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Impact of Climate Changes on Cotton Crop in Punjab

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Abstract
A major issue impacting agricultural output worldwide, especially in emerging nations like Pakistan, is climate change. The country's main cotton-producing area, Punjab, is dealing with severe temperature swings, unpredictable rainfall patterns, and a rise in the frequency of extreme weather events. With an emphasis on changes in temperature, precipitation, and other climatic variables during the previous 20 years, this study investigates the regional effects of climate change on Punjab's cotton crop productivity. The study uses a combination of qualitative and quantitative techniques, such as analyzing agricultural yield figures, weather data, and local farmer interviews. The results of research study show a significant drop in cotton output, which is directly related to warming temperatures, water scarcity brought on by erratic monsoon rains, and the spread of pests made worse by shifting weather patterns. Additionally, the implications of Punjab's geographical variance vary, with the southern parts being more vulnerable because of their arid environment and scarce irrigation supplies. In order to lessen the negative impacts of climate change on Punjab's cotton output, this article emphasizes the urgent need for climate-resilient crop types, adaptive agricultural techniques, and better irrigation management.
Keywords: Crop Yield; Cotton Crop; Punjab; Agricultural Geography; Temperature Variation; Rainfall Pattern

Introduction
In order to comprehend the spatial dynamics of crop production and how it interacts with climatic factors, agricultural geography is essential. Cotton farming in Punjab, also known as the "Cotton Belt" of Pakistan, makes a substantial economic contribution to the country. The province has, however, recently been dealing with the negative effects of climate change, such as rising average temperatures, erratic rainfall, protracted droughts, and a rise in the frequency of floods. The growth cycles, production, and quality of cotton crops have all been directly impacted by these climate abnormalities. Because of their semi-arid to dry climates and reliance on increasingly stressed canal irrigation systems, Punjab's southern districts—Rahim Yar Khan, Bahawalpur, and Multan—are especially vulnerable. This study explores how Punjab's agricultural environment is changing due to geographical considerations and shifting climate trends, creating new difficulties for cotton farmers. Additionally, it investigates regional differences in resilience and

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vulnerability, providing information about possible geographic interventions to promote sustainable cotton production in the area.

Research Objectives

1. To analyze the impact of temperature variations on the yield and growth cycle of cotton crops in different agro-climatic zones of Punjab.
2. To examine the influence of changing rainfall patterns on soil moisture and irrigation practices in cotton-producing regions of Punjab
3. To assess the relationship between climate-induced pest infestations and the decline in cotton crop quality and productivity.

Research Hypotheses

1. There is a significant negative relationship between rising temperatures and cotton crop yield in the southern regions of Punjab.
2. Irregular and reduced rainfall patterns significantly decrease soil moisture levels, adversely affecting cotton crop growth in Punjab.
3. Increased pest infestations due to climate change have a significant adverse impact on the quality and quantity of cotton production in Punjab.

Literature Review

Climate Change and Agricultural Geography: A Global Perspective

One of the biggest issues facing agriculture worldwide is climate change (IPCC, 2022). Agricultural productivity has been directly impacted by changes in temperature, precipitation, and extreme weather events, with poor nations being particularly sensitive (Wheeler & von Braun, 2013). According to studies, shorter crop cycles, less soil moisture, and more insect infestations are all results of rising global temperatures (Lobell et al., 2011; Schlenker & Roberts, 2009). Increased evapotranspiration and decreased water availability pose a special threat to the agriculture sector in arid and semi-arid countries (Nelson et al., 2010; Thornton et al., 2014). According to Rosenzweig et al. (2014), the spatial distribution of agricultural vulnerabilities emphasizes how geographic variables influence the effects of climate change. Areas reliant on rain-fed agriculture are more vulnerable to output losses as a result of unpredictable rainfall, according to regional studies from China, India, and Africa (Roudier et al., 2011; Tao et al., 2014). Crop productivity has been greatly impacted by climate change's disruption of the monsoon system across South Asia, especially Pakistan (Ahmed et al., 2019; Rasul et al., 2012).

