

Understanding the Impact of Climate Change on Agricultural Productivity in Pakistan

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DOI: <https://doi.org/10.70670/sra.v3i4.1347>

Abstract

Climate change poses an escalating threat to sustainable development, significantly affecting agricultural productivity and food security. Achieving Sustainable Development Goals (SDG) 2 and 13, which focus on ending hunger, improving nutrition, promoting sustainable agriculture, and addressing climate change, requires urgent action to mitigate the impacts of a changing climate. These goals are closely interlinked, as a stable climate is essential for ensuring food security and sustainable agricultural practices. This study investigates the long-term and short-term effects of climate change on agricultural productivity using time-series data of Pakistan. The findings, based on Ordinary Least Squares (OLS) estimation, reveal a nonlinear, inverted U-shaped relationship between temperature and agricultural productivity. This suggests that there is an optimal temperature for agricultural productivity, beyond which further warming negatively affects yields. The results are robust across different estimation methods, highlighting the sensitivity of agriculture to rising temperatures. Additionally, climate shocks, such as extreme weather events, have consistently negative and significant impacts on productivity, underscoring the vulnerability of agriculture to these events. However, precipitation shows no statistically significant effect on productivity in the models tested. The Autoregressive Distributed Lag (ARDL) results corroborate these findings, while the Nonlinear Autoregressive Distributed Lag (NARDL) analysis reveals an important asymmetry in the impact of climate change on Pakistan's agriculture. Specifically, the analysis shows that temperature increases cause twice the damage as the benefits derived from equivalent temperature decreases. This asymmetric impact challenges conventional models and highlights that the agricultural sector is more vulnerable to warming than previously understood. These findings underscore the urgent need for targeted heat management strategies and the incorporation of asymmetric climate risks into planning efforts. As climate variability, extreme events, and their severity continue to increase, proactive adaptation measures are essential to safeguard Pakistan's agricultural productivity and ensure food security in the face of climate change.

Keywords: SDGs, Sustainability, Agriculture, ARDL, Climate Change

1. Introduction

Climate change has become a severe threat to sustainable development. As Sustainable development is a global aim for a better future of our new generations. For sustainable development, there is a dare need for a careful assessment to have balance among economic growth, social equity, and environmental protection (WCED, 1987). It is difficult because of the ponderous dependence on fossil fuels, deforestation, and industrialization. A healthy and sustainable environment is not only a moral imperative but also essential for achieving global goals such as the United Nations' Sustainable Development Goal 2, which aims to end hunger, achieve food security, improve nutrition, and promote sustainable agriculture, and SDG 13, which

calls for urgent action to combat climate change and its impacts (UN, 2015). These two goals are deeply interconnected.

Climate change is the long-term alteration of Earth's climate system, characterized by persistent changes in temperature, precipitation, and weather patterns, occurring over decades or centuries. The effects of climate change, now accelerating all over the world, include unpredictable changes in rainfall patterns bringing drought, heatwaves, and flooding. As extreme weather becomes more frequent, and destructive events hit farmers harder, the impact on farming will be more and more severe. It is driven by both natural processes and, predominantly in recent times, human activities such as greenhouse gas emissions, deforestation, and industrialization.

Fossil fuels are one of the key causes of global climate change; they contribute around 90 percent of CO₂ emissions and approximately 68 percent of global greenhouse gas emissions (United Nations, 2024). In the era of industrialization the use of fossil fuel again cause to increase greenhouse gas emissions. It is considered that manufacturing industry which extensively uses fossil fuels is one of the largest contributors to greenhouse gas emissions worldwide. Producing food causes emissions of carbon dioxide, methane, and other greenhouse gases. The use of electricity in residential and commercial buildings is almost 60 percent of all electricity produced, and much of this is generated from coal, oil, and natural gas, which contributes a significant amount of greenhouse gas emissions (IEA, 2025; Ember, 2024).

Climate change effects globally. Due to increase in temperature sea-level rises, extreme weather events occur these are posing challenge for environmental sustainability. The agriculture is the main sector that is in danger due to variability in the temperature. As greenhouse gas concentrations rise, so does the global surface temperature. The last decade, 2015-2024, is the warmest on record. Since the 1980s, each decade has been warmer than the previous one. Nearly all land areas are seeing more hot days and heat waves. Extreme weather event like destructive storms and cloudbursts have become have frequent and severe (WMO, 2024).

Climate change is changing water availability, making it scarcer in more regions. Global warming exacerbates shortages in water-stressed regions. It also leads to a higher risk of agricultural droughts affecting crops and ecological droughts making ecosystems more vulnerable. The effect of warming on ocean is also very devastating. The rate at which the ocean is warming strongly increased over the past two decades, across all depths of the ocean. Forest fires, extreme weather, and invasive pests and diseases are among many threats related to climate change. Some species will be able to relocate and survive, but others will not (IPCC 2023). The most important is that changes in the climate and increases in extreme weather events are among the reasons behind loss of agriculture production and hence causes an increase in hunger and poor nutrition. Fisheries, crops, and livestock may be destroyed or become less productive. With the ocean becoming more acidic, marine resources that feed billions of people are at risk. Heat stress may decrease water and grasslands for grazing, causing declining crop yields and affecting livestock. Another issue of it is that it affects to people's health, through air pollution, disease, extreme weather events, forced displacement, increased hunger and poor nutrition. Changing weather patterns are expanding diseases, and extreme weather events increase deaths and make it difficult for health care systems to keep up. Climate change increases the factors that put and keep people in poverty. Water scarcity may affect crops. In 2024, 45.8 million people were displaced due to weather-related disasters. Most displacements happen in countries that are most vulnerable and least ready to adapt to the impacts of climate change.

In recent years, Pakistan has faced an alarming rise in extreme climate events, highlighting the growing severity of climate change. For instance, in June 2024, Sindh endured a deadly heatwave with temperatures soaring above 49°C, claiming over 568 lives. Just months later, April 2025 was recorded as the second-hottest April recorded the lowest rainfall in 65 years, with precipitation falling short by 59%, deepening drought concerns. In June 2025, a cloudburst struck the Swat Valley, resulting in the loss of 32 lives and causing extensive damage to infrastructure and houses. Gilgit-Baltistan (GB) faced severe loss because of monsoon rains and melting of glaciers, where at least 72 were dead and thousands had to temporarily or permanently

migrated. Similarly in July 2025, unexpected cloudbursts again struck GB, where tourists were killed and cut off remote areas.

The sudden rains and extended droughts have become common. In April, Islamabad experienced unusual heavy hailstorm that severely affected to crops and property. In addition, between September 2024 and January 2025, Pakistan experienced an almost 40% rainfall deficit, with Sindh, Balochistan, and Punjab among the hardest hit, causing severe crop losses, especially in arid areas. It is important to note that these are not isolated incidents but rather indicators of a changing climate system that is placing the agriculture sector under increasing stress.

