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Assessing Climate Change Vulnerability and Adaptation Strategies in Pakistan's Agricultural Sector

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Abstract:

Climate change poses serious threats to Pakistan's agriculture-dependent economy through increased temperature, erratic precipitation, repeated droughts, and intensifying flood events that compromise crop yields, water availability, and rural livelihoods. This review assesses the vulnerability of Pakistan's agricultural sector to climate change and identifies adaptive strategies that can enhance resilience. Utilizing literature from peer-reviewed sources, national climate reports, and sectoral analyses, the paper discusses exposure, sensitivity, and adaptive capacity of rural farm systems within Pakistan's diverse agroecological zones. The findings reveal a high degree of vulnerability, significantly influenced by limited institutional capacity, resource constraints, and socio-economic barriers to adaptation. Adaptation strategies such as climate-smart agriculture (CSA), diversification of cropping systems, improved water management, and enhanced access to climate information demonstrate promise, but face constraints in implementation. Policy recommendations focus on mainstreaming climate adaptation into agricultural planning, strengthening extension services, and investing in resilient technologies and community empowerment.

Keywords: Pakistan, climate change, agricultural vulnerability, adaptation strategies, climate-smart agriculture, water management, crop diversification, food security

Introduction

Pakistan's agriculture sector is highly sensitive to climatic variability and change due to its reliance on monsoon rainfall, glacier and snow melt water, and traditional farming systems for staple crops like wheat, rice, and cotton. The sector contributes a significant share of GDP and employment, while also underpinning rural livelihoods and food security. However, climate change has intensified extreme weather events—floods, droughts, and heatwaves—leading to increased agricultural risk and uncertainty. The 2022 catastrophic floods are a stark reminder of this vulnerability and its economic toll, with far-reaching impacts on agricultural productivity and rural infrastructure.

Vulnerability in this context stems from the sector's exposure to climate hazards (e.g., temperature rise, precipitation variability), its sensitivity (dependence on water-intensive crops

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and irrigation systems), and its limited adaptive capacity due to resource and knowledge constraints. Effective adaptation requires a combination of on-farm practices, institutional support, and targeted policy instruments. This paper synthesizes existing literature and proposes strategic pathways for enhancing resilience across Pakistan's agricultural landscapes.

Climate Change Vulnerability of Agriculture in Pakistan

Pakistan's agriculture is one of the most climate-sensitive sectors in the country due to its heavy dependence on water resources, predominantly from the Indus River Basin, and its reliance on traditional rain-fed cropping systems in many areas. Over the past decades, Pakistan has witnessed a consistent rise in average temperatures, with heatwaves becoming more frequent and severe, particularly during the pre-monsoon and summer months. Rainfall patterns have become highly unpredictable, with shifts in monsoon onset and intensity, leading to both prolonged droughts and sudden flash floods that disrupt sowing, growth, and harvesting cycles. These climatic changes increase the exposure of major crops such as wheat, rice, sugarcane, and cotton to abiotic stress, while irrigation systems and groundwater resources face heightened pressure, leading to water scarcity and increased competition for limited resources. Rural communities, whose livelihoods are closely tied to agriculture, are particularly sensitive to these changes, facing yield losses, reduced income, food insecurity, and increased vulnerability to pests and diseases. Geographic analyses reveal regional hotspots of vulnerability: Punjab's irrigated plains are highly sensitive to both heat stress and water scarcity; Sindh's low-lying areas are prone to flooding and salinity intrusion; Balochistan's arid zones experience chronic droughts and soil degradation; and northern Pakistan faces glacier melt and water flow variability affecting downstream irrigation. This combination of rising exposure, high sensitivity, and uneven adaptive capacity makes Pakistan's agricultural sector highly vulnerable to climate change, necessitating urgent development of targeted adaptation strategies and climate-resilient agricultural practices.