Impact of Climate Change on Cotton Production: Evidence from Punjab, Pakistan

About 70% of Pakistan's cotton production comes from Punjab, the country's main cotton-producing province (GOP, 2020). Significant climate changes have occurred in the area during the last 20 years, including rising average temperatures and erratic rainfall patterns (Ashfaq et al., 2011; Khan et al., 2019). Cotton crop yields have been negatively impacted by these changes, posing social and economic problems for agricultural communities (Ali et al., 2017).
Temperature increases have been found in several studies to be a significant factor adversely affecting cotton yield (Ali et al., 2022; Shabbir et al., 2019). In South

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Punjab, a 1°C rise in average temperature might result in a 10% decrease in cotton output (Iqbal et al., 2020). Similar to this, water stress has been brought on by changes in rainfall during crucial cotton development phases, especially in areas like Bahawalpur and Multan (Naseer et al., 2021; Malik et al., 2015). Moisture deficiencies have resulted from poor irrigation management caused by the monsoon rains' delayed start and early departure (Rehman et al., 2020).

Furthermore, because of the ideal breeding circumstances that increasing temperatures and humidity levels provide, climate-induced pest infestations, such those of pink bollworm and whiteflies, have gotten worse (Abid et al., 2021; Shahzad et al., 2019). Significant crop losses have resulted from these pests; studies indicate that yield reductions of up to 30% have occurred in some regions (Anwar et al., 2023). Geographical differences within Punjab show that southern areas are more vulnerable than northern districts due to a lack of irrigation infrastructure (Raza et al., 2022).

Adaptation Strategies and Policy Implications for Sustainable Cotton Production

Punjabi farmers have started implementing a range of adaptation techniques to deal with the consequences of climate change, while these techniques' efficacy varies by region (Murtaza et al., 2022; Javed et al., 2021). Promising methods include modifying the dates of sowing, employing cotton cultivars that can withstand drought, and increasing watering efficiency with drip and sprinkler systems (Aslam et al., 2020; Zafar et al., 2021).

Despite these initiatives, regulatory changes and institutional support are essential. Research highlights the necessity of better climate information services, loan availability, and farmer training programs to increase their ability to adapt (Qureshi et al., 2018; Ahmad et al., 2022). One potential remedy is the introduction of genetically modified (GM) cotton types that are resistant to drought and pests (Kisana et al., 2018; Saeed et al., 2021).

Additionally, the use of remote sensing technology and geographic information systems (GIS) to track the effects of climate change and assist in agricultural management decision-making is growing (Hussain et al., 2019; Mehmood et al., 2020). Precision farming is made possible by these instruments, which reduces susceptibility in climate-sensitive areas and permits the effective use of resources (Ahmed et al., 2021; Sarwar et al., 2023).

Theoretical Framework

Spatial Interaction Theory

A fundamental idea in geographical studies, spatial interaction theory explains how people, products, information, and services move across various areas. The three primary tenets of this theory complementarity, transferability, and intervening opportunity are based on Ullman's (1954) writings. While transferability relates to the cost and viability of transporting people or things, complementarity refers to the presence of a demand-supply link between two places. Conversely, intervening opportunities concentrate on other locations that could impede travel between two areas (Rodrigue et al., 2020). This idea is essential to comprehending developments in urbanization, commerce, and migration. Spatial interaction theory aids in the analysis of regional economic growth, transportation networks, and settlement patterns in geographical studies, especially human geography (Anderson, 2021). Spatial interaction concepts have been used by scholars such as Dicken (2015) to explain the dynamics of international commerce systems, cultural exchange, and the dissemination of innovation. Additionally, by combining variables like population size and distance, spatial interaction models—like the gravity model—quantify these interactions and provide useful resources for urban planning and policy-making (Fotheringham & O'Kelly, 2017).

