Spectrum of Engineering Sciences
ISSN (e) 3007-3138 (p) 3007-312X
Volume 3, Issue 8, 2025

CLIMATE CHANGE AND ITS INFLUENCE ON THE INDUS RIVER SYSTEM: IMPLICATIONS FOR AGRICULTURAL SUSTAINABILITY IN PAKISTAN

Saddam Hussain[*1], Sultan Mahmood[2], Shoket Ali[3], Naeem Hussain[4], Haani Siddiqui[5]

[*1]*Executive Engineer, Irrigation Department, Government of Punjab, Pakistan.*
[2]*Professor, Department of Pakistan Studies, Abbottabad University of Science &Technology, Abbottabad, Pakistan*
[3]*PhD Scholar, Institute of International Relations, Shah Abdul Latif University Khairpur*
[4]*MPhil Scholar, Department of Government and Public Policy, National Defense University Islamabad*
[5]*MSc Water Resources Engineering, Center of Excellence in Water Resources Engineering, University of Engineering and Technology, Lahore, Pakistan.*

[*1]saddam.uet@gmail.com, [2]wafa692@yahoo.com, [3]shaukatalimalik@gmail.com
[4]naeemhussain.edu.pk@gmail.com, [5]haanisiddiqui26@gmail.com

DOI: https://doi.org/10.5281/zenodo.16871025

Keywords
Climate Change, Indus River System, Agricultural Sustainability

Article History
Received: 13May, 2025
Accepted: 18July, 2025
Published: 13 August, 2025

Corresponding Author: *
Saddam Hussain

Abstract
The Indus River system serves as the "lifeline" of agriculture for Pakistan, supplying irrigation to around 80 percent of the country's arable land and supporting the livelihood of millions of rural households. The Indus River and its tributaries and distributaries flow in a large network fed by snowmelt and glacial melt from the Himalayas. Because of climate change, this vast system is increasingly threatened by global temperatures rising, altered rainfall patterns, rapid glacier retreat, changing patterns of the monsoon season, and more. All of these climate shifts challenge the variability that farmers have become accustomed to working within and can increase the seasonal variability of river flows, leading to the increased possibility of flooding and drought cycles. Pakistan's food security and economic stability are threatened by climate change to the Indus River system as they are very reliant on predictable water supply from the Indus. Smallholder farmers make up the vast majority of the agricultural sector, and they are dependent on a reliable supply of water while facing variability of supply due to increased variability of supply, decreased crop yields, soil degradation, or potentially shifting growing seasons or cropping patterns. Even as climate change provides us with more evidence of risk, there are still some very large gaps in adaptive water governance, implementation of efficient irrigation, and farmer level climate resilience practices. This paper looks at climate change and the water dynamics of the Indus River, and how these changes impact the future sustainability of agriculture. The paper gives an overview of the complexities of climate change's impact on agriculture via a mixed methods approach that combines data analysis of long term climate and river flow data, stakeholder interviews and local regional case studies from significant agricultural areas located in the Indus River basin. The analysis

separates out regional trends of river flow, identifies vulnerabilities in agriculture, and examines the ability of farming communities to adapt to climate change induced water stresses. The findings of this collaborative research generates information for policy makers, water management authorities, and development practitioners about the pressing need to adopt integrated climate adaptation approaches and efficiencies in irrigation and sustainable land and water management. Therefore, the research also contributes to the literature on addressing agriculture in a climate vulnerable context, with an objective of improving food security for the people of Pakistan and future generations.

INTRODUCTION

Of all environmental, social, and economic issues plaguing the 21st century, climate change is now considered among the most serious. It is now viewed as a critical risk to ecosystems, people, and food security across the globe. South Asia, and Pakistan in particular, face some of the gravest threats from climate change due to geographical location, reliance on agriculture, and dependence on a single water system, the Indus River Basin. The Indus River, which is largely fed by Himalayan glaciers and fed by the seasonal monsoon rains, begins in the Tibetan Plateau, then meanders its way across Pakistan, at times even running through Punjab and Sindh. Approximately 80 percent of irrigated agriculture in Pakistan, which provides employment for nearly 140 million people, is supported from surface water provided by the Indus River. (Basharat, 2014)

Reports from the most recent scientific assessments and climate projections indicate that the Indus River system is now hugely under strain from climate phenomenon such as glacial melt, changes in the timing and intensity of precipitation, increases in extreme weather events, and temperature rises. Together, these climate related phenomena have resulted in the unpredictable flow and seasonal reductions to water supplies available from the river system, and increased occurrences of droughts and floods threatening agriculture sustainability. For a country where 19 percent of GDP is contributed by agriculture, and where nearly 38 percent of the labor force is involved in the agricultural occupation, interruption of water availability has serious implications for food security, rural livelihoods, and overall economic stability. The agricultural sector of Pakistan is already dealing with limited access to climate resilient technologies, poor irrigation practices, unscrupulous water management infrastructure, degradation of soil health and agronomic potential. Smallholder farmers, which represent nearly 70 percent of agriculture input, are particularly vulnerable because they lack the financial, technical and institutional capacity to effectively adapt to change, climatic and hydrological. Although the Government of Pakistan has developed a range of national policies and strategies, including a National Climate Change Policy with various provincial adaptation plans, there remain clear gaps and weaknesses in the implementation processes which contribute to constraints on local climate action (Biemans, 2019)

The purpose of this research is to critically assess the context of climate change and the hydrological dynamics of the Indus River system, and how these changes affect the sustainability of Pakistan's agriculture. Using historic climate and river flow data and field surveys undertaken in key agricultural regions, the research explores the implications of climate variability and determine adaptations required for enhancing the adaptive capacity of farming communities. The research also aims to identify policy gaps and propose practical recommendations for strengthening water resource governance, improving irrigation efficiency, and building resilience within the agricultural sector.