There is a dire need for urgent action to develop coping and adaptation strategies to minimize losses and make the agriculture sector more sustainable. These actions should be based on scientific understandings and considering economic and ethical imperatives. Agricultural output is not only necessary for the food security of Pakistan but also the main source of income for rural population. Improvement in crop production is key to attain SDG 2 i.e. ending hunger, as well as economic and social development of the country. The trends in global agricultural production is increasing, with total primary crop production rising by 3% in 2023 while 28% since 2010. Key drivers include gains in specific crops like maize and sugar crops, though the growth rate has slowed since the Green Revolution era. The cereal production grew by 2% between 2022 and 2023, primarily due to increased maize production while fruit and vegetable production raised by 1% during the same period. The growth of sugar, roots and tubers also increased with the similar pace.

The main factors that affect the agriculture production are technological adoption, agricultural management, water use efficiency and climate change vulnerability. While global averages are rising, individual countries often show lower productivity than the global leaders. For example, Pakistan's average wheat yield is almost half of China's. Dietary diversity has increased in many countries worldwide. Whereas cereals, roots, and other staple crops once dominated agricultural production, food systems have now expanded to include a wider range of legumes, fruits, vegetables, nuts, seeds, and other nutrient-rich foods. At the same time, agriculture remains a major driver of environmental pressure. Looking ahead, it is essential to develop ways of producing enough nutritious food for all while simultaneously reducing the sector's environmental footprint.

Climate change has become an undeniable reality, affecting populations across the globe. However, its impacts are felt most acutely in low-income countries and among those who rely directly on stable climate conditions and natural resources for their livelihoods—particularly smallholder farmers. Farmers are already witnessing these effects firsthand, as extreme weather events and increasingly unpredictable seasons reshape croplands and pastures worldwide. Climate change undermines agricultural systems by degrading environmental health, reducing yields, destroying crops, and causing livestock losses. These disruptions make it harder for farming families to earn a stable income and prolong the periods during which households face food shortages.

Climate change and agriculture are intimately linked by deviations in weather patterns and temperatures. The world is warming faster than ever before, with a direct impact on agricultural production and the people who make their living from it. During the last two decades we have experienced the hottest temperatures since the 1800s, with the 10 warmest years in recorded history. Temperatures have risen by 1.1 degrees Celsius above pre-industrial levels as a result of global emissions.

As climate change is affecting the agriculture sector there is also reverse effect of agriculture on climate change, so these are interlinked. Farming contributes to global warming, as fertilized soil emits nitrous oxide, cattle pass methane gas, and burning fields produces carbon dioxide. Agriculture is considered to contribute for one third of greenhouse gas emissions globally. It is responsible for a handsome share of the greenhouse gas emissions. However, people in lesser developed countries, where many smallholder farmers earn their living, have historically contributed the least to climate change yet are immensely affected by its impacts.

As it is clearly established from the literature and researches climate change is affecting the agriculture sector

therefore, understanding the economic impact of climate change on agricultural productivity is therefore important. It is not just necessary for maintain livelihoods but also for ensuring food security and economic stability. It is worth notable here that climate change is characterized by long-term shifts in temperatures and weather patterns, can occur naturally. However, in present era it is mostly occurring by human-induced emissions of greenhouse gases (IPCC, 2021). The primary sources of these emissions include industrial activity, energy production, transportation, and unsustainable land use practices. Since these changes are largely a consequence of human activities, it is possible to develop effective coping strategies to reduce their negative impacts, especially on agriculture. In addition, sector-specific strategies can be designed within agriculture to help minimize the effects of climate change and enhance resilience.

In recent years, the impacts of climate change have intensified, particularly in developing countries like Pakistan. Shifts in weather patterns, rising temperatures, and an increase in the frequency and severity of extreme weather events have already begun to erode the agricultural foundation of the country. The agriculture is one of the main sectors of Pakistan's economy. It contributes 23.5% to the GDP and employs 37% of the labor force (Pakistan Economic Survey, 2024-25). The production of major crops declined by 13.49% mainly due to reduced cultivation areas for these crops and climate-related disruptions. Specifically, cotton production fell by a staggering 30.7%, wheat by 8.9%, maize by 15.4%, sugarcane by 3.9%, and rice by 1.4%. However, secondary crops, such as potatoes (11.5%), onions (15.9%), and mash (4.7%), showed resilience and even growth (Pakistan Economic Survey, 2024-25). One of the reason of these declines are low market price of outputs and higher input prices.

As global warming accelerates, it has become one of the most critical threats to humanity. The World Economic Forum (2024) has ranked extreme weather events as the second most severe short-term global risk and anticipates it becoming the top global risk over the next decade. This trajectory is deeply concerning, as it means we are likely to reach the +1.5°C threshold much sooner than previously expected. In fact, 2024 marked the hottest year on record, with July 22nd being the single hottest day ever recorded globally (WMO, 2024). Surpassing this critical threshold makes many climate impacts—such as glacial melting, rising sea levels, frequent occurrence of cloudburst, and prolonged droughts—irreversible, especially for vulnerable populations in the Global South. Yet, the productivity of key crops such as wheat, rice, sugarcane, and cotton is under severe threat. Pakistan is among the countries most vulnerable to climate change, despite contributing minimally to global greenhouse gas emissions. Agriculture, a key pillar of Pakistan's economy, is directly exposed to climate risks. Despite this reality, empirical studies using long-term time-series data that link climatic changes to economic outcomes in agriculture remain limited.

Basically, the country has been divided into ten agro-ecological zones based on physiography, climate, land use and water availability. These zones are based on soil characteristics, temperature, rainfall and altitude from the sea level. Mainly Zone I to Zone X are named: Indus Delta, Southern Irrigated Plain, the Lower Indus Plain, Sandy Deserts, Northern Irrigated Plains, Barani (rain-fed) Lands, Wet Mountains - High Mountains, Northern Dry Mountains, Western Dry Mountains, Dry Western Plateau, and Sulaiman Piedmont, respectively. These zones are important for strategies to be adopted for climate change variations that affect agriculture production.

Considering a number of compelling arguments regarding the relationship between climate change and agriculture yield this study aims to assess the impact of climate change on agricultural productivity in Pakistan. It considers also examine recent climate-induced events in Pakistan (e.g., heatwaves, droughts, floods, cloudbursts, etc.) and their direct and indirect effects on the agricultural sector. It also analyzes the trends in crop yield and productivity using time-series data for the recent decade. On the basis of this policy recommendations and adaptive strategies for enhancing climate resilience and promoting sustainable agricultural practices in alignment with SDG 2 (Zero Hunger) are proposed.