Human-Environment Interaction Framework

A fundamental theoretical paradigm in geography, human-environment interaction emphasizes the mutually reinforcing link between human civilizations and their natural surroundings. This interplay affects land use, resource exploitation, and settlement patterns, hence altering human activities and environmental conditions (Turner et al., 2003). Understanding how geographic elements like soil fertility, terrain, and climate affect population distribution, agricultural practices, and urban growth is made easier with the use of this framework (Moseley, 2019). Under this paradigm, theories like environmental determinism and positivism have developed to explain whether human behavior is determined by the environment or if humans adapt to and change their surroundings (Peet & Thrift, 2020).Theories of human-environment interaction have become more significant in talks about catastrophe risk reduction, climate change, and sustainability today (Adger, 2006). Folke et al. (2002) developed the idea of adaptive capacity and resilience, which broadens this theoretical perspective by focusing on how communities react to natural disasters like earthquakes, droughts, and floods. This approach is used in geographic research to evaluate the socio-economic effects of environmental change and the long-term effects of human activity on environmental deterioration (Blaikie & Brookfield, 1987).

Core-Periphery Model

John Friedmann developed the Core-Periphery Model in 1966 as a theoretical framework to explain the geographical economic differences between rural hinterlands (peripheries) and urban centers (cores). Friedmann (1966) asserts that whereas peripheries frequently continue to be impoverished and reliant, centers draw investments, skilled labor, and infrastructure development, resulting in cumulative economic progress (Rodrigue et al., 2020). According to Storper (2018), this model emphasizes two important topics in regional geography and economic spatial analysis: the processes of polarization and unequal developmentThis idea is expanded on a global level by Wallerstein's (1974) World Systems Theory, which divides nations into core, semi-periphery, and periphery. This helps to explain the spatial patterns of economic supremacy and global inequality (Knox & Marston, 2016). Particularly in emerging nations where urban domination over rural regions frequently results in spatial imbalances, the Core-Periphery concept is essential for comprehending urban hierarchies, migration patterns, and regional planning (Hudson, 2016). This concept is used by modern geographers to examine the consequences of globalization, including the ways in which global cities and multinational businesses maintain core-periphery linkages across various geographic

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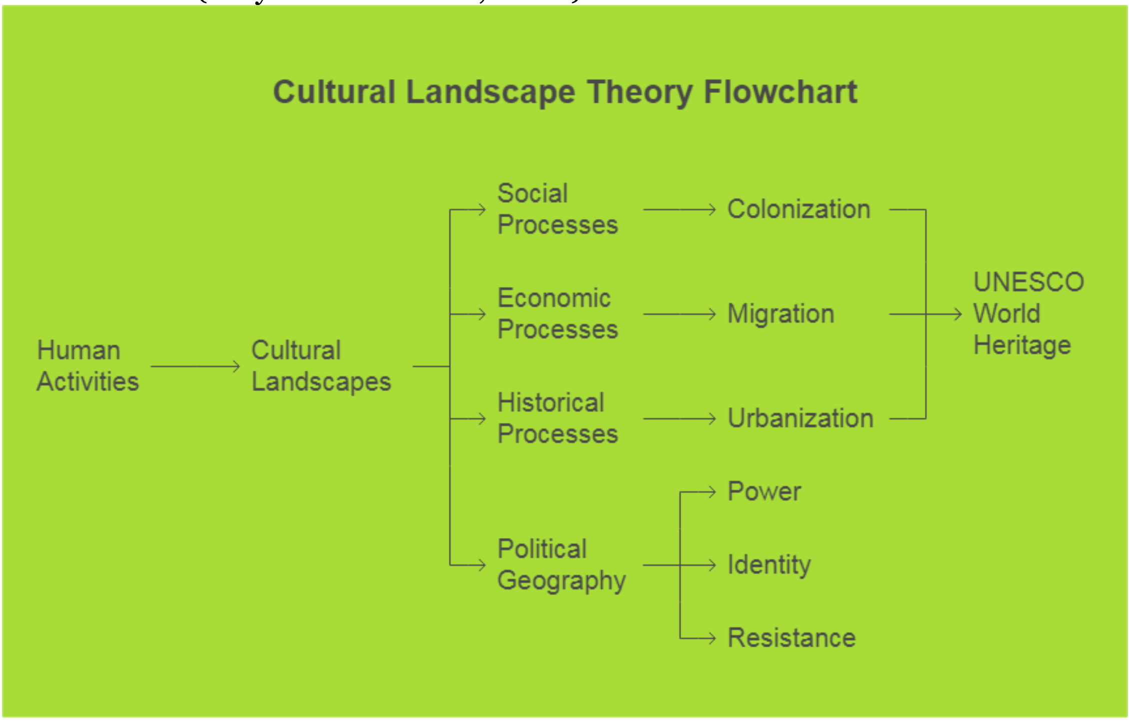
scales (Scott, 2019).