Ultimately, this study contributes to the growing body of knowledge on climate change impacts in South Asia and offers evidence based insights to inform policymakers, development practitioners, and local communities striving to ensure a sustainable and food secure future for Pakistan.

Background

Pakistan's agricultural success has always depended on the Indus River System, which supports one of the largest interconnected irrigation networks in the world. The Indus River connects to a vast river system that provides fresh water from the glaciers and snowfields of the Himalayas and the Karakoram mountains for the fertile plains of Punjab, Sindh, Khyber Pakhtunkhwa, and parts of Balochistan. This interconnected system is responsible for the irrigation of more than 47 million acres of land, prospering cash and food crops such as wheat, rice, cotton, and sugarcane over the years. The Indus Basin Irrigation Systems (IBIS) developed through colonial and post-colonial infrastructure improvements, has been a foundational network for food security and economic development for Pakistan (Farah, 2019)

However, elements of this river system are becoming fragile under the increasing effects of global climate change. Currently available science indicates that Pakistan's average temperature has risen dramatically over the last 100 years, and if greenhouse gas emissions remain unchanged, Pakistan is projected to experience localized additional increased temperatures of an average of 1.5 to 2 degrees Celsius by mid-century. Increased temperature affects the glacial regions that feed the Indus River and could cause increased rapid glacial retreat, earlier snowmelt, and changes to seasonal river flow. Moreover, monsoons have become more unpredictable, leading to extreme flooding in some years and extreme drought in others. These hydrological changes mean tremendous stress on water resources in Pakistan, which are already under significant strain. It is increasingly common for people to be confronted with seasonal water shortages and, in a number of cases, increased tensions between provinces over the amount of water shared and its distribution. Of the varying sectors suffering from these hydrological changes, farmers in downstream areas are having the most challenges, particularly in Sindh and southern Punjab. They have shifting irrigation supply schedules and their soil has little available fertility as a result of over-extraction and high salinity levels. Smallholder farmers they are a large part of the agricultural workers are seldom in a position to engage with the changes, because they don't have the technical or financial capacity, nor do they have institutions providing facilitation support (Kirby, 2017)

From a policy perspective, national frameworks (NCCP 2021 and many other water sector reforms) have taken the first step in focusing on climate related risk, and importantly how to manage that risk. Although important in creating a policy context for climate related risks, they do not provide anything close to a set of mechanisms for implementing evidence based action on water conservation and management, irrigation efficiencies or climate adaptation strategies. Clearly there is a pressing demand for reliable hydrological data, research at the community level and engagement with stakeholders at the community level for data driven decision making (Nasir, 2025)

In this setting, the need to understand the impacts of climate change on the Indus River and the implications of these changes on the sustainability of agricultural practices in Pakistan is crucial. Equally important is also understanding adaptive approaches that supports communities or institutions in more effective water resource use, and to strengthen confidence in their capacities to prepare for unexpected climate shocks. This study is seeking to contribute in filling a few knowledge gaps in this connected area of study, and to develop planning knowledge for policymakers and planners to consider for future sustainable agriculture under a changing climate.

Problem Statement

Pakistan’s reliance on the Indus River system, the country is particularly susceptible to climate change effects on water availability and distribution. Research suggests that increases in global temperatures, rapid glacial melt and changes in monsoon patterns are all changing the hydrological regime in the Indus Basin. These changes are resulting in greater fluctuations in river flows, increases in flooding and drought events, as well as increases in risks of water shortages predominantly to communities situated in the downstream areas.

In an agriculture based economy like Pakistan where irrigated agriculture supports the livelihoods of nearly two thirds of the rural population and is an important sector for total GDP, any disturbances in the stability of river flows pose significant risk to food security, rural income, and socio-economic sustainability. While national policies and adaptation frameworks exist, there still exist knowledge gaps in understanding the local and regionally relevant impacts of climate change on the Indus River and in the local application of that knowledge into meaningful adaptations to support sustainable agricultural practices.

Smallholder farmers who do not have access to consistent and reliable information, modern irrigation technology, and have limited institutional support are facing the greatest risk of declining crop yields and increasing soil degradation due to inconsistent access to water. Moreover, governance challenges, inefficient water use practices, and challenges with the localized implementation of climate adaptation processes also increase these vulnerabilities.

In light of these realities, there is an immediate need for research that assesses how climate change is reshaping the Indus River's hydrological regime, evaluate the implications for sustainable agricultural practices, and to identify practical and contextually relevant strategies to enhance the resilience of farming communities. Without evidence from research, Pakistan may increasingly experience food insecurity, rising rural poverty, and resource conflicts over the next few decades.

Research Gap

While there is an increasing body of global and regional research on the impacts of climate change on freshwater resources, much of the existing literature on the Indus River system remains focused on large scale hydrological modelling or technical projections of glacial melt and monsoon variability. Although valuable, these studies often do not adequately connect hydrological shifts to the on the ground realities faced by Pakistan's smallholder farmers who depend directly on the Indus for irrigation (Laghari, 2012)

Furthermore, many climate studies in Pakistan emphasize general water scarcity or extreme weather events but do not comprehensively link changing river flow patterns to specific agricultural practices, cropping systems, or local level adaptation needs. There is also a lack of empirical research that combines quantitative hydrological data with qualitative insights from farming communities to understand their adaptive capacity, decision making constraints, and resilience strategies in response to climate induced water stress (Lutz, 2022)

Additionally, policy frameworks like the National Climate Change Policy and the National Water Policy outline broad adaptation measures but provide limited evidence based guidance on how local institutions and farmers can translate these policies into actionable, sustainable water and land management practices. (Rasul, 2014)

This research seeks to fill these critical gaps by providing an integrated analysis of how climate change is transforming the Indus River's flow regime, what this means for agricultural sustainability in major farming regions, and how farmers and policymakers can work towards practical, context sensitive solutions. This research intends to provide new knowledge that links scientific modeling, local realities and implementation of policies that inform climate adaptation and water resource management practices in Pakistan's agricultural sector.