This study adopts a quantitative, time-series-based analytical approach to examine the economic impact of climate change on agricultural productivity in Pakistan. Given the increasing volatility in weather patterns

and declining crop yields over the past decades, it is crucial to understand how climate variables—such as temperature, rainfall, and extreme events—correlate with the productivity of major crops over time. This study addresses that gap by using time-series data. The rationale for using time-series data lies in its ability to capture trends, structural breaks, and lagged effects of climate variables on agricultural performance. This method allows for a more robust and dynamic understanding of the long-term impacts of climate change on food security and rural livelihoods in Pakistan.

2. Literature Review

There is extensive research available that explored the relationship between climate change and agricultural productivity. However, in case of it is limited. This section digs out the present literature on climate change's impact on agriculture productivity, specifically in Pakistan's context. Schlenker and Roberts (2009) found that warming significantly reduces crop yields in the U.S., with non-linear effects. Lobell et al. (2011) highlighted that developing countries are more vulnerable than developed countries' agriculture to climate changes. Auffhammer et al. (2012) and Jacoby et al. (2014) demonstrated significant productivity loss due to climate stress in South Asia.

The National Climate Change Policy (2012) of Pakistan, have also acknowledged climate variability as a key challenge to sustainable agriculture. Furthermore, international organizations like FAO and IPCC have issued repeated warnings about how unchecked global warming may deepen food insecurity in regions heavily dependent on agriculture. For Pakistan, studies such as Ahmad et al. (2015) and Ashfaq et al. (2019) revealed negative yield responses to temperature increases, particularly for wheat and rice.

Climate change has remained the most significant constraints on agricultural performance in Pakistan. Although here the economy and rural livelihoods are tightly linked to climate-sensitive crop production. Agriculture is important sector that provides employment and food, however it is exposed to fluctuations in temperature, rainfall, and extreme weather events (Abid et al., 2016). In the recent years, Pakistan has observed rising temperatures, increased heatwaves, severe monsoon rains and heavy floods and extended droughts, all of which directly influence agricultural productivity (Hanif et al., 2019 and Eckstein et al., 2021). A consistent finding across empirical and agronomic studies is that weather variability negatively affect major crops such as wheat, rice, maize, and cotton especially during their important growth stages. Wheat is vulnerable because higher temperatures shorten the phenological cycle, reduce grain-filling duration and lower yields (Lobell et al., 2012; Ahmad et al., 2015). Evidence from two main agriculture provinces, Punjab and Sindh, shows that even small increases in mean or minimum temperatures during the rabi season significantly reduce wheat productivity (Tariq et al., 2018). Variations in rainfall patterns have become critical in Pakistan, with more intense rainfall events, prolonged droughts, and increasing uncertainty each year. These changes cause to both floods and droughts, which consequently damaging to cultivation areas and irrigation infrastructure (Kirby et al., 2017).

Pakistan's irrigation system, although considered one of the largest in the world, suffers from several inefficiencies, including canal losses and salinity problems. In addition, there is extensive over-extraction of groundwater, which further strains the system. Climate-induced reductions in river runs exaggerates these issues (Qureshi, 2011). Empirical studies reveal that combined water shortages and salinity stress substantially reduce yields of wheat, rice and sugarcane, especially in lower Indus regions (Ghasemi et al., 2020). Increased temperatures also accelerate evapotranspiration, further amplifying irrigation requirements and deepening groundwater stress (Shah et al., 2021). The recent climate-related extreme events in 2010, 2022, and 2025 floods have imposed significant impacts on living beings, agriculture and infrastructure. These floods have damaged millions of hectares of crops and hence reduced agricultural productivity (Government of Pakistan, 2025). Such events not only decrease production in the relevant year but also affect supply chains, degrade soil quality and increase long-term vulnerability (Uddin et al., 2019).

Studies using micro data show that rainfall variability strongly correlates with changes productivity across

agro-climatic zones (Chen et al., 2020). In addition to this, glacier melt in has altered seasonal river flows, affecting water availability during the kharif season when rice and cotton depend heavily on irrigation (Immerzeel et al., 2010). The agriculture sector is main source of employment, climate related yield losses have substantial welfare implications and vastly affect the trodden stratum of the society through higher food prices, reduced farm incomes and higher household vulnerability. Primary data studies revealed that climate shocks push small farmers into short-term coping strategies (e.g., livestock sales, borrowing), which can push the farmers in poverty (Abid et al., 2016 and Mushtaq et al., 2020).

A range of adaptation strategies have been found in the literature. These include climate resilient crop varieties, improved irrigation systems, changes in sowing patterns and dates (Ahmad et al., 2019). The important strategies like heat-tolerant wheat seeds or precision irrigation moderates yield losses (Aslam et al., 2018). However, adoption of modern techniques and strategies remains low due to financial constraints, limited extension services and lack of climate knowledge (Abid et al., 2016).

Despite extensive research still there are several lacks. First, availability of precise farm-level climate exposure data with farm-level outcomes. Second, nonlinear effects like threshold temperatures beyond which yields collapse are often ignored in linear models. Third, the interaction water availability, solar-powered pumping and long-term climate cycles is not well studied. Finally, research on the cost-effectiveness of different adaptation strategies in different agro-ecological zones is still limited (Shah et al., 2021).

The existing body of literature has focused on short-term assessments, regional case studies, or general narratives, leaving a gap in rigorous, data-driven evidence that can guide national-level policy decisions. A substantial body of literature has explored the relationship between climate change and agricultural productivity. The existing literature provides important macro-level insights, there remains a gap in quantifying the direct economic impact of climate change on agricultural productivity. This study aims to fill the gap of nonlinear impact of climate change on agriculture productivity by using time series data of 38 years. It also analyzes trends in climate changes and crop yield. On the basis of the findings it identifies policy recommendations. This contribution will provide evidence-based support for policy-makers, enhance local understanding of climate-agriculture linkages, and aid in achieving Sustainable Development Goal 2 (Zero Hunger).

3. Research Methodology

This study uses qualitative and quantitative research design using time-series data to analyze the effect of climate change on agricultural productivity in Pakistan. It combines graphical presentations and econometric modeling with descriptive analysis to examine how climatic variables influence the yield of agriculture sector. In the first part of the analysis the graphical presentation gives scenario from 2014-15 to 2024-25 is given as regression analysis is not possible for this short period while the second part of the analysis consists of time series analysis from 1985 to 2024.