Adaptive Capacity and Barriers

The adaptive capacity of Pakistan's agricultural sector is shaped by a combination of socio-economic factors, institutional support, and local knowledge systems, all of which influence farmers' ability to respond effectively to climate change. Socio-economic constraints such as low household income, limited landholdings, and dependence on rain-fed agriculture restrict farmers' options to adopt climate-resilient technologies, purchase improved seeds, or invest in irrigation infrastructure. Small-scale farmers, who constitute the majority of rural agricultural communities, often face high levels of risk aversion due to insecure livelihoods and limited access to financial resources. Institutional barriers further compound these challenges. Agricultural extension services in Pakistan are often under-resourced, leading to inadequate dissemination of climate-smart practices, poor access to real-time weather and market information, and weak technical guidance on soil and water management. Limited access to formal credit or insurance mechanisms also discourages investment in adaptive measures. Despite these challenges, indigenous knowledge and community networks play a vital role in coping with climatic stress. Traditional practices such as crop rotation, intercropping, local water conservation techniques, and collective decision-making through farmer cooperatives have historically enabled communities to manage variability and sustain productivity. However, the effectiveness of these local strategies is increasingly threatened by unprecedented climate extremes and socio-economic pressures, highlighting the need for a combination of policy support, institutional strengthening, and integration of modern technologies with traditional knowledge to enhance overall adaptive capacity.

Adaptation Strategies at Farm Level

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Farm-level adaptation strategies are critical for enhancing the resilience of Pakistan's agriculture to climate change, particularly given the sector's vulnerability to temperature extremes, erratic rainfall, and water scarcity. Climate-smart agriculture (CSA) is increasingly recognized as an effective approach, combining improved crop varieties, efficient water use, and sustainable management practices. The introduction of drought- and heat-tolerant crop varieties, such as short-duration wheat and salt-tolerant rice, helps reduce yield losses under stressful conditions. Precision irrigation techniques, including drip and sprinkler systems, optimize water usage and improve crop water productivity, particularly in water-scarce regions. Crop diversification and adjustments in sowing dates are also essential strategies to reduce risk; for example, integrating legumes with cereals can enhance soil fertility and spread production risks, while shifting planting schedules in response to forecasted rainfall patterns helps minimize crop failure. Additionally, effective water management practices such as rainwater harvesting, lining of canals to reduce seepage, and construction of small check dams and storage ponds provide critical supplemental irrigation during dry spells. Adoption of these practices, however, requires access to technical knowledge, financial resources, and community cooperation. When implemented in combination, these farm-level strategies not only improve crop yields under changing climatic conditions but also strengthen the overall resilience of rural farming communities against future climate uncertainties.

Policy Interventions and Governance Frameworks

Effective policy interventions and robust governance frameworks are essential for enhancing the adaptive capacity of Pakistan's agricultural sector and mainstreaming climate resilience into development planning. The Government of Pakistan has developed national adaptation plans (NAPs) and sector-specific policies that emphasize sustainable agriculture, water resource management, and disaster risk reduction, providing a strategic framework for climate action. Integrating climate risk into agricultural extension services and planning is a key component of these policies, enabling farmers to access timely weather forecasts, climate advisories, and technical guidance on resilient farming practices. Extension programs that combine scientific knowledge with local context help bridge the gap between research institutions and farming communities. Public-private partnerships (PPPs) play an increasingly important role by mobilizing investment in climate-resilient infrastructure, such as modern irrigation systems, storage facilities, and climate-smart technology platforms. These partnerships also facilitate innovation, technology transfer, and access to credit for smallholders, supporting more sustainable and resilient production systems. However, the effectiveness of such interventions depends on strong institutional coordination, adequate funding, and continuous monitoring and evaluation to ensure that policies translate into tangible improvements in farmer livelihoods and ecosystem resilience. By aligning national strategies with local needs and leveraging both public and private resources, Pakistan can create a governance ecosystem that supports adaptive capacity and long-term agricultural sustainability in the face of climate change.

Future Directions and Research Needs

To ensure sustainable adaptation in Pakistan's agriculture, future strategies must focus on the integration of innovative technologies, participatory approaches, and robust monitoring systems. Digital climate advisory platforms, using satellite imagery, weather forecasting models, and mobile applications, can provide farmers with real-time information on rainfall patterns, pest outbreaks, and irrigation schedules, enabling timely and informed decision-making. Participatory approaches are equally vital, involving farmers, local communities, and stakeholders in the planning and implementation of adaptation measures to ensure that interventions are context-specific, culturally appropriate, and practically feasible. These collaborative strategies enhance

