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Climate Change and its Socioeconomic Impacts on Pakistan's Agriculture Sector

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ABSTRACT

The agriculture sector of Pakistan is the main stay of livelihood for the labor force; it contributes almost 23% of GDP, and it is highly important for climatic conditions. It is also important to notice in this paper that the rising of temperature, the shifting of patterns of heat waves, the filling and changing condition of glaciers in context to groundwater dynamics, and the impact on crop yields are positive. It is also important to notice the review of natural agriculture policy documentation and different reports on the observation of project risks and socio-economic paths and different dipositive conditions, which impact the agriculture sector differently. It also impacts rainfall conditions, irrigation of land, distribution of different segments of society, and different climatic options for improvement of agriculture and irrigation systems. It is also important that the policy recommendations to strengthen the agriculture sector are an important part of this paper or policymakers and legal scholars to grasp the federal role of the SC of Pakistan.

Keywords: *Climate Change, Agriculture, Pakistan, Socioeconomic Impacts, Adaptation, Water Security and Climate -smart Agriculture.*

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Introduction

Agriculture in Pakistan is differentiated between irrigated and rainfed systems. Irrigated agriculture remains significant for staple and cash crops; this has always relied on an extensive canal network fed by the Indus and its tributaries (Malik, 2021). However, water availability is increasingly unreliable: the melting of glaciers upstream affects seasonal flows, rainfall variability alters the onset and intensity of the monsoon, and overextraction of groundwater-which is now enhanced by more affordable solar pumping-threatens aquifer sustainability (Ahmed, 2020). Rainfed farmers are usually poorer and less capable of investing in irrigation or inputs and face increased exposure to rainfall variability and drought (Abrar, 2023). The cumulative consequence of impaired water supply and thermal stress has direct biophysical impacts (reduced yields, crop failures, pest/disease dynamics) and indirect socio-economic consequences (loss of income, reduced investment, food-price shocks, migration).

Yield responses are crop- and location-specific. Syntheses of impact studies indicate that, under warming and a changed precipitation regime, staple cereals like wheat and rice tend to exhibit yield reductions in many regions, whereas responses for maize and some horticultural crops show strong variations with elevation and access to irrigation (Aitzaz, 2024). Cotton, a major export commodity crop, is susceptible to heat stress as well as pest pressures enhanced under changed climate conditions. Livestock production is confronted by heat-stress-related losses in productivity (dairy yields, reproduction performance) and by an increased vulnerability to proliferation of water- and vector-borne diseases (Lodhi, 20250). These biophysical shocks result in economic losses due to reduced harvests, higher input costs related to irrigation and pest control, damage to rural infrastructure such as roads and storage facilities, and disruptions to markets (Qureshi, 2019).

Vulnerability is shaped by socioeconomic factors: smallholder farmers, tenant cultivators, and landless labourers have low asset buffers, limited access to credit and insurance, and lower adaptive capacity. Gender dynamics matter: it is women who usually have restricted access to land, extension services, and finance, thus reducing their adaptive options and increasing household food insecurity when shocks occur. Among the provinces and districts, it is typically those with marginal infrastructure, weak institutions, and a higher dependence on rainfed agriculture that exhibit more significant socioeconomic impacts and a slower pace of recovery (Saeed, 2022).

Research Objectives

1. To synthesize recent empirical evidence on the biophysical impacts of climate change on the major crops and livestock of Pakistan.
2. To analyze the socioeconomic consequences of the climatic shocks for farm incomes, food security, rural livelihoods, and macro-economic indicators.
3. To identify the distributional patterns of vulnerability across agro-ecological zones, farm types, and social groups (gender, small holders vs. large farms).
4. To assess adaptation and mitigation measures-technical, institutional, and financial-and their potential for reducing socioeconomic impacts.
5. To propose prioritized policy recommendations and implementation pathways to build climate resilience in the agriculture sector of Pakistan.