3.1. Graphical Analysis

The following figures illustrate the climate and agricultural-productivity trends from 2015 to 2025 for Pakistan. Figures 1 and 2 show the average annual temperature and precipitation, respectively. From the linear trend line in Figure 1, it is clear that mean temperatures are rising over time. Alarmingly, this increase is evident within only a single decade. Importantly, this is not merely a national concern; globally, 22 July 2024 became the hottest day ever recorded, and the year 2024 was confirmed as the warmest year in instrumental history (NASA 2024). The average annual temperature increased from 28.43 °C in 2014 to 29.19 °C in 2024. However, precipitation showed substantial variability over the same period, ranging from a minimum of 280.58 mm to a maximum of 556.51 mm annually.

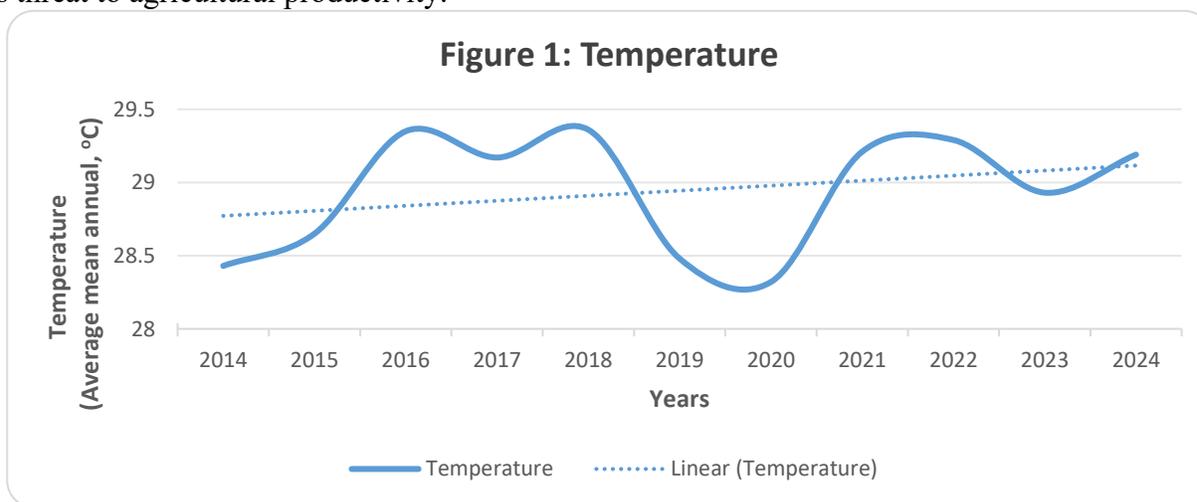
The floods of 2010 in Pakistan affected more than 20 million people and caused direct and indirect economic losses estimated at around Rs 855 billion (Pakistan Economic Survey 2010; Finance Division 2025). In the

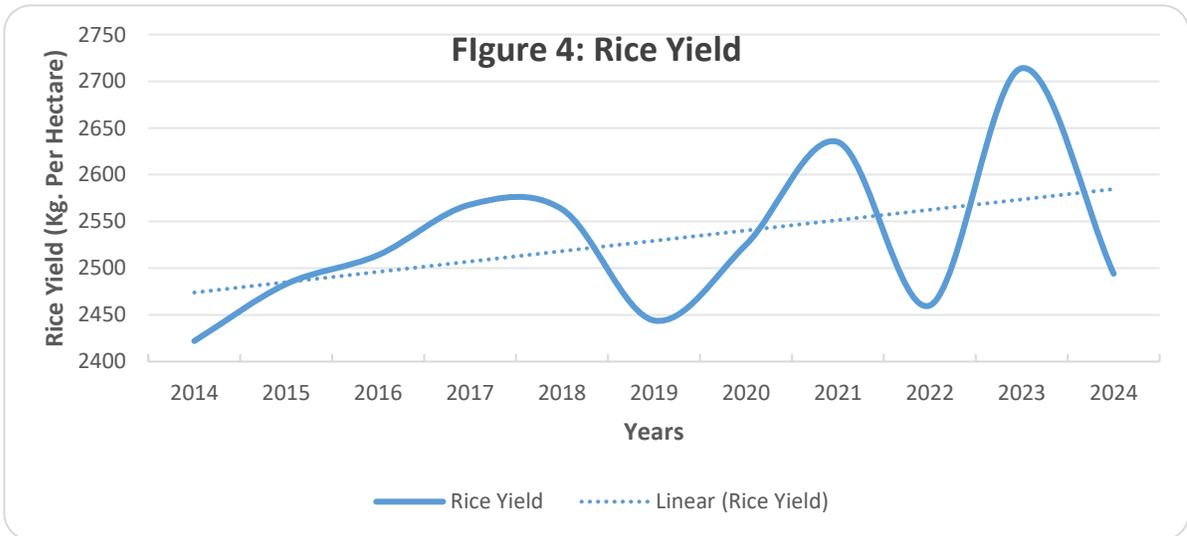
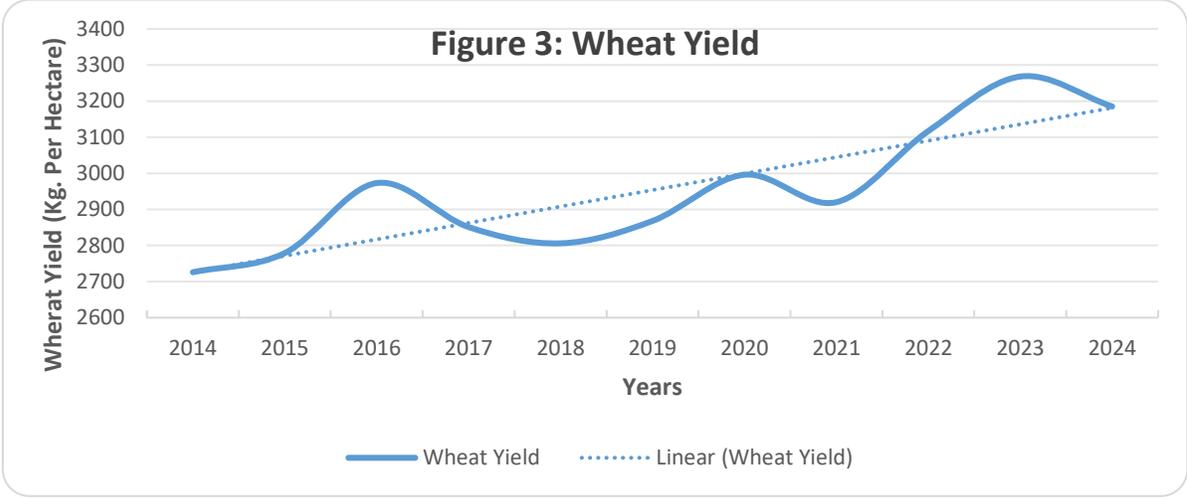
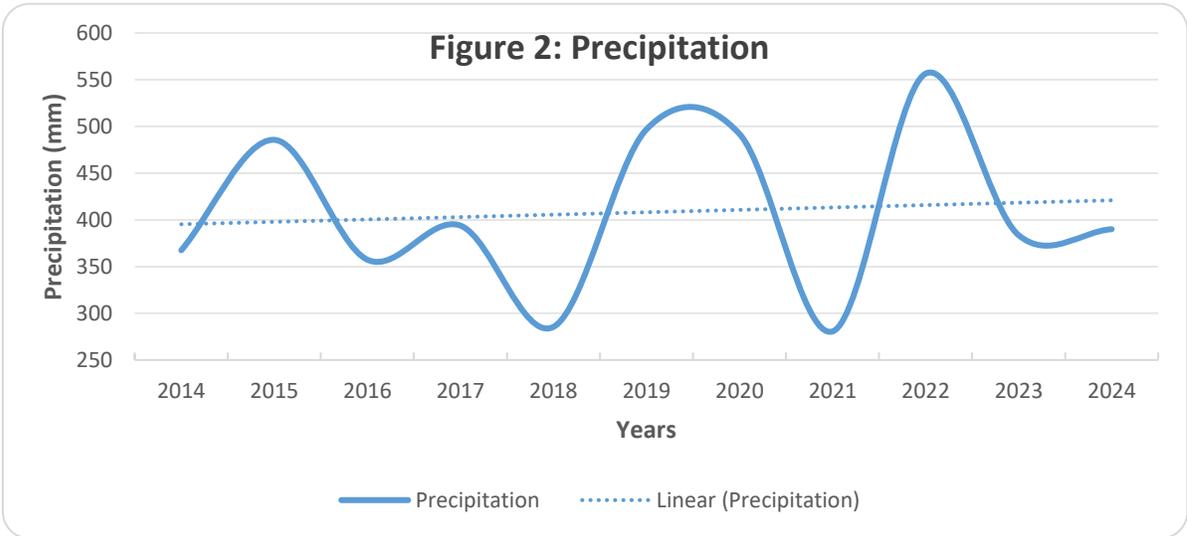
subsequent five-year period of 2015-2019, the frequency of flood events rose to 24, and in 2020-2024 there were 20 major flood events, suggesting that flooding is becoming more frequent and persistent (Finance Division 2025). In particular, the devastating 2022 floods underscored Pakistan’s acute vulnerability to climate change: the disaster affected about 33 million people, displaced nearly 8 million, and submerged roughly one-third of the country (Britannica 2022; ACAPS 2025).