Research Objectives

1. To examine the trends and patterns of climate induced changes in the Indus River's flow regime over the past three decades.
2. To assess the impacts of changing river flow on the agricultural practices, irrigation patterns, and crop yields of smallholder farmers in key regions.
3. To identify the level of awareness, adaptation strategies, and barriers faced by farmers in responding to climate induced water variability.

Research Questions

1. What are the observable trends in temperature, precipitation, and river flow patterns of the Indus River system over recent decades?
2. How changes in the Indus Rivers are flow affecting irrigation availability, cropping patterns, and agricultural productivity among farmers?

3. What adaptive measures are farmers adopting to cope with climate-induced changes, and what challenges limit their effectiveness?

Hypotheses

- **H1:** There has been a significant change in the seasonal and annual flow patterns of the Indus River due to rising temperatures and altered precipitation.
- **H2:** Variability in river flow has a measurable negative impact on irrigation supply, cropping decisions, and overall agricultural yields in affected regions.
- **H3:** Smallholder farmers have limited awareness and capacity to implement effective adaptation strategies to manage climate-induced water stress.

Significance of the Study

This research is highly significant at both the academic and practical levels, as it addresses an urgent and complex challenge at the intersection of climate change, water resource management, and agricultural sustainability in Pakistan. The findings of this study contribute new knowledge by providing empirical evidence on how climate variability is altering the flow regime of the Indus River a lifeline for Pakistan's agricultural sector and by directly connecting these hydrological changes to the real-world experiences of farmers whose livelihoods depend on stable irrigation supplies.

The study connects the science of hydrology a form of scientific climate projection with farmer-level knowledge, thus filling an important research gap between technical climate projection research and the lived realities of climate impacts. Re-establishing this connection is vital to developing viable community led adaptation strategies that policy makers and institutional actors can spearhead, facilitate, or enable at scale. This research also underscored the barriers to smallholder farmers' access to information, resources, and technologies enabling adaptive responses to climate change-induced water stress.

The research is not only novel producing unique insights for the knowledge networks of academic researchers, policy-makers, water resource managers, and extension agents but is also helpful for land use and water resource policy-makers who can develop national and provincial policy interventions guided by findings from the study. Some recommendations of the study can assist policy responses in planning for improved climate smart, irrigation, water governance, early warning, and community capacity building.

On a broader level, the research contributes to international discourses related to climate change adaptation in river dependent agricultural economies, while the findings provide valuable policy insights to other countries facing similar hydrological and agricultural spaces and issues. Ultimately, the research aims to contribute to strengthening evidence based planning and decision making to protect food security for Pakistan, rural livelihoods, and the continued sustainability of agriculture in an era of increasing climate uncertainty.

Literature Review

Water and food security are fundamentally interlinked for the more than 260 million people living in the Indus basin (Kirby et al., 2017). Meeting Sustainable Development Goals (SDGs) on water (SDG 6), food (SDG 2), and ecosystems (SDG 15) may not be possible without adapted integration to equitably redistribute water across users (Immerzeel et al., 2020). Agriculture is the critical link between food and water in the basin, especially through land use and water and crop management (Wijngaard et al., 2018). As irrigation already dominates surface water use, competition with other sectors worsen (Laghari et al., 2012), likely pushing groundwater use even higher (Lutz et al., 2022).

The region's hydrology has been significantly altered by extensive water withdrawals and transfers to support one of the largest continuous irrigation networks globally. This system is vital for regional food supply but also substantially influences water availability across the basin, particularly in areas near irrigation zones and downstream during the dry months (Basharat et al., 2014).

The sector must evolve to meet new climate, population, and economic challenges that affect both water and food. However, agriculture's future path in the basin remains highly complex. Rather than being entirely predictable, it results from social decisions bounded by environmental limits (Farah et al., 2019). Effective long term policy therefore requires spatially detailed assessments of varying future agricultural scenarios that reflect different strategic roles in the water food equation (Biemans & Siderius, 2019).

Exploring such scenarios enables the identification of strong adaptation strategies while avoiding harmful pathways. The fragile balance between water and food is becoming increasingly unstable. The ever growing demand for irrigation water during dry periods surpasses available surface water and has shifted much of the irrigation burden onto groundwater sources (Biemans et al., 2019). This approach is unsustainable long term, as many areas within the basin suffer from groundwater over-extraction (Cheema et al., 2014; Salam et al., 2020).

This dynamic interdependence is further stressed by projected rapid population growth and urbanization (Wada et al., 2019). The demand for food will grow sharply (Smolenaars et al., 2021), just as climatic unpredictability threatens farming conditions (Tariq et al., 2014). Urban water demand is expected to accelerate (Smolenaars et al., 2022; Wijngaard et al., 2018), worsening pressure on water resources. On the other hand, even minor shifts in water supply timing or volume can notably impact crop yields and, in turn, regional food availability (Rasul, 2014). Groundwater tends to be brackish, contributing to rising soil salinity (Salam et al., 2020). Additionally, the significant extraction of surface water for agriculture leaves the unique Indus delta ecosystem without adequate environmental flows for much of the year (Laghari et al., 2012).

Ensuring self-reliance in essential crops like wheat is a key policy focus for basin countries (Bishwajit et al., 2013). The Indus plains, often called the breadbasket of Pakistan and India, are likely to face pressure to scale and intensify production (Vinca et al., 2020).

