein, the province's sanitation projects give building toilets top priority over other factors such as maintenance, behavioral change, and environmental resilience. This increases population sensitivity to the effects of climate change. This narrow viewpoint on water and sewage management compromises the effectiveness of these initiatives and fuels cycles of poverty, inequality, and environmental damage. Punjab's water and sanitation management has to be completely climate-adapted to reach the Sustainable Development Goals. This calls for a change from compartmentalized methods to

community-oriented ones stressing adaptation, sustainability, and resilience. By implementing a thorough and inclusive approach to water and sewage management, Punjab might more successfully handle the linked concerns of poverty, inequality, and climate change. In the end, this would guarantee that its people live in a fairer, more stable, and longer future. Especially with reference to Punjab's rural population, this study seeks to show the connectivity among climate change, water, sanitation, and sustainable development. Examining the interactions among these several components helps this study to give evidence-based insights to legislators, practitioners, and stakeholders. The main goal is to equip these groups with the required knowledge to make wise decisions that would help to build climate-resilient water and sanitation infrastructure, support sustainable livelihoods, and protect the health and safety of Punjabi rural communities. The present state of Punjab's rural water and sewage systems will be investigated in this paper, together with the effects of climate change on these systems and methods to improve their resilience to climate change while promoting sustainable development. By proving the complex interactions among these components, this study aims to dramatically affect the worldwide debate on climate change, sustainable development, and human well-being. Local policy and practice will also be affected by it.

### **Objectives of the Study**

- ▶ Investigate the integrated impacts of climate change on water resources and sanitation in rural Punjab.
- ▶ Analyze the vulnerability of rural communities to climate-related water and sanitation hazards.
- ▶ Evaluate the challenges and opportunities for achieving the Sustainable Development Goals (SDGs) in Punjab, with a focus on subnational challenges.
- ▶ Assess the effectiveness of existing policies and programs in addressing climate change impacts on water resources and sanitation.
- ▶ Develop recommendations for strengthening institutional capacity and governance for climate-resilient water and sanitation management.

### **Material and Methods**

Using a qualitative research approach, the scientists thoroughly evaluated the susceptibility of water supplies and sanitation infrastructure in rural Punjab, Pakistan, to climate change and its consequences for sustainable development. Rigid academic criteria for publication guide the procedure of using qualitative approaches to guarantee thorough analysis and data triangulation. Beginning with qualitative data collection and analysis, this study uses an explanatory sequential methods design, followed by qualitative exploration to contextualize the results (Creswell & Clark, [2018](#)). This architecture helps one to grasp the research subject completely. Analyzing meteorological, hydrological, and socioeconomic statistics helps one to find trends, weaknesses, and links. It lays a basis for comprehending the intricate interactions among sanitation, water supplies, and climate change. To evaluate data and closely examine governance systems, gender dynamics, and community-level difficulties, the qualitative phase consists of in-depth interviews and focus group discussions (FGDs), thereby obtaining nuanced knowledge of the reality of rural people. Combining results from both stages helps us create policy recommendations in line with the Sustainable Development Goals (SDGs), therefore offering a comprehensive knowledge of the climate-water-sanitation nexus and its consequences for Punjab's sustainable development. A multimodal data collecting system was used, using qualitative methods. Data is obtained from numerous sources, including CMIP6 climate forecasts (SSP2-4.5) for 2024–2050 and the Pakistan Meteorological Department (PMD) for historical climate data (2000–2023). Obtained from the Pakistan Council of Research in Water Resources (PCRWR, 2022) is hydrological data, including groundwater levels, depletion rates, and pollutants. Ten districts in Punjab province have sanitation and health data gathered using WHO/UNICEF Joint Monitoring Program (JMP) indicators in addition to records

from local health offices on waterborne diseases. Source Pakistan Bureau of Statistics (2023) Socio-economic statistics include poverty rates, gender-specific labor participation, and educational attainment. Qualitative data is collected through key informant interviews (KIIs) with 25 stakeholders, focus group discussions (FGDs) with households, women, and community leaders in flood and drought-prone districts, and field observations in 20 villages to document infrastructure conditions and environmental degradation.

A multi-stage sampling strategy was employed to select districts for qualitative data collection. Districts were selected based on the Punjab Disaster Management Authority's (PDMA) vulnerability index, ensuring representation of diverse climatic zones. Qualitative data collection employed purposive sampling, targeting communities with high climate exposure, such as frequent floods and low sanitation coverage, typically less than 30%. Particular emphasis was placed on marginalized groups, including women and elders, to capture their unique experiences and perspectives. Data analysis was conducted in two different steps. The analysis involved thematic analysis of interview and focus group discussion transcripts using NVivo 14.0, which identified key themes such as gender-based water burdens and infrastructure neglect. Triangulation was used to validate findings against field observations, survey data, and secondary reports, ensuring the reliability and accuracy of the results.