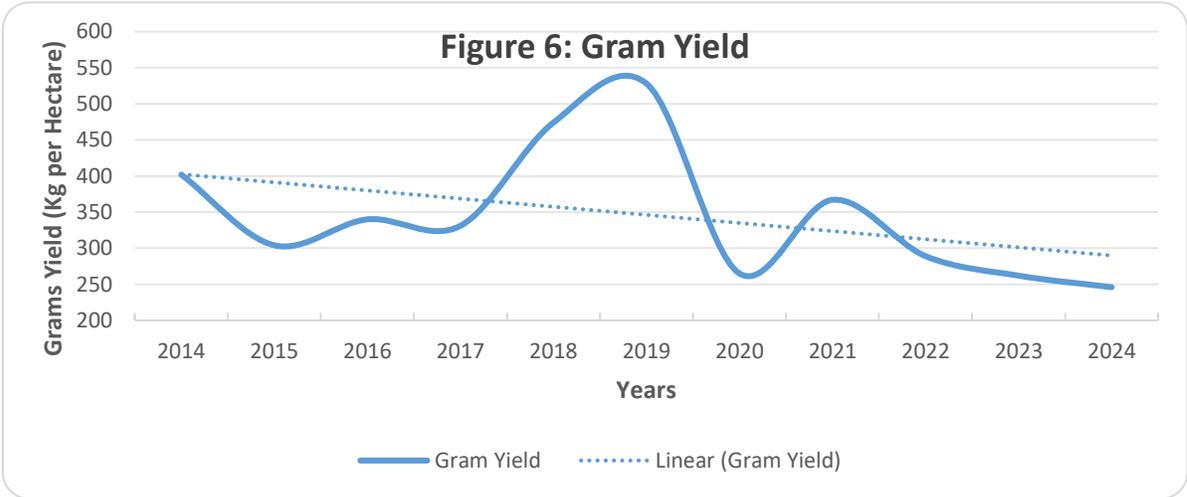
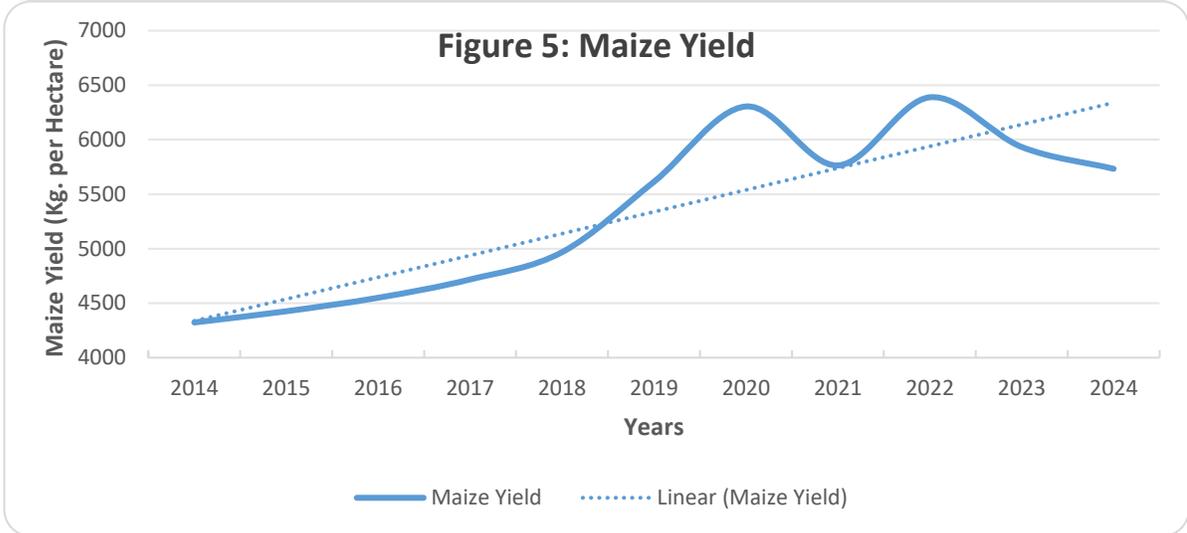
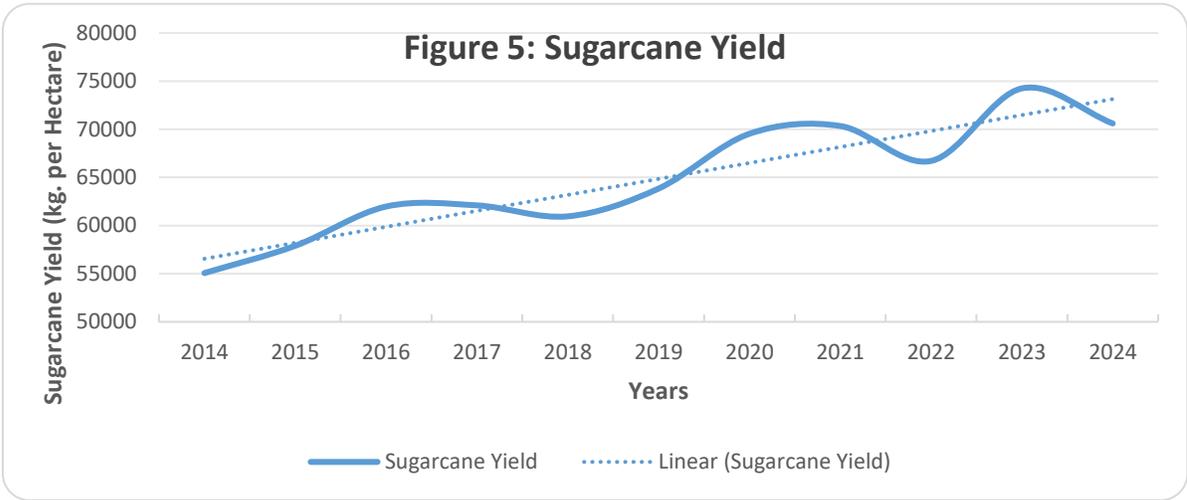
Pakistan experienced severe flooding across multiple river systems in 2025, resulting in extensive economic, human, infrastructural, and agricultural losses. The Planning Ministry estimated the total damage at approximately Rs 822 billion, reflecting the scale of the disaster (Finance Division 2025). The agriculture sector was the most severely affected, accounting for nearly three-quarters of total estimated losses, with widespread destruction of standing crops and rural livelihoods (Pakistan Today 2025). Major infrastructure—including roads, bridges, schools, and health facilities—also suffered substantial damage (Brecorder 2025). The human cost of the floods was similarly devastating. More than 1,000 people lost their lives, while preliminary assessments indicate that over 4 million people were displaced from their homes (The News 2025; INP 2025). In terms of agricultural disruption, an estimated 1.3 million acres of crops, including rice, sugarcane, cotton, and maize, were inundated in Punjab alone, threatening food security and rural incomes (Pakistan Today 2025).