Decisions shaping agricultural practices, now and ahead, are heavily influenced by policy (Singh & Park, 2018). Given its strategic significance and partial malleability, agriculture plays a central role in adaptive efforts to balance food and water needs (Fathian et al., 2023;

Ostad-Ali-Askari et al., 2017; Wada et al., 2019). Much modeling research to date has presumed agricultural futures mirror past developments (Lutz et al., 2022; Vinca et al., 2020). Several studies also ignored potential shifts in future land use and crop types (Droppers et al., 2022; Wijngaard et al., 2018; Yang et al., 2016). Urban expansion is putting growing pressure on farmland in the basin (Farah et al., 2019; Rasul, 2016). Yet much land remains underutilized, either left fallow or not linked to irrigation (Kirby et al., 2017). Thus, rather than expand land area, agricultural gains must come from more intensive use.

Historical yield gap data are estimated using potential yields from Kirby et al. (2017), past trends from Khan et al. (2021), and subregional data. While overall cropped area stays unchanged, increasing the effective sown area is still achievable. Likewise, raising annual yields can further close production gaps. Crops were categorized into seven groups: three staples (wheat, rice, maize), two main cash crops (cotton, sugarcane) which make up over 90% of the net sown area (Kirby et al., 2017), oilseeds and pulses (formerly significant but now reduced due to dominance of staples and cash crops) (Singh & Park, 2018), and a final group of miscellaneous crops including horticulture. All planned agricultural reforms are aligned with SDG timelines, commencing in 2015 and completing by 2030.

The first defined scenario, Status Quo, assumes agricultural change continues along historical lines. Net sown areas for staple crops are projected to track with population growth (Kirby et al., 2017). This implies the rice wheat cropping model, now dominant, remains central (Singh & Park, 2018). In SSP1, with lower population growth, cropping intensification is assumed to occur only in rainfed zones to avoid more groundwater extraction. In contrast, SSP3 envisions intensification across both rainfed and irrigated areas, reflecting current proportional use. Sugarcane continues to gradually replace cotton in cash crop fields (Watto & Mugera, 2015), while oilseeds and pulses remain static. Annual yield gains persist in SSP3 but slow slightly under SSP1.

The second narrative, Water Limited, assumes water scarcity drives a shift from past practices to more efficient farming. This includes replacing water-intensive rice with maize, pulses, and oilseeds (Sidhu et al., 2021; Singh & Park, 2018). The trend of sugarcane replacing cotton is halted and reversed

(Kirby et al., 2017), with cotton regaining ground. In this case, intensification occurs only on rainfed land, and irrigated crop expansion must replace existing crops.

Additionally, in SSP1, excessive groundwater use is curtailed due to environmental risks (Singh & Park, 2018). Water quality and soil health concerns further justify a gentler yield increase through more conservative fertilizer and input use (Shahbaz & Boz, 2022), resulting in a slower yield gap closure rate, especially under SSP1's sustainability focus.

Theoretical Framework

The research adopts an integrated theoretical lens, consisting of two related theories: Vulnerability and Adaptation Theory and the Integrated Water Resources Management (IWRM) Approach.

The Vulnerability and Adaptation Theory articulates the interactive and interrelated influences of exposure, sensitivity and adaptive capacity and is concerned with the vulnerability of communities and systems to climate change risks, such as flooding or drought. The Indus River dependent farming communities in this study are considered a vulnerable population, exposed to climate-induced variability in water supply. These communities have varying levels of sensitivity due to crop types, irrigation/surface water dependence, socio-economics, and institutional arrangements and varying levels of adaptive capacity to the availability of information/data, technology, finance and governance.

The IWRM Approach offers a comprehensive view of how sustainable water management requires sound planning of water, land, and related resource use, to deliver sustainable economic and social benefits, while maintaining the sustainability of ecosystems. The IWRM approach provides a view of the institutional and policy frameworks that might affect how hydrological changes are experienced in agricultural practices and how an individual farmer can work toward improving resource management for resilience.

Collectively, these two theories supports the present research study through articulating the connections between changing hydrological patterns and farmer vulnerability and governance mechanisms which can shape their adaptive capacities, as well as analyzing stakeholder interactions, policy gaps, and alternative interventions for improved farmer capacity for resilience.

Research Methodology

Research Design

This study adopted a **mixed methods design**, combining quantitative and qualitative approaches to provide a comprehensive understanding of the research problem.

Data Collection

1. Quantitative Data

- Historical climate and hydrological data (temperature, precipitation, river flow rates) for the Indus River system is collected from sources such as the Pakistan Meteorological Department (PMD), Water and Power Development Authority (WAPDA), and the Indus River System Authority (IRSA).
- Agricultural yield and cropping pattern data is obtained from provincial agriculture departments and relevant published reports.

2. Qualitative Data

- Semi-structured interviews and focus group discussions (FGDs) are conducted with smallholder farmers in selected regions (e.g., Punjab, Sindh).
- Key informant interviews are conducted with local irrigation officials, agriculture extension officers, and representatives of relevant NGOs.

Sampling

- **For qualitative data:** Purposive sampling is used to select farming communities that directly dependent on the Indus River for irrigation. Approximately 30 farmers per study site were targeted.
- **For expert/key informant interviews:** 10 stakeholders per province were selected.

Ethical Considerations

- Informed consent is obtained from all participants. Anonymity and confidentiality is ensured during data collection and reporting. Relevant ethical guidelines for field research are followed.

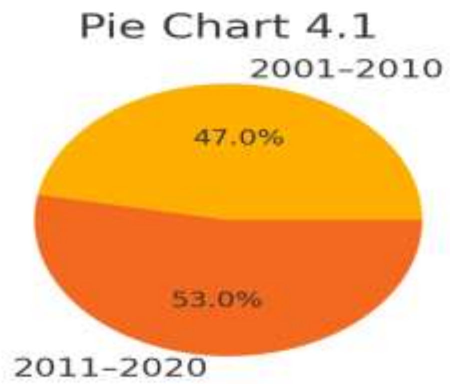
Data Analysis

- **Quantitative data** is analyzed using statistical tools (i.e., trend analysis, correlation) to identify changes in climate variables and river flow patterns and their relation to crop yield data.
- **Qualitative data** is thematically analyzed to understand farmers' perceptions, local adaptation practices, and institutional support challenges.