In this study, researchers adhered to rigorous ethical standards to ensure that the rights and dignity of participants were respected. Informed consent was obtained from all participants through written agreements, with assurance of anonymity to protect their identities. To maintain confidentiality, all data was anonymized and stored securely to prevent unauthorized access. Furthermore, the study's results were disseminated through community workshops, promoting beneficence by supporting local adaptation planning and empowering communities to make informed decisions about their climate resilience and sustainable development.

Furthermore, it acknowledges several limitations that were carefully addressed to ensure the reliability and accuracy of the findings. Data gaps in hydrological records from remote districts were mitigated through spatial interpolation techniques. Ensemble models were employed to generate future scenarios to minimize uncertainties in climate projections. Additionally, potential recall bias in self-reported survey data was mitigated by cross-verifying responses with observational records, thereby enhancing the validity of the results.

## **Results and Major Findings**

This part aggregates the qualitative findings to provide a whole picture of Punjab's rural areas' vulnerability to climate change. We underline water resources and hygienic infrastructure and how they affect long-term growth. The foundation of the research is three connected ideas. Hydro-climatic trends are first examined to ascertain how climate change may affect water quality, volume, and accessibility. Considered are the intricate interactions among sanitation, water, and human health. This shows how crucial sanitation and water are to lowering the health risks resulting from climate change. Differences in socioeconomic development are ultimately looked at to show how climate change aggravates already-existing inequalities by disproportionately hurting impoverished areas and hindering long-term progress.

### **Hydro-Climatic Trends and Water Resource Vulnerability**

Punjab's temperature and precipitation patterns clearly demonstrate a warming trend; since 1990, the temperature has risen 1.8°C. Sen's slope estimate (0.06°C/year) and the Mann-Kendall test ( $p = 0.01$ ) both support this. Linked with this warming trend, the amount of rain falling before spring has reduced by 12% in the past twenty years. With a coefficient of variation (CV) of 25%, the Pakistan Meteorological Department (PMD) likewise notes that monsoon variability has grown. This implies that floods, as well as drought, are now rather likely to occur. Notably, the length of dry spells in areas like Bahawalpur and Muzaffargarh rose by 18% between 2010 and 2023. This worsens issues and emphasizes the need for WASH practices and water

management techniques resistant to climate change for these at-risk areas. Punjab suffers greatly from declining groundwater levels and worsening water quality. Particularly in dry places, linear regression models reveal fast declining groundwater levels at a rate of 0.7 meters per year ( $R^2 = 0.74$ ). Since too much groundwater is being used for agriculture, aquifer levels have dropped greatly. They have dropped down to at least 45 meters in southern Punjab. Furthermore, 32% of wells are contaminated by saltwater intrusion, hence unfit for human consumption (PCRWR, 2022). Arsenic levels are even more alarming as in 58% of samples, they exceed the 10 micrograms per liter advised by the World Health Organisation (WHO). Ali et al. (2021) claim that more skin lesions in Bahawalpur are strongly linked ( $r = 0.68$ ,  $p = 0.02$ ) to this element. This emphasizes the need to manage groundwater responsibly and monitor water quality. The declining surface water resources of Pakistan seriously threaten their drinking water security. Underground water scarcity has increased by thirty percent since 2000. This is largely due to 1.2% yearly declining river flows. The amount of drinkable water is strongly influenced by this shortage, particularly in rural locations where obtaining water from other sources is difficult. It's even worse, as studies from areas like Gujranwala indicate that during droughts, yields drop by 40 to 50 percent, which forces farmers to utilize deep pumps and remove significant water supplies from people's consumption. Finding fresh approaches to managing water and ensuring everyone has equal access to this vital resource immediately is highly crucial as the safety of the country's drinking water is at risk.

### **Sanitation Infrastructure Failures and Health Impacts**

Pakistan's increasing frequency of floods, now 30% more common since 2000 (NDMA, 2023), is exacerbating sanitation breakdowns with devastating health consequences. Floodwaters destroy pit latrines and contaminate water sources, creating ideal conditions for waterborne diseases to spread. In Muzaffargarh, the 2014 floods damaged 60% of latrines, leading to a staggering 40% increase in diarrheal diseases (95% CI: 1.3-1.7). Qualitative data underscore the inadequacy of post-disaster recovery efforts, with a local NGO worker lamenting, "Latrines are rebuilt in the same flood-prone areas. It's a cycle of disease" (KII). This highlights the urgent need for climate-resilient sanitation infrastructure and effective disaster recovery strategies to prevent the spread of waterborne diseases and protect public health.

Despite concerted sanitation efforts, a staggering 41% of rural households in Pakistan continue to practice open defecation (PBS, 2023). Focus group discussions with women revealed that cultural resistance to latrine use and affordability barriers are significant obstacles to adopting safe sanitation practices. The consequences are dire: contaminated water sources are linked to 25% of under-five mortality in Pakistan (WHO, 2023), with flood-prone districts bearing the brunt of this preventable tragedy. The persistence of open defecation underscores the need for targeted interventions that address the complex socio-cultural and economic factors driving this behavior, ultimately ensuring that all households have access to safe, affordable, and dignified sanitation facilities.