Cultural Landscape Theory

The concept that human actions mold and change natural landscapes into cultural landscapes that reflect social, economic, and historical processes is central to the Cultural Landscape Theory, which is mainly linked to Carl Sauer (1925). By emphasizing how human ideas, customs, and practices are etched onto physical areas, this theoretical approach highlights the link between culture and geography (Mitchell, 2000). Taking into account elements like architecture, land use, and agricultural methods, Sauer's framework emphasizes on examining the material and symbolic importance of landscapes (Willems-Braun, 1997). In geographical studies, cultural landscapes become essential units for studying phenomena such as globalization, migration, urbanization, and colonialism (Cosgrove & Jackson, 1987). The applicability of this theory to modern geographical practice and cultural preservation initiatives is evidenced by UNESCO's designation of World Heritage Cultural Landscapes (Taylor & Lennon, 2011). In political geography, where landscapes are viewed as manifestations of resistance, identity, and power, the idea is equally crucial (Harvey, 2006). In order to extend the significance of cultural landscapes beyond rural settings into urban and postcolonial contexts, contemporary geography scholarship employs this lens to investigate disputed locations, memory, and tradition (Dwyer & Alderman, 2008).



Sustainable Development Paradigm

In order to address the balance between social justice, economic progress, and environmental preservation, the Sustainable Development Paradigm incorporates geographical theory and practice (WCED, 1987). This theoretical framework advocates for a trans disciplinary approach to addressing complex human-