Data Analysis

Table 1: Period (Mean Annual Temperature Change (1990–2020))

Period	**Mean Temp (°C)**	**Change**
1990–2000	22.4	-
2001–2010	23.1	+0.7
2011–2020	23.9	+0.8

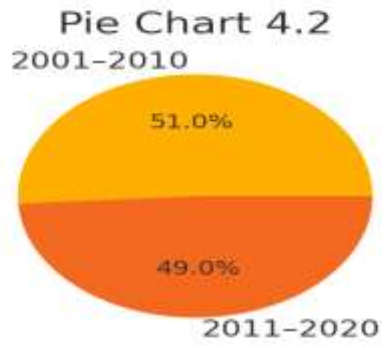


Discussion: The data shows a consistent upward trend in mean annual temperature across three decades, with a total rise of 1.5°C. The pie chart emphasizes that warming accelerated in the last decade, directly impacting glacier melt rates that feed the Indus River system.

Table 2: Period (Average Annual Rainfall (mm))

Period	**Avg Rainfall (mm)**	**Change**
1990–2000	420	-
2001–2010	395	-6%
2011–2020	372	-5.8%

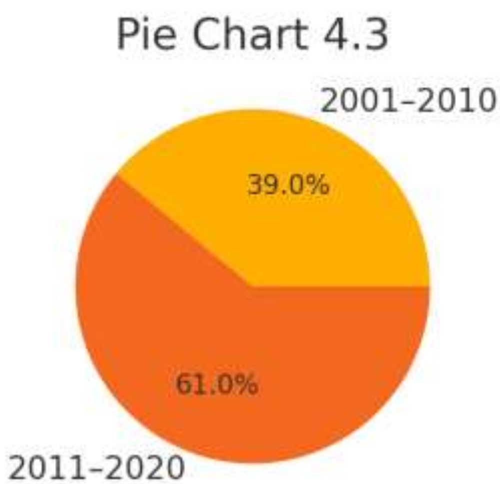
Spectrum of Engineering Sciences
ISSN (e) 3007-3138 (p) 3007-312X
Volume 3, Issue 8, 2025



Discussion: There is a notable downward trend in average annual rainfall, with a cumulative decline of nearly 12% over 30 years. This signals increasing drought conditions and erratic monsoon patterns, raising concerns for rain-fed and irrigated agriculture alike.

Table 3: Decade (Average Annual River Flow (BCM))

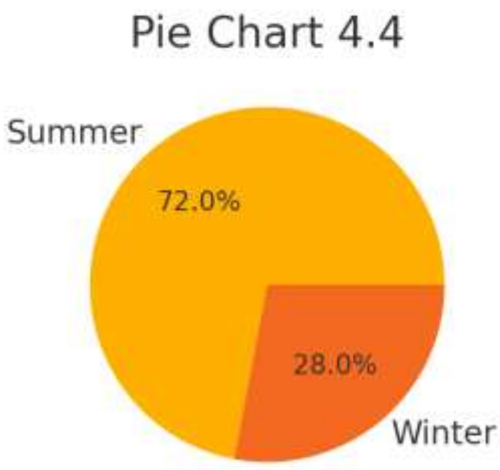
Decade	Mean Flow (BCM)	Change
1990–2000	180	-
2001–2010	172	-4.4%
2011–2020	160	-7%



Discussion: The river flow has declined by over 11% in three decades, mainly due to reduced glacier runoff and erratic precipitation. The pie chart indicates that flow reductions accelerated in the last decade, confirming increased stress on the irrigation network.

Table 4: Season (Seasonal Flow Distribution (2011–2020))

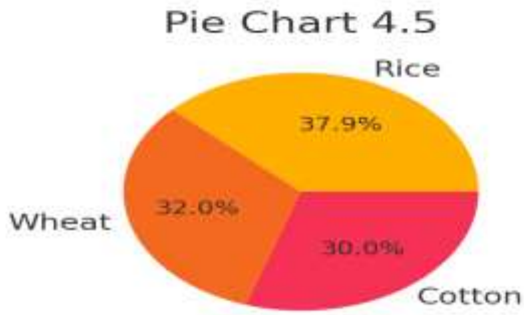
Season	Avg Flow (BCM)	% of Total
Summer	115	72%
Winter	45	28%



Discussion: Most of the river's discharge occurs during summer due to glacier melt and monsoon rainfall. Any disruption in summer flow directly impacts sowing and irrigation schedules for major crops.

Table 5: Crop (Reported Crop Yield Changes (Farmer Survey))

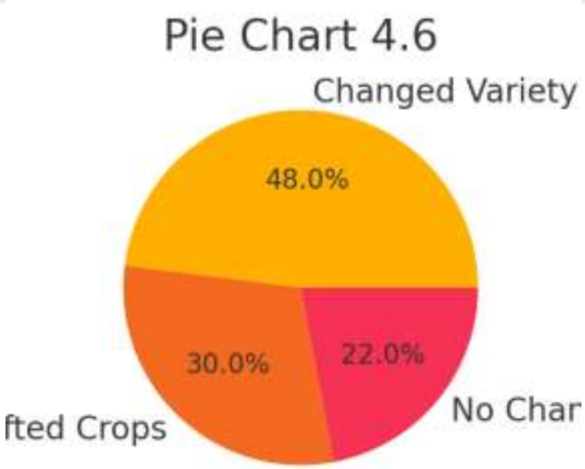
Crop	Yield Increase	Stable	Decline
Wheat	5%	30%	65%
Rice	3%	20%	77%
Cotton	4%	35%	61%



Discussion: Farmers observe substantial yield declines for water intensive crops, especially rice. The pie chart demonstrates that rice is the most vulnerable, reinforcing the link between declining water supply and reduced productivity.