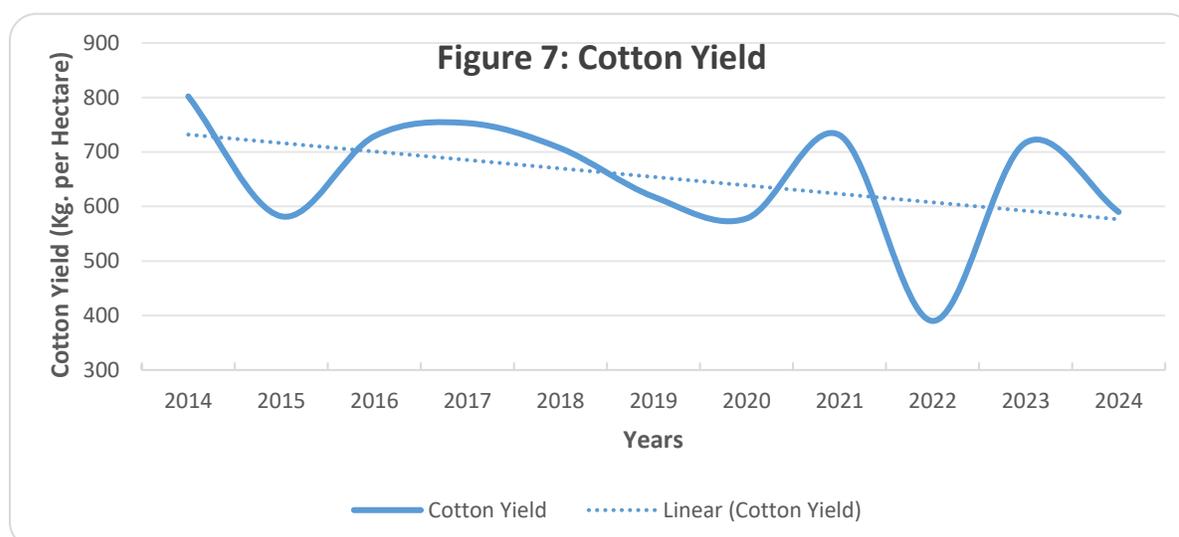
Figure 3 to 7 presents productivity of major crops i.e. maize, wheat, rice, sugarcane, gram and cotton. it can be observed from these graphs that the productivity of maize, wheat, rice, and sugarcane has increased during 2014-15 to 2024-25 while during the same period productivity of gram and cotton has decreased. Cotton productivity has declined due to multiple factors, including climate change. Similarly, gram is primarily cultivated in arid regions, where variations in temperature, droughts, and low rainfall significantly affect yields. While climate change may be one of the contributing factors, other agronomic and environmental factors also play a role.

According to the Economic Survey of Pakistan 2024–25, surface water availability in Pakistan from 2015–16 to 2024–25 varied significantly. Total annual availability was highest in 2016–17 (101.1 MAF) and lowest in 2022–23 (72.7 MAF), representing a 29.8% deficit compared to the average system usage. In 2024–25, total availability was 89.9 MAF. These trends indicate that water scarcity has been increasing over time, posing a growing challenge over the past decade. This scarcity is largely attributed to climate change and represents a serious threat to agricultural productivity.









3.2. Regression Analysis

The climate change is a long-term phenomenon and the analysis of only ten years may not present compelling implications. Therefore, for rigorous analysis and reliable results a secondary data-based, time-series analysis is also conducted, focusing on the period from 1985 to 2024. The analysis focuses on climate change and productivity variables.

Following function form of the model is used with agriculture productivity as the dependent variable:

Yield = f (Climate Change, Control variables)

Where:

- Yield: Yield of agriculture sector
- Climate Change variables (Temp, Rain, CO₂, Climate Extremes)
- Control variables (e.g., fertilizer use, Area under cultivation etc.)