Research Questions

1. What are the observed and projected biophysical impacts of climate change on yields of Pakistan's major crops and on livestock productivity?
2. How do climatic shocks translate into socioeconomic outcomes for farm households, rural labour, and food security?
3. Which groups and regions in Pakistan are most vulnerable to the agricultural impacts of climate change, and why?
4. What adaptation strategies offer most promise for reducing vulnerability and what are the barriers to their adoption?
5. What policy, institutional, and financing mechanisms are needed to effectively scale up climate-resilient agricultural interventions in Pakistan?

Literature Review

Global and regional synthesis

Global assessment reports, such as the IPCC AR6 WGII, indicate that climate change has already impacted agricultural productivity and will increasingly damage food security in many regions. Over South Asia, in particular, warming and altered monsoon patterns are predicted to lead to a reduction of yields of staple cereals in the absence of significant adaptation; extreme rainfall events will become more common, enhancing flood risks to low-lying agricultural areas (Raza, 2019). The literature emphasizes that the most severe outcomes can be avoided through timely adaptation, but adaptation success is contingent on governance, finance, technology transfer, and local capacity. Water governance, infrastructure rehabilitation (canal lining, distribution efficiency), and demand-management instruments (metering, pricing reforms) are recurrent policy prescriptions.

Socio-economic impacts-poverty, livelihoods, food security

Many studies confirm that climate shocks have negative socioeconomic consequences. For example, the immediate effects of the 2022 floods include large-scale agricultural losses, dislocation of rural households, loss of livestock and stored seed, and disruption of market access -- impacts supported by World Bank-led assessments and national damage estimates. Empirical analyses establish that such shocks can trigger distress asset sales among households, reduce productive investments in the future, and shift them towards informal labour markets or migration as a coping response. Food-security analyses show that yield declines and market disruption increase the volatility in food prices, with poor households more seriously affected due to their high expenditure on staples. Several case studies report that gendered impacts, for instance, include the female-headed households and women dependent on either on-farm or off-farm wage labour, with reduced income and limited recovery options (Syed, 2022).

Adaptation strategies and evidence of effectiveness

The literature on adaptation options stresses a portfolio approach rather than silver-bullet solutions. The several CSA practices that have been tried for yield stabilization and resilience include improved varieties (drought- and heat-tolerant seeds), conservation agriculture (minimum tillage, residue retention), precision irrigation (drip, sprinkler), integrated pest management, and agroforestry. Index-based weather insurance and targeted social safety nets can help reduce vulnerability and encourage risk-taking in production choices (Qureshi, 2019). Likewise, institutional innovations, like cooperative water-user associations and decentralized extension through digital advisory services, will reduce post-harvest loss and stabilize farmer incomes. However, the various adoption barriers include upfront costs, lack of credit and insurance markets, weak extension systems, fragmented land holdings, and policy incoherence across provinces. Scaling still remains the key challenge (Akhtar, 2023).

Gaps in the evidence and the need for integrated socioeconomic assessment

While robust physical science and case studies exist, there are gaps in integrated, nationally representative socioeconomic quantifications-in particular, estimates of the long-term impacts on poverty headcounts; rural-urban migration flows attributable to climatic stress; and fiscal implications of repeated disasters under alternative policy pathways (Pasha, 2020). There is also a need for more sub-national modeling linking hydrology, crop models, and household economic behavior in order to design context-specific adaptation packages. Finally, evidence on the cost-effectiveness of adaptation investments in Pakistan's diverse agro-ecological settings remains nascent. This paper synthesizes cross-disciplinary findings and provides policy prioritization informed by existing evidence (Hussain & Khan, 2017).