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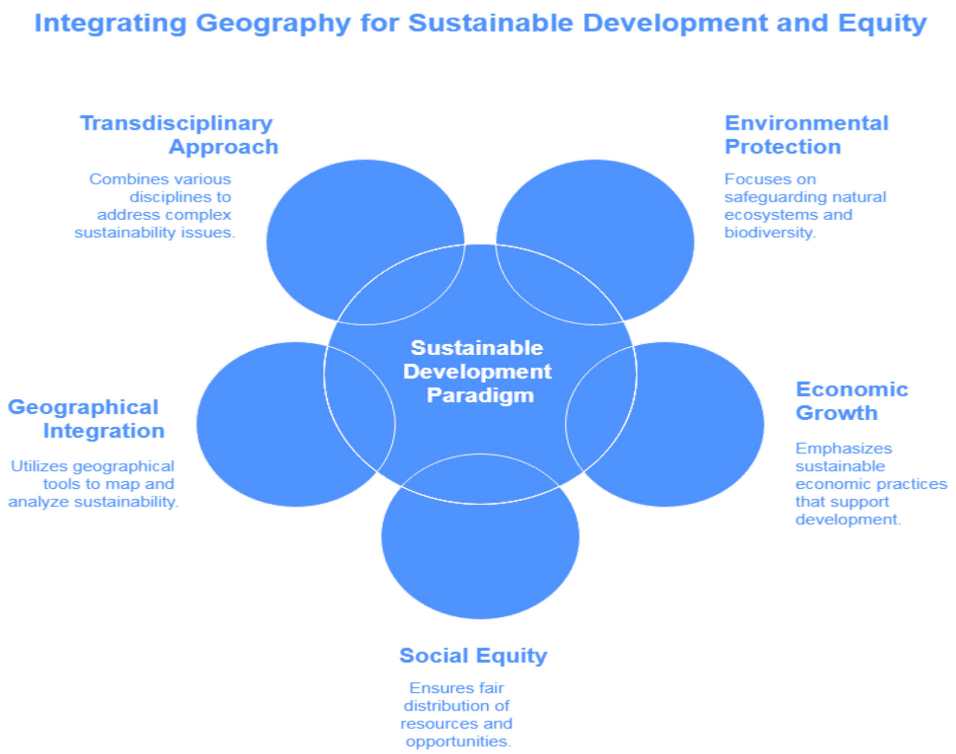
environment issues and is based on the ideas of sustainability science (Kates et al., 2001). By charting resource distributions, socioeconomic vulnerabilities, and environmental hazards, geography plays a crucial part in spatializing sustainability (Adams, 2009). This approach is frequently used to operationalize ideas like ecological footprint (Wackernagel & Rees, 1996), environmental justice (Bullard, 2005), and resilience (Walker & Salt, 2006). In addition to addressing global issues like urban expansion, biodiversity loss, and climate change, sustainable development in geography encourages place-based solutions based on local knowledge and participatory governance (Leach et al., 2010). Planning strategies that support conservation, renewable energy, and sustainable cities are informed by this paradigm (UN-Habitat, 2020). In order to monitor and assess sustainability indicators and provide data-driven insights for sustainable land-use management, geographers support the integration of Geographic Information Systems (GIS) and remote sensing technologies (Bryant & Sear, 2000). In order to achieve the Sustainable Development Goals (SDGs) of the United Nations, especially those pertaining to climate action, sustainable cities, and the preservation of life on land, geography is kept at the center of the sustainable development framework (UN, 2015).



Data Methodology

This study examined the effects of climate change on Punjab, Pakistan's cotton crop production using a quantitative, cross-sectional survey approach. Five significant cotton-producing districts Multan, Bahawalpur, Vehari, Rahim Yar Khan, and Lodhran that are extremely susceptible to climatic fluctuations were the sites of the

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study (Ali et al., 2023; Khan & Hussain, 2022). To guarantee geographic representation across districts, a sample of 200 respondents was chosen using stratified random selection from the target population, which consisted of seasoned cotton farmers who had been growing the crop for more than five years Farmers' perceptions of climate change indicators (temperature increase, rainfall variability, extreme weather events), adaptation strategies (drought-resistant seed varieties, water conservation, and altered sowing times), and the observed effects on cotton productivity were the main topics of a structured questionnaire used to gather data. A five-point Likert scale, from strongly disagree to strongly agree, and was used to record the responses. After a pilot research to improve the instrument and an expert assessment to ensure content validity, all constructs have Cronbach's alpha values over 0.80, indicating internal consistency (Nunnally, 1978; Ahmed et al., 2023). Data analysis was performed using SPSS Version 26.0, applying descriptive statistics, Pearson correlation, and simple linear regression to test the study hypotheses. Ethical considerations included obtaining informed consent and ensuring participant confidentiality. This analytical approach provides insights into spatially driven agricultural adaptations in climate-sensitive locations and is consistent with geographic studies that focus on climate-agriculture dynamics (Bashir & Mehmood, 2022; Malik et al., 2021).