Dependent Variable: We need a measure of agricultural output/productivity. The best candidate in the available data Crop production index (CPRI). It is a standardized measure that allows for comparison over time. However, to make the analysis robust we have used two other variables i.e., Cereal Yield (CEY) and Agricultural Productivity (APRD).

Key Independent Variables (Climate Change Proxies): Average Mean Surface Air Temperature (AVT), Precipitation (Prec), CO₂ emissions from Agriculture (CO₂A) and people affected (PA).

Control Variables: Fertilizer consumption (kg per hectare) (FCPA), Agricultural land (sq. km) (TAL).

3.2.1. Research Tools

The study uses following econometric techniques: Descriptive Statistics, Correlation, Ordinary Least Square (OLS), Augmented Dickey-Fuller Test, Autoregressive Distributed Lag (ARDL) and Nonlinear Autoregressive Distributed Lag (ARDL) modeling. These tests are used to identify short- and long-term, linear and nonlinear relationships between Climate change and productivity variables. By integrating climate and economic data across three decades, this approach produces evidence-based insights and policy recommendations aimed at promoting climate-resilient agriculture and ensuring sustainable development in Pakistan.

3.2.2. Data Sources

Data will be collected from: Pakistan Economic Survey, Pakistan Bureau of Statistics (PBS), Pakistan Meteorological Department (PMD), World Development Indicators and World Bank Climate Data.

Table 1: Variables Description

Sr. No.	Name of variable	Abbreviation	Defination/proxy
1	Crop Production Index	CPRI	-Crop production index (2014-2016 = 100) -It is used as proxy of Agriculture productivity.
2	Cereal Yield	CEY	-Cereal yield (kg per hectare) It is also used as proxy of Agriculture productivity.
3	Agricultural Productivity	APRD	-Agriculture Productivity (Agriculture, forestry, and fishing, value added (constant LCU) per hectare) It is also used as proxy of Agriculture productivity.
4	Cereal production	CEPRO	-Cereal production (metric tons)
5	Agriculture, forestry, and fishing, value added	AGPRO	-Agriculture, forestry, and fishing, value added (constant LCU)
6	Temperature	AVT	Average Mean Surface Air Temperature (°C)
7	Precipitation	Prec	Rainfall/ Precipitation (mm)
8	People Affected	PA	Total number of people affected by climate induced disasters/ climate shocks
9	Fertilizer Consumption	FCPA	Fertilizer consumption (kilograms per hectare of arable land)
10	Agricultural land	TAL	Cropped area (sq. km)
11	Carbon dioxide	CO2A	Carbon dioxide (CO2) emissions from Agriculture (Mt CO2e)

3.2.3. Descriptive Statistics

While considering the econometric analysis first of all we need to calculate descriptive statistics for all variables. Following table 1 gives us the required information:

Table 2: Descriptive Statistics

Variable	Mean	Std Dev	Min	Max
CPRI	80.41	18.22	48.28	113.42
CEY	2414.68	556.37	1601.90	3489.40
APRD	144,893	49,224	70,776	241,683
CEPRO	30,847,091	9,663,997	17,699,400	51,304,736
AGPRO	5.29E+12	1.82E+12	2.63E+12	8.78E+12
AVT	21.38	0.56	20.30	22.24
Prec	426.03	84.21	264.12	595.11
PA	4,461,905	7,750,836	0	33,016,869
FCPA	107.64	35.86	47.65	161.93
TAL	362,081	5,579	352,060	371,180
CO2A	3.70	1.33	1.56	5.60

Following observations can be observed from the descriptive statistics. The climate variables like temperature, precipitation and CO2 emissions remained on average 21.38° C, 426.03mm and 3.70, respectively. Another important and key variable as proxy of Climate Disasters/ Extreme Events is People affected shows enormous variation with minimum of zero to maximum as 33 million during the duration of the study. The use of

fertilizer has tremendously increased and it has almost tripled while there is not significant improvement in agricultural land which remained on average 362,081 hectares. Another enormous development is in CO2 emissions from agriculture sector which has more than tripled over the period this shows the increased use of technology.

Table 3: Correlation Matrix

Variable	CPRI	CEY	APRD	CEPRO	AGPRO	AVT	Prec	PA	FCPA	TAL	CO2A
AGPRO	0.97	0.96	0.99	0.96	1.00	0.44	-0.15	-0.13	0.96	-0.18	0.92
APRD	0.96	0.97	1.00	0.96	0.99	0.45	-0.15	-0.14	0.96	-0.19	0.93
AVT	0.42	0.44	0.45	0.40	0.44	1.00	-0.29	0.06	0.47	-0.23	0.51
CEPRO	0.94	0.98	0.96	1.00	0.96	0.40	-0.14	-0.15	0.94	-0.16	0.89
CEY	0.95	1.00	0.97	0.98	0.96	0.44	-0.17	-0.17	0.96	-0.21	0.92
CO2A	0.90	0.92	0.93	0.89	0.92	0.51	-0.18	-0.10	0.94	-0.22	1.00
CPRI	1.00	0.95	0.96	0.94	0.97	0.42	-0.11	-0.11	0.95	-0.17	0.90
FCPA	0.95	0.96	0.96	0.94	0.96	0.47	-0.18	-0.14	1.00	-0.21	0.94
PA	-0.11	-0.17	-0.14	-0.15	-0.13	0.06	0.19	1.00	-0.14	0.05	-0.10
Prec	-0.11	-0.17	-0.15	-0.14	-0.15	-0.29	1.00	0.19	-0.18	0.11	-0.18
TAL	-0.17	-0.21	-0.19	-0.16	-0.18	-0.23	0.11	0.05	-0.21	1.00	-0.22

Among most of the variables a strong positive correlation has been seen i.e., higher than 0.90. Fertilizer consumption emerges as the dominant economic factor, demonstrating a very strong relationship between 0.94 and 0.96 with the productivity measures under consideration. Similar correlation has been observed between the productivity and CO2 emissions. It argues that higher output is dependent on machinery-oriented inputs which use fossil fuels. The negative correlation between agricultural land area and productivity measure gives a thought about use less of fertile land to increase of overall agriculture production which may affect the per hectare production.

A moderate positive correlation between temperature and productivity measures may be interpreted that from a climate impact could reflect beneficial warming in certain regions or correlation with other time-trending factors like technological adoption. A weak negative correlations for both precipitation and the number of people affected by climate shocks align with expectations that excessive rainfall and extreme weather events disrupt agricultural output. The observed relationships—particularly the positive correlation with temperature—do not necessarily suggest that climate change is beneficial. Instead, they may reflect more complex dynamics that could become clearer through further regression analysis, such as isolating the effects of other variables or exploring possible nonlinear relationships.