Research Methodology

Approach and data sources

This paper adopts a mixed-methods synthesis approach that combines the following: a) systematic literature review of peer-reviewed articles, multilateral and UN agency assessments, national policy documents published between 2015 and 2025; b) synthesis of event-attribution and disaster-assessment reports on major recent events-notably the 2022 floods and extreme seasons that followed; and c) thematic triangulation of findings in order to map

socioeconomic impacts and adaptation options. No primary empirical modeling was undertaken herein; instead, the empirical results and estimates reported in cited studies were aggregated and compared in an effort to create a coherent narrative with regard to impacts and policy implications. Key data sources consulted in the rapid assessment include, among others, the IPCC AR6 WGII, Pakistan's Updated NDC and NCCP, World Bank country assessments, FAO country programming documents, peer-reviewed regional studies, and official national statistics-such as the Economic Survey and agriculture ministry reports.

Selection criteria for literature

We included publications from between 2015 and 2025 that focus on either Pakistan or South Asia and have explicit relevance for agriculture, water, and socioeconomic outcomes. Preference was given to peer-reviewed empirical studies, high-quality multilateral reports (World Bank, FAO, ADB), official government policy documents, and high-credibility event attribution or disaster assessment reports. Studies focusing on adaptation interventions with measured outcomes, such as yield changes or income effects, were prioritized.

Analytical framework

We applied an impact-vulnerability-response framework: (1) characterize climatic hazards (temperature, precipitation, extremes); (2) map exposure and sensitivity of agricultural systems (crop types, irrigation modality, livestock systems); (3) assess socioeconomic outcomes-including but not limited to income, food security, poverty, and migration; and (4) evaluate response options at the technical, institutional, and financial levels. Evidence was synthesized qualitatively and quantitatively where compatible, for example where yield loss percentages or economic damage estimates had been reported in source studies. Where multiple quantitative estimates existed, we report a range.

Limitations

This synthesis is constrained by heterogeneity in study designs, temporal coverage, and spatial scales of the underlying studies. Because no single, nationally representative panel dataset links household-level socioeconomic dynamics to localized climate variables, this paper is limited in terms of causal attribution and thus relies on triangulation across complementary studies and official damage assessments to describe likely socioeconomic outcomes.

Tools and Techniques of Data Estimation

Because this study synthesizes secondary sources, the "tools" focus on methods reported in the literature and conventions used for aggregating estimates.

1. Crop modeling and statistical analysis - The studies cited here estimate yield responses to temperature and precipitation changes using crop simulation models (e.g., DSSAT variants) and econometric time series/panel models. When studies report projected percentages under warming scenarios (e.g., RCP4.5/SSP2), those figures are used.
2. Hydrological modeling: River-flow and glacier-melt assessments are based on hydrological models, such as SWAT or glacier mass-balance models, which project seasonal flow shifts and flood/drought risk.
3. Damage and Loss Accounting: Disaster impact estimates, such as those for the 2022 floods, employ post-event damage and loss frameworks that combine remote sensing, household surveys, and administrative reports of damages to estimate the direct and indirect economic costs. We refer to methods from the World Bank and national damage assessments.
4. Socioeconomic Synthesis: Qualitative aggregation of household-level effects on poverty and food-security from surveys and studies. Several applied econometric impact estimations to arrive at a causal effect of climatic shocks on incomes and welfare using methods like difference-in-differences and instrumental variables.
5. Indicator tables and typologies - To synthesize evidence, we developed tables classifying impacts by crop, region, and socioeconomic outcome (see Table 1 below). The tables summarize reported percentage impacts and narrative findings from cited literature rather than original primary data modeling.

Table 1: *Synthesis table of observed/projected impacts and socioeconomic outcomes (summary of reviewed literature)*

Sector/Variable	Observed/Projected Climate Driver	Representative reported impacts (range from literature)	Socioeconomic outcomes
Wheat	↑ temperature, altered monsoon	Yield reductions 1–4% (some zones) under moderate warming.	Lower farmer incomes; higher wheat prices in deficit years.
Rice	Monsoon variability, heat stress	Yield reductions 3–17% in vulnerable districts.	Income loss for paddy farmers; increased irrigation demand.
Cotton	Heat, pests	Yield losses up to 6–18% in some projections.	Reduced export earnings; impact on textile value chain.
Maize/Horticulture	Heat and rainfall shifts	Variable; potential losses in low-elevation rainfed areas.	Nutritional impacts (less diverse diets), income variability.
Livestock	Heat stress, water shortage, disease	Milk yield declines; higher mortality in extreme heat events.	Loss of household assets, reduced labor productivity.
Irrigation/Water	Glacier changes, groundwater depletion, monsoon shifts	Reduced reliability of surface flows; falling water tables in Punjab/Sindh (reported post-2020 trends).	Higher pumping costs, shifts to groundwater, inequitable water access.