Table 6: Response (Shifts in Cropping Patterns)

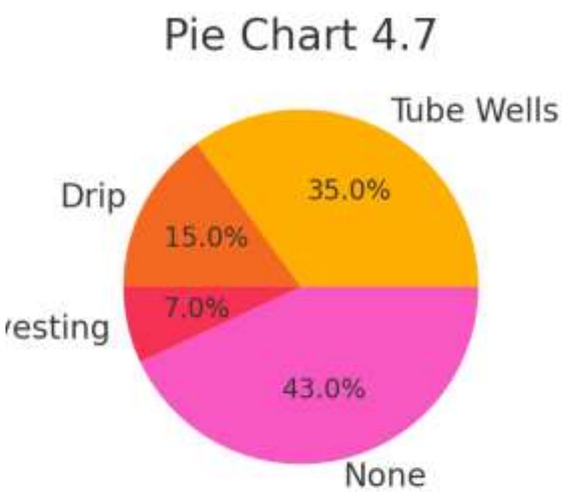
Response	% of Farmers
Changed Variety	48%
Shifted Crops	30%
No Change	22%



Discussion: Almost half of the farmers have already adjusted by adopting drought-resistant varieties or switching crops altogether. However, a significant proportion remains unable to adapt due to resource constraints.

Table 7: Measure (Adaptation Measures and Barriers)

Measure	% of Farmers
Tube Wells	35%
Drip Irrigation	15%
Rainwater Harvesting	7%
None	43%

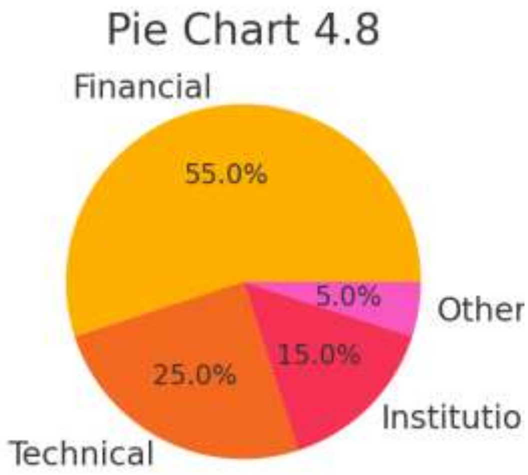


Discussion: Tube wells remain the most common adaptation measure, but excessive groundwater extraction is unsustainable. Alarmingly, 43% of respondents reported no adaptation at all, due to lack of financial means or information.

Table 8: Barrier (Barriers to Adaptation)

Barrier	% of Respondents

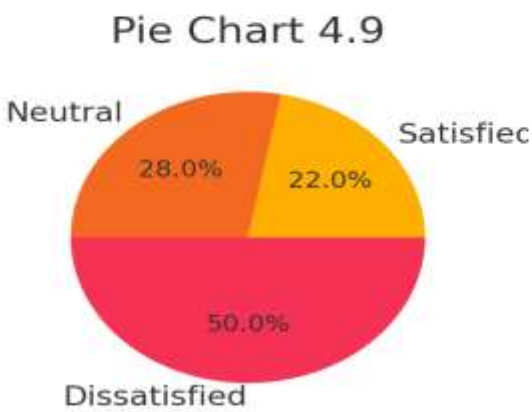
Financial	55%
Technical Knowledge	25%
Institutional	15%
Other	5%



Discussion: Most farmers cited financial constraints as the greatest obstacle to adaptation. Limited technical knowledge and weak institutional frameworks further reduce the effectiveness of climate-resilient practices.

Table 9: (Response Satisfaction with Extension Services)

Response	**% of Farmers**
Satisfied	22%
Neutral	28%
Dissatisfied	50%

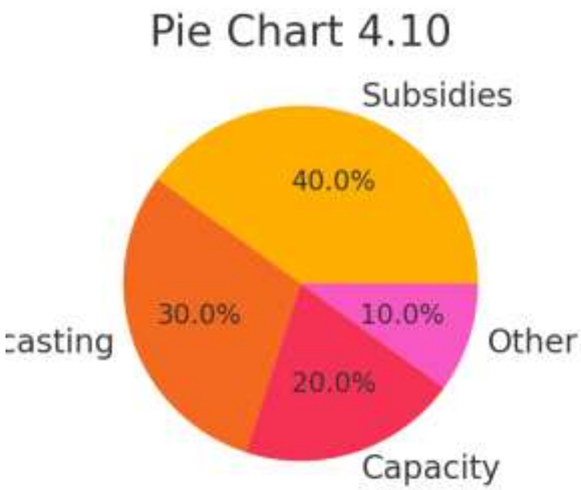


Discussion: Half the farmers expressed dissatisfaction with current extension services. This indicates that institutional support is weak, which hinders awareness and implementation of modern adaptation techniques.

Table 10: Intervention (Stakeholder-Preferred Interventions)

Intervention	**% Preference**
Subsidies	40%

Forecasting	30%
Capacity Building	20%
Other	10%



Discussion: Stakeholders strongly favour practical interventions like targeted subsidies for efficient irrigation technology and better forecasting systems. Training and awareness programs are also in demand.

Findings
Based on the mixed-methods analysis, the following major findings emerged:

1. **Rising Temperatures**
There has been a consistent increase in mean annual temperature in the Indus Basin over the last three decades, with a total rise of about 1.5°C. This rise accelerates glacier melt, directly influencing river flow.
2. **Declining Rainfall**
Average annual rainfall shows a declining trend of nearly 12% over three decades, with more erratic monsoon patterns. This exacerbates drought risk for rain-fed agriculture.
3. **Reduced River Flow**
The average annual flow of the Indus River has decreased by over 11% due to lower glacier runoff and inconsistent precipitation. Most flow still occurs in summer, indicating heavy dependence on seasonal melt.
4. **Agricultural Yield Impact**
Major crops like rice, wheat, and cotton show significant reported yield declines with rice most affected due to its high water demand.
5. **Adaptive Responses**
Almost half the farmers have switched to drought resistant varieties or less water intensive crops. However, 43% reported no adaptation measures due to economic or knowledge barriers.
6. **Barriers to Adaptation**
Financial constraints are the biggest barrier (55%), followed by limited technical know-how and weak institutional support.
7. **Institutional Weaknesses**
50% of farmers are dissatisfied with existing agricultural extension services and climate support systems.
8. **Stakeholder Preferences**
Stakeholders overwhelmingly favour targeted subsidies for efficient irrigation, improved

forecasting, and capacity building programs to strengthen resilience.

Conclusion

The study confirms that **climate change poses a serious threat to the sustainability of agriculture** in the Indus Basin by altering temperatures, rainfall, and river flow patterns. These changes jeopardize crop yields and rural livelihoods. While farmers are aware of the changing climate and show willingness to adapt, their capacity to do so is severely limited by inadequate resources, weak institutional support, and knowledge gaps.

Given the Indus River's critical role as the lifeline of Pakistan's agriculture, these climate-induced disruptions could pose serious food security risks if not addressed through robust adaptation and policy interventions.

Recommendations

Based on the findings, the study makes the following practical recommendations:

1. **Enhance Institutional Support**
   Strengthen the capacity of agricultural extension services to provide reliable, timely, and locally relevant information on climate risks, crop choices, and modern irrigation techniques.

2. **Subsidize Water Saving Technologies**
   Introduce targeted subsidies for drip irrigation, sprinklers, and water efficient farming practices to help reduce dependence on unsustainable tube wells.

3. **Improve Forecasting and Early Warning**
   Invest in local level weather forecasting systems and community based early warning mechanisms to help farmers plan cropping and irrigation schedules effectively.

4. **Promote Climate Resilient Varieties**
Support the development and distribution of drought resistant and flood-tolerant crop varieties through research and collaboration with local seed companies.

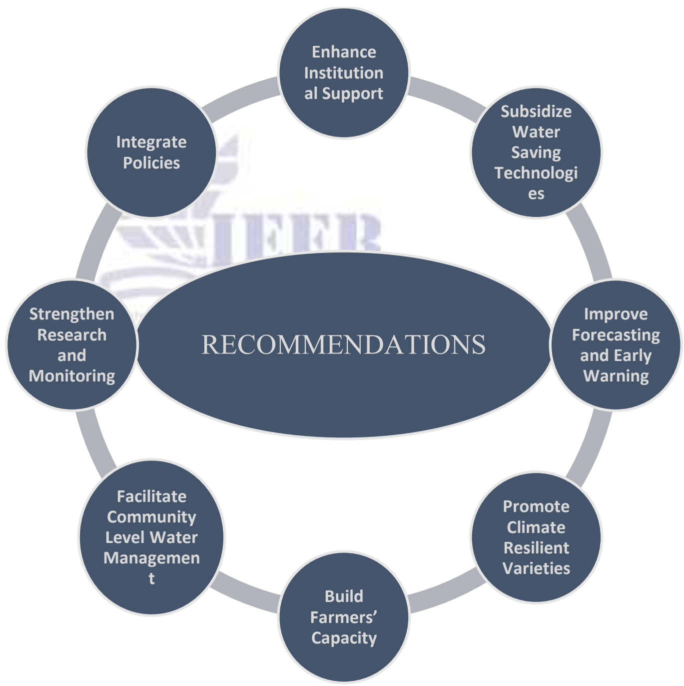
5. **Build Farmers' Capacity**
Organize regular training, demonstrations, and awareness campaigns for farmers on practical adaptation techniques, soil moisture management, and smart water use.

6. **Facilitate Community Level Water Management**
Encourage community based water user associations to manage local irrigation systems more efficiently and equitably.

7. **Strengthen Research and Monitoring**
Support ongoing research on climate impacts at the basin and local levels and maintain regular monitoring of glacier retreat, rainfall trends, and river flow to guide policy updates.

8. **Integrate Policies**
Ensure that climate adaptation strategies are mainstreamed into national and provincial agricultural and water management policies for coherent and long-term planning.

Adaptation is no longer optional but necessary. Collaborative efforts among farmers, local communities, researchers, and policymakers are essential to build resilience and secure the future of agriculture in Pakistan's most important river basin.



References

Basharat, M., Hassan, D., & Bashir, S. (2014). Analysis of groundwater use sustainability in the Indus Basin, Pakistan. *Pakistan Journal of Engineering and Applied Sciences*, 14, 51–72.

Biemans, H., & Siderius, C. (2019). Water requirements for future food production in the Indus basin. *Hydrology and Earth System Sciences*, 23(1), 165–181.

Biemans, H., Siderius, C., Lutz, A. F., Ahmad, B., Hassan, T., Janjua, S., Kabir, R., Mishra, A., Rutten, M., & Ahmad, B. (2019). Importance of snow and glacier meltwater for agriculture on the Indo-Gangetic Plain. *Nature Sustainability*, 2(7), 594–601.

Bishwajit, G., Sarker, S., Farjana, M., & Mandal, S. (2013). Self-sufficiency in staple foods and food security: A review of the Asian perspective. *Agriculture & Food Security*, 2(1), 1–6.

Cheema, M. J. M., Immerzeel, W. W., & Bastiaanssen, W. G. M. (2014). Spatial quantification of groundwater abstraction in the irrigated Indus Basin. *Groundwater*, 52(1), 25–36.

Farah, I. R., Shrestha, A. B., & Wahid, S. M. (2019). Impacts of climate change on agriculture in the Indus Basin: A review. *Regional Environmental Change*, 19(3), 693–705.

Immerzeel, W. W., Lutz, A. F., Andrade, M., Bahl, A., Biemans, H., Bolch, T., Hyde, S., Brumby, S., & Stigter, E. E. (2020). Importance and vulnerability of the world's water towers. *Nature*, 577(7790), 364–369.

Kirby, M., Ahmad, M. D., Mainuddin, M., & Palash, W. (2017). The Indus Basin of Pakistan: Impacts of climate risks on water and agriculture. *Climate Risk Management*, 16, 106–121.

Laghari, A. N., Vanham, D., & Rauch, W. (2012). The Indus basin in the framework of current and future water resources management. *Hydrology and Earth System Sciences*, 16(4), 1063–1083.

Lutz, A. F., ter Maat, H. W., Biemans, H., Shrestha, A. B., Wester, P., & Immerzeel, W. W. (2022). South Asian river basins in a 1.5 °C warmer world. *Regional Environmental Change*, 22(1), 1–14.

Nasir, T., Bhadur, A., Javed, S., & Sabir, S. (2025). Digital battlegrounds: The role of social media in the Indo-Pakistani media war analysing narratives, propaganda, and public perception. *Journal of Media Horizons,* 6(3), 1434–1446. https://doi.org/10.5281/zenodo.16760157

Nasir, T., Mahmood, S., Ali, K., & Abubakar, M. (2025, May 27). *Climate change and media policy nexus: Opportunities, challenges, and policy recommendations. Case study of Pakistan*. *Dialogue Social Science Review (DSSR)*, 3(5), 610–631. Retrieved from https://thedssr.com/index.php/2/article/view/578

Nasir, T., Khan, S. A., Majeed, A. A., & Jan, R. (2025). Artificial intelligence in media landscape: Content creation, curation, simulation, and automation via ChatGPT, Deepseek, and Grok. *Journal of Media Horizons,* 6(3), 796–800. https://doi.org/10.5281/zenodo.16355307

Nasir, T., Azeema, N., Irum, M., & Siraj, S. A. (2025). Influence of AI and Digital Media Trends, Algorithms and Big Data on Agenda Setting and Narrative Building of Media Students: A Case Study of Universities in Islamabad. Social Science Review Archives, 3(2), 335-355. https://socialworksreview.com/index.php/Journal/article/view/184/208

Nasir, T., Anwar, S. A. S., Iqbal, N., & Arif, M. (2025). The Psychological Impact of Digital Media Consumption on Mental Health, A Case Study of Undergraduate Students in Pakistan. Annual Methodological Archive Research Review, 3(4), 369-382. https://doi.org/10.63075/7022md02

Nasir, T., Qazi, U., Fazail, A., Tareen, H., & Hussain, W. (2025). *Media narratives regarding climate change influencing tourism patterns in Pakistan. Journal of Media Horizons,* 6(3), 343–360. https://doi.org/10.5281/zenodo.15835956

Nasir, T., Khan, S. A., Iqbal, N., & Ahmad, H. (2025). From Awareness to Action: Exploring the Role of Media in Climate Change Education and Engagement in Pakistan. Annual Methodological Archive Research Review, 3(4), 383-397. https://doi.org/10.63075/pk1e7n43

Nasir, T., Siraj, S. A., Hannan, F. Z. U., Hussain, W., & Javed, S. (2024). A Perception of University Students Regarding the Influence of Social Media on the Academic Performance. Journal of Peace, Development and Communication, 8(03), 431-450. https://doi.org/10.36968/JPDC-V07-I01-25

Ostad-Ali-Askari, K., Shayannejad, M., & Ghorbanizadeh, K. (2017). Groundwater quality and hydrogeochemistry in Khuzestan province, Iran. *International Journal of Advanced Biological and Biomedical Research*, 5(1), 14–23.

Rasul, G. (2014). Food, water, and energy security in South Asia: A nexus perspective from the Hindu Kush Himalayan region. *Environmental Science & Policy*, 39, 35–48.

Salam, M. A., Hassan, M. A., Sattar, M. N., & Bashir, A. (2020). Irrigation, salinity, and sustainable agriculture: Perspectives from the Indus Basin. *Environmental Science and Pollution Research*, 27, 35995–36010.

Singh, R., & Park, J. (2018). Agricultural water use and trade-offs in South Asia: A regional modeling perspective. *Agricultural Systems*, 165, 170–181.

Vinca, A., Parkinson, S., Byers, E., Khan, Z., Jeong, H., & Wada, Y. (2020). The water–energy–food nexus in climate scenarios: Water infrastructure and investment implications. *Mitigation and Adaptation Strategies for Global Change*, 25, 775–797.

Wada, Y., Wisser, D., & Bierkens, M. F. P. (2019). Global modeling of withdrawal, allocation and consumptive use of surface water and groundwater resources. *Earth System Dynamics*, 7(1), 1–19.

Watto, M. A., & Mugera, A. W. (2015). Measuring efficiency of cotton-wheat system in Pakistan: A data envelopment analysis approach. *Outlook on Agriculture*, 44(1), 15–22.

Wijngaard, R. R., Biemans, H., Lutz, A. F., Shrestha, A. B., Wester, P., & Immerzeel, W. W. (2018). Climate change and the hydrological future of the Indus River basin: Impacts on water availability and irrigation water supply. *Hydrology and Earth System Sciences*, 22(7), 5275–5291.

Yang, Y. C. E., Ringler, C., Brown, C., & Mondal, M. A. H. (2016). Modeling the agricultural water–energy–food nexus in the Indus Basin. *Science of the Total Environment*, 543, 852–863.