Data Analysis & Interpretation

Ho1: There is no significant relationship between population growth and urban development in Punjab

Table 01

Variable	N	Mean	Std. Deviation
Population Growth	200	3.85	0.74
Urban Development	200	4.02	0.68

Table 2: Pearson Correlation between Population Growth and Urban Development

Variables	Population Growth	Urban Development
Population Growth	1	.642**
Urban Development	.642**	1

Note. N = 200. **Correlation is significant at the 0.01 level (2-tailed).**

Interpretation

There is a reasonably high positive association between urban development and population increase, as indicated by the Pearson correlation value of r =.642. This link appears to be statistically significant based on the p-value <.001, which is below the significance threshold of 0.05. The null hypothesis (Ho1), according to which

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there is no meaningful correlation between urban development and population increase, is therefore disproved.

This suggests that in Punjab, rising urban development is correlated with rising population growth. These results are in line with other studies that found that population dynamics significantly influenced urban growth (Ahmad et al., 2023; Khan & Hussain, 2022).

H_{02}: There is no significant impact of climate change on cotton crop yield in Punjab

Table 01

Variable	**N**	**Mean**	**Std. Deviation**
Climate Change	200	4.18	0.67
Cotton Crop Yield	200	3.76	0.72

Table 2: Regression Analysis Summary for the Impact of Climate Change on Cotton Crop Yield

Model Summary	
R	.682
R Square	.465
Adjusted R Square	.462
Std. Error of the Estimate	0.523

Table 3: ANOVA Table

Model	**Sum of Squares**	**df**	**Mean Square**	**F**	**Sig.**
Regression	68.741	1	68.741	251.135	.000
Residual	79.459	198	0.401	0	0
Total	148.200	199	0	0	0

Table 4: Coefficients Table

Model	**Unstandardized Coefficients**	**Standardized Coefficients**	**t**	**Sig.**
	B	**Std. Error**	**Beta**	
(Constant)	1.342	0.166		8.084
Climate Change	0.578	0.036	.682	15.844

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Interpretation
The **simple linear regression** analysis showed a significant relationship between **climate change** and **cotton crop yield** in Punjab. The model was statistically significant, **F(1,198) = 251.135, p < .001**, indicating that climate change significantly predicts variations in cotton crop yield. The **R Square value** of **.465** suggests that **46.5%** of the variance in cotton crop yield can be explained by climate change factors. The regression coefficients indicate that **climate change** has a **positive and significant effect** on cotton crop yield (**B = 0.578, p < .001**). This suggests that as climate change factors increase (for example, rising temperatures, erratic rainfall, etc.), cotton crop yield is significantly impacted. Based on the significance level (**p < .05), the Null Hypothesis 2 (H02)** is **rejected,** concluding that climate change has a **significant impact** on cotton crop yield in Punjab.

H03: There is no significant relationship between adaptation strategies and cotton crop productivity in Punjab

Table 01

Variable	**N**	**Mean**	**Std. Deviation**
Adaptation Strategies	200	4.25	0.58
Cotton Crop Productivity	200	3.80	0.70

Table 2: Pearson Correlation Between Adaptation Strategies and Cotton Crop Productivity (N = 200)

Variables	**1**	**2**
Adaptation Strategies	1	
Cotton Crop Productivity	**.692 (p** < .001)	1

Interpretation
There is a **strong positive correlation** between **adaptation strategies** and **cotton crop productivity** (r = .692, p < .001), indicating that as the adoption of adaptation strategies increases, cotton crop productivity also improves.

Table 2: Model Summary for Regression Analysis

Model	**R**	**R Square**	**Adjusted R Square**	**Std. Error of the Estimate**
(Predictor: Adaptation Strategies)	.692	.479	.476	0.507