### **Socio-Economic and Gender Disparities**

A devastating cycle of poverty and climate vulnerability is gripping rural Pakistan. Water scarcity has driven 35% of smallholder farmers into debt, exacerbating their economic precariousness (World Bank, 2022). In Chakwal, drought-induced crop failures have forced 40% of households to migrate seasonally, eroding community resilience and social cohesion (FGDs). A vulnerability index analysis (PCA) revealed that low adaptive capacity, characterized by extreme poverty (income < \$2/day) and limited literacy (< 45%), is a dominant driver of vulnerability in 7 out of 10 districts. This highlights the urgent need for targeted interventions that address the intersecting challenges of poverty, climate change, and social vulnerability.

In Pakistan, women bear the disproportionate burden of drinking water insecurity, spending 4-6 hours daily collecting water, often at the cost of their physical health. A staggering 72% of women report musculoskeletal injuries due to water collection. The situation worsens post flood, as women's workloads increase exponentially. A participant from Rajanpur poignantly shared, "After the floods, we walk 8 km to find clean water; my daughters miss school" (FGD). Furthermore, women's limited decision-making power perpetuates their marginalization, with only 12% participating in water management committees. This glaring inequality underscores the need for inclusive water governance and gender-sensitive policies that recognize and address the unique burdens and rights of women in water-scarce communities.

### **Implications for Sustainable Development Goals (SDGs)**

Pakistan's development toward SDG 13 (action on climate change) and SDG 6 (clean water and sewage) are at risk. Unbelievably, just 28% of households have access to proper water management, and 45 million individuals lack greater hygiene. Punjab's adaptable ability number (0.32/1) is below the national average according to the NDMA (2023). This indicates that support for sustainable development and resilience enhancement calls for a quick response. The water crisis in Pakistan affects numerous Sustainable Development Goals (SDGs), including slowing down progress on several goals and worsening poverty, gender inequality, and health hazards. Water issues cause Punjab to lose \$1.2 billion a year in crops, worsening poverty (SDG 1) World Bank, 2022). Like obtaining water, unpaid caring inhibits women's income-earning capacity, therefore aggravating gender disparities (SDG 5). And 128,000 children die annually from diarrhea brought on by contaminated water. This emphasizes the need to enhance water, sanitation, and hygiene (WASH) services in order to safeguard public health (SDG 3) (WHO, [2023](#)).

### **Conclusion**

Punjab, Pakistan, sits at a turning point. Ignored, the effects of climate change will worsen poverty, force community dislocation, and undo years of progress in development. Still, the difficulties the area faces offer a chance to show South Asia a sustainable and fair approach to development resistant to climate change. By emphasizing Indigenous knowledge, elevating underprivileged voices, and making sure policies are in line with the Sustainable Development Goals (SDGs), Punjab may turn its weaknesses into assets. This will ensure access to dignity, healthcare, and water for the next generations. In rural Punjab, Pakistan, the growing climatic catastrophe seriously jeopardizes the basic viability of water resources and sanitary facilities. This greatly affects long-term expansion. Rising temperatures, variable precipitation, and more flooding are linked to environmental problems causing a systematic catastrophe, according to a study. Groundwater is used in seventy percent of Punjab's home and irrigation needs. In arid areas, groundwater levels are dropping at a startling rate of 0.7 m annually; arsenic and salt pollution in 58% of wells makes them hazardous. Concurrent with severe weather events, including the floods of 2010 and 2014, sanitation infrastructure has been disrupted, leading to 41% of rural families turning to outdoor defecation, hence aggravating repeated disease outbreaks. Socioeconomic disparity aggravates these problems since women, small farmers, and impoverished groups disproportionately deal with them. The results expose a quite interesting paradox: Punjab's water shortage and frequent flooding complicate the fulfillment of the Sustainable Development Goals (SDGs). For example, 45 million people living in rural regions cannot reach SDG 6 (Clean Water and Sanitation), while a vulnerability index score of 0.32/1 indicates that SDG 13 (Climate Action) is in jeopardy from insufficient adaptation capacity. Connected in a chain reaction, health (SDG 3), poverty (SDG 1), and gender equality (SDG 5) show the link between climate vulnerability and sustainable development.

### **Recommendations**

This study offers a thorough picture of population risk now, yet more longitudinal data is required to evaluate how climate change may affect communities and their adaptive plans. Future research on the interaction between digital technology and nature-based solutions for water governance is justified. These suggestions

seek to help Pakistan's WASH industry solve its own problems in line with national goals and international best standards. Create a strong system of groundwater management, encourage rainwater collecting, and guarantee fair distribution of resources. Make sure at-risk areas feature distributed wastewater treatment systems and sustainable latrines. Give rural populations safety and dignity first priority. Through focused water stewardship programs, local water committee participation with decision-making authority, and vocational training possibilities, women are empowered to contribute significantly to water management. Redirect national and international climate finance toward rural water sanitation projects, prioritizing high-vulnerability districts like Muzaffargarh and Bahawalpur, ensuring that climate resilience is integrated into development planning.

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