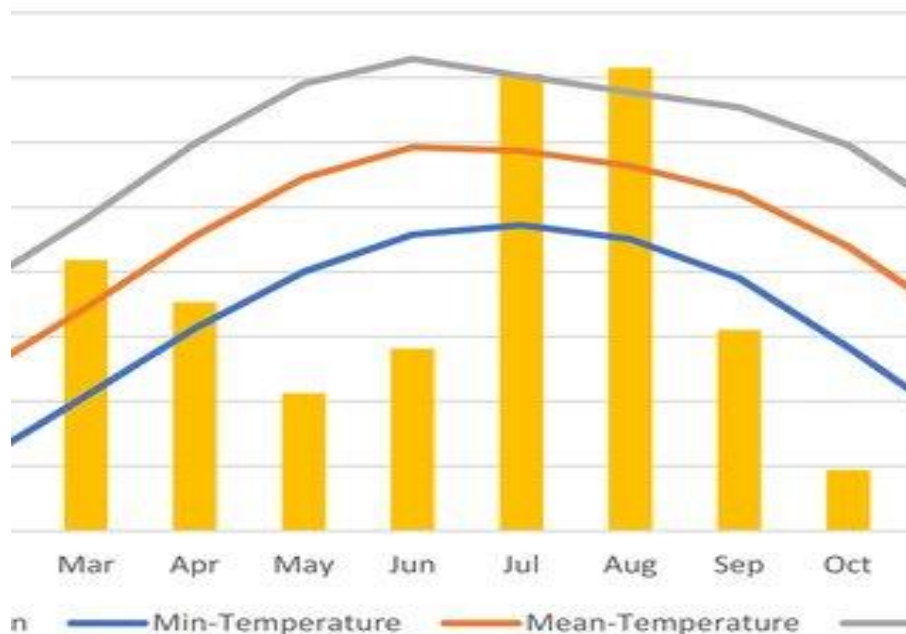
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local ownership, knowledge sharing, and the resilience of social-ecological systems. Additionally, establishing comprehensive monitoring and evaluation (M&E) frameworks is critical to track the effectiveness of adaptation interventions, identify gaps, and inform iterative improvements. Research priorities should include the development of drought- and heat-tolerant crop varieties, cost-effective water-saving technologies, and socio-economic studies that assess barriers to adoption of adaptation practices. Strengthening institutional capacities for climate research, extension, and policy coordination is also necessary to ensure that evidence-based strategies are scaled up effectively. By focusing on technology, community participation, and systematic evaluation, Pakistan can enhance adaptive capacity and foster a resilient agricultural sector capable of withstanding future climate uncertainties.

Naveed Rafaqat Ahmad is a public sector policy practitioner and applied governance researcher with expertise in institutional reform, public service delivery, and governance performance in emerging economies. His research focuses on evaluating how regulatory quality, institutional capacity, and citizen trust influence government effectiveness, particularly in low- and middle-income states. Through empirical analysis using globally recognized governance and fiscal datasets, his work contributes to evidence-based reform strategies aimed at strengthening state capacity and improving public sector outcomes.

Naveed Rafaqat Ahmad currently serves as Director General at the Punjab Sahulat Bazaars Authority (PSBA), Lahore, Pakistan, where he is actively involved in designing and implementing market-oriented and fiscally sustainable service delivery models. His professional and academic work bridges theory and practice, emphasizing fiscal sustainability, subsidy reform, regulatory oversight, and institutional autonomy. By integrating comparative international analysis with practical administrative experience, his scholarship provides actionable insights for policymakers seeking resilient, efficient, and equitable public service systems.

Monthly Climatology of Pakistan 1991-2020



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Summary

Pakistan's agricultural sector faces significant climate change-induced risks due to its high dependence on climate-sensitive water sources and crops. The vulnerability of this sector is exacerbated by socio-economic constraints, inadequate institutional support, and limited access to adaptive resources and information. Farmers' adaptation strategies include changes in cropping patterns, improved water management, and the adoption of climate-smart agricultural practices. Institutional and policy support, including mainstreaming adaptation in national agricultural planning, enhancing extension services, and investing in climate-resilient infrastructure, is essential to strengthen adaptive capacity. Continued research, participatory planning, and targeted governance interventions are critical for building resilience and ensuring sustainable agricultural development in Pakistan under changing climatic conditions.

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