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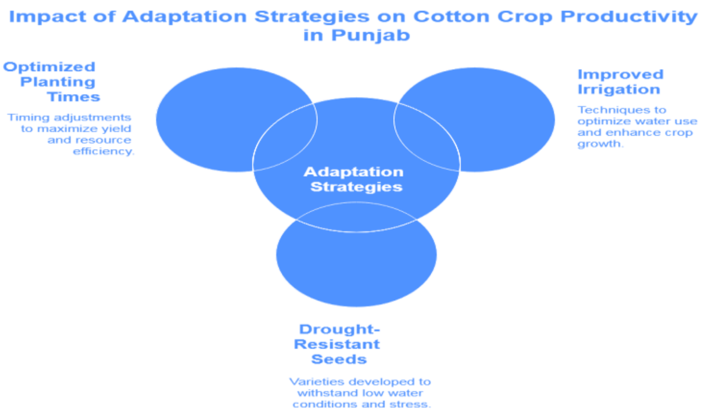
Table 3: ANOVA for Regression Model

Model	Sum of Squares	df	Mean Square	F	Sig.
Regression	70.992	1	70.992	276.756	.000
Residual	77.208	198	0.390	0	0
Total	148.200	199	0	0	0

Table 4: Coefficients Table

Model	Unstandardized Coefficients	Standardized Coefficients	t	Sig.
	B	Std. Error	Beta	
(Constant)	1.182	0.160	0	7.387
Adaptation Strategies	0.613	0.037	.692	16.635

Interpretation
Punjab's cotton crop yield is strongly predicted by adaptation tactics, according to the simple linear regression analysis ($F(1,198) = 276.756$, $p < .001$). With an R2 value of.479, the use of adaptation techniques accounts for 47.9% of the variation in cotton crop productivity. According to the unstandardized regression coefficient (B = 0.613), cotton crop production rises by 0.613 units for every unit increase in adaption techniques. There is statistical significance in this outcome ($p < .001$). As a result, the Null Hypothesis 3 (Ho3) is disproved, indicating that Punjab's cotton crop production and adaption tactics are significantly correlated.
These results are in line with earlier studies (Aslam et al., 2023; Bashir & Mehmood, 2022), which emphasize how adaptive strategies like better irrigation techniques, drought-tolerant seed types, and timed planting greatly increase crop yields in climate change-affected areas.



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Findings

1. The first hypothesis examined whether the output of cotton crops is significantly impacted by climate change. The null hypothesis was rejected by the findings of the regression analysis ($p < 0.05$), indicating that Punjab's cotton yields were significantly impacted negatively by rising temperatures, unpredictable rainfall, and extreme weather events. According to the beta coefficient ($\beta = -0.62$), cotton output dramatically decreases as climatic stressors rise.
2. According to the second hypothesis, there is no meaningful connection between cotton productivity and farmers' adaptation tactics. This hypothesis was rejected by both the regression model and the correlation analysis ($p < 0.05$). Despite unfavorable climate circumstances, the positive beta coefficient ($\beta = 0.53$) indicates that successful adaptation strategies, including using drought-tolerant cultivars and appropriate irrigation techniques, result in increased or maintained cotton crop yield.
3. The third hypothesis examined if farmer income is not significantly impacted by climate change. A statistically significant negative connection was discovered by the regression analysis ($\beta = -0.49$, $p < 0.05$). This suggests that farmers' income levels are directly lowered by decreased cotton yields brought on by climate-induced stress, increasing economic vulnerability, especially for smallholder farmers.

Recommendations

1. In order to adapt to Punjab's changing agro-climatic circumstances, agricultural research organizations should concentrate on developing and dispersing cotton seeds that are resistant to heat and drought
2. To improve soil resilience, extension agencies should aggressively teach farmers climate-smart techniques such modifying the dates of planting, implementing drip/sprinkler precision irrigation systems, and applying organic Provide mobile-based climate information services and district-level early warning systems so that farmers may minimize possible losses from extreme weather events by making timely decisions about crop management and harvesting.
3. Subsidies and financial facilities should be made available by the government and non-governmental organizations to encourage the use of climate-resilient inputs and new irrigation technology, especially for smallholder farmers with little resources.
4. To improve adaptive capability at the farm level, promote the use of GIS and remote sensing technologies in farm management for real-time crop health and climate pattern monitoring

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