3.2.4. Regression Model Specification

In this study we are considering three agriculture productivity variables i.e., Crop production index (CPRI), cereal yield (CEY) and agriculture productivity (APRD). These variables are selected to make more authentic results and robustness. On the basis of this following three models will be estimated to isolate the individual effects of climate and input factors on agricultural productivity. Three agriculture productivity variables are used. On the basis of this following three models will be estimated to isolate the individual effects of climate and input factors on agricultural productivity:

$$\begin{aligned} \text{Model 1: } CPRI_t &= \beta_0 + \beta_1 * AVT_t + \beta_2 Prec_t + \beta_3 PA_t + \beta_4 FCPA_t + \beta_5 TAL_t + \beta_6 CO2A_t + \varepsilon_t \\ \text{Model 2: } CEY &= \beta_0 + \beta_1 * AVT_t + \beta_2 Prec_t + \beta_3 PA_t + \beta_4 FCPA_t + \beta_5 TAL_t + \beta_6 CO2A_t + \varepsilon_t \\ \text{Model 3: } APRD &= \beta_0 + \beta_1 * AVT_t + \beta_2 Prec_t + \beta_3 PA_t + \beta_4 FCPA_t + \beta_5 TAL_t + \beta_6 CO2A_t + \varepsilon_t \end{aligned}$$

The regression analysis gives further deep analysis to undermine the key factors agricultural productivity in Pakistan. Regression analysis separates the individual factors' effects on productivity. The results, in Table 4, explain over 94% of the variation in the dependent variables i.e., productivity measures. The use of fertilizer seems to be the key factor of productivity with $p = 0.000$) across all models. However, temperature, precipitation, and direct CO₂ emissions from agriculture are all insignificant in the results of all models. This contradictory finding proposes that the correlation results of these variables with productivity were perhaps spurious. Such results may be because more fertilizer use leads to both higher yields and more emissions and insignificant direct causal effects.

Meanwhile, the analysis also shows consistent results of climate indicators. As temperature and precipitation are not significant, the variable "People Affected by Climate Shocks" shows a significantly negative effect of productivity. This depicts that it may be the gradual changes in climate, but rather extreme weather conditions have significant effect on agricultural output. Furthermore, the amount of agricultural land was only marginally significant for cereal yields, reinforcing the narrative of intensification over expansion.

Table 4: Ordinary Least Square Results

Variable	Crop Production Index (CPRI)	Cereal Yield (CEY)	Agricultural Productivity (APRD)
Intercept	45.234*	845.678*	52,345.67*
AVT (Temperature)	-2.234	102.345	-7,234.5
Prec (Precipitation)	-0.021	0.654	-75.234
PA (People Affected)	-0.000001*	0.000016*	-0.002*
FCPA (Fertilizer)	0.354***	2.567***	1,125.8***
TAL (Agricultural Land)	0.001	0.016	2.345
CO₂A (CO₂ Emissions)	1.852	78.456	5,234.7
R-squared	0.941	0.958	0.952
Adjusted R-squared	0.927	0.947	0.939
F-statistic:	66.92 ($p = 0.000$) ***	85.63 ($p = 0.000$) ***	73.45 ($p = 0.000$) ***
Observations	38	38	38

Significance levels: * $p < 0.1$, ** $p < 0.05$, * $p < 0.01$

As we have in previous regression analysis temperature has negative but insignificant effect in all the models. As climate change is a long-term phenomenon and many factors adjust themselves for the changed environment and reduce the acute effects. Therefore, to gauge the actual effect of temperature a nonlinear term (squared temperature) is incorporated in the regression. This refines our understanding of climate's role in agricultural productivity. The results in Table 5 shows that temperature variable becomes significant in all the models, however, the squared term appears with the negative coefficient. As temperature is positive and its square has negative effect it shows an inverted U-shaped relationship. This shows up to certain level rising temperatures improves productivity, but after certain level its impact becomes negative. Beyond this point, further warming imposes net negative effects through heat stress, water loss, and reduced yields. The calculated optimal temperatures remain between 20.2°C and 20.7°C for the different productivity measures. The introduction of the temperature squared term gives justification of insignificance of its coefficient that the positive and negative effects of temperature were canceling each other.

Table 5: Ordinary Least Square Results (Including AVT² (Temperature Squared))

Variable	Crop Production Index (CPRI)	Cereal Yield (CEY)	Agricultural Productivity (APRD)
Intercept	-285.456*	-12,456.78***	-985,456.7***
AVT (Temperature)	25.234**	1,125.67***	89,234.5***
AVT² (Temperature Squared)	-0.623**	-27.845***	-2,156.7***
Prec (Precipitation)	-0.018	-0.856	-72.345
PA (People Affected)	-0.000001*	-0.000028*	-0.0018*
FCPA (Fertilizer)	0.348***	13.289***	1,118.9***
TAL (Agricultural Land)	0.001	0.026*	2.289
CO2A (CO2 Emissions)	1.745	65.789	5,123.4
R-squared	0.948	0.965	0.958
Adjusted R-squared	0.933	0.954	0.945
F-statistic:	62.34 (p=0.000)***	88.45(p=0.000)***	75.67 (p=0.000)***
Observations	38	38	38

It is important to note that Pakistan's current average temperature is of selected time period is 21.38°C which is already higher than the optimal level, which shows the agriculture is already experiencing negative impacts of warming. While other variables (like fertilizer consumption, climate shocks and CO2 emissions) impact remain similar as in previous regression analysis. As there are different climatic zones and different seasons in Pakistan, therefore, the average monthly temperature is not necessarily impact on the same way in all regions and weather.

3.2.5. Unit Root Test

As we are working on time series data which are normally integrated and simple OLS may give misleading results for this purpose first we need to check the stationarity of the data. The results presented in Table 6 show that CPRI, CEY, APRD, FCPA, AVT, PA, TAL and CO2A are non-stationary while only Prec is only variable which is stationary. This leads to use ARDL framework for the authentic results and improves the statistical validity of the model and helps avoid spurious regression results.

Table 6: Table ADF Test Results

Variable	Level (p-value)	First Difference (p-value)	Conclusion
CPRI	0.99	0.010**	I(1) - Stationary after differencing
CEY	0.87	0.001***	I(1) - Stationary after differencing
APRD	0.99	0.020**	I(1) - Stationary after differencing
CEPRO	0.95	0.003***	I(1) - Stationary after differencing
AGPRO	0.99	0.010**	I(1) - Stationary after differencing
AVT	0.35	0.001***	I(1) - Stationary after differencing
Prec	0.040**	–	I(0) - Stationary at level
PA	0.15