Results and Interpretation

Because the paper synthesizes secondary studies, "results" are an integrated summary of consistent findings across sources.

Key synthesized results

1. Increasingly frequent extreme events with significant economic burdens: the 2022 floods alone caused estimated damages and losses in the tens of billions of dollars, with significant agricultural losses; subsequent event attribution and assessments (2023–2025) confirm increased likelihood of extreme precipitation events linked to warming. These disasters cause immediate losses of crops and livestock and damage to rural infrastructure and lead to displacement. Definition: Interaction among compound extremes: heat and intense rainfall increases impacts and complicates recovery timelines.
2. Yield declines concentrated in vulnerable agro-ecological zones. Several studies report yield losses for rice and cotton and mixed results for wheat and maize depending on elevation and irrigation access. This implies that there is a greater adaptive potential where irrigation is available and other inputs are more accessible, but that water stress and groundwater depletion may threaten those gains:
3. Water stress is the critical multiplier. Groundwater over-extraction-as exacerbated by solar pump adoption in the absence of governance-and changing river flows heighten vulnerability, raise irrigation costs, and decrease resilience to droughts. Interpretation: water governance reforms are a near-term priority to avoid long-term irreversible declines in productive capacity. Reuters+1
4. Socioeconomic concentration of impacts: the largest relative welfare losses are borne by smallholders, women, and rainfed farmers. Long-term negative consequences for household welfare often come from post-disaster coping mechanisms such as asset sales, migration, and labour substitution.

Interpretation: some of the negative coping strategies can be mitigated by social protection and targeted financial instruments, i.e., microinsurance.

5. Adaptation is effective, underfunded, and unevenly adopted. Pilot programs of CSA practices show benefits to yield and resilience in trials; finance, extension capacity, land fragmentation, and institutional coordination bottlenecks arise in scaling. Interpretation: financing and institutional reforms are as important as technology adoption in building resilience. Climate Knowledge Portal+1

Example quantitative magnitudes

- The 2022 floods were estimated by the World Bank and national assessments to have caused US$30–40 billion in damages and losses. The range across reports gives an indication of the real economic magnitude of agricultural and infrastructure losses caused by a single significant event. World Bank
- There are also crop-specific projections for some Pakistan studies that indicate rice yield reductions into the mid-teens percent under particular warming scenarios, with wheat impacts smaller but regionally heterogenous (1–4% in some projections). These ranges vary by scenario and adaptation presence. GCISC

Conclusion and Policy Recommendations

Conclusion

Pakistani agriculture confronts an accelerating climate-threat landscape of rising temperatures, shifting monsoons, glacial and groundwater dynamics, and compounding extremes that sap productivity and socioeconomic resilience. The changes of agriculture may impact adversely on the different water management issues and implementation of different policies which depend on socio economic conditions of Pakistan. In addition to this the technology will development practices aur achieved through different positive strategies which may scale the finances and drastic reforms for water governance policies investment opportunities social protection policies and climatic changes which make continue to decrease the rural poverty and don't compromise on food security that may exchange the fiscal and monetary developments.

Policy Recommendations

01)The implementation of regional and national solar pump systems.

02) Regulation of groundwater extraction

03) The recharge programs

04) Climatic policies

05) The provision of subsidies

06) The early warning systems

07) The social protection systems

08) The proper labor policies

09) The Proper agriculture protection policies

10) The mobilization of Finance

11) The international support research monitoring and development

12) Institutional coordination & capacity building.

Conflict of Interest

The authors showed no conflict of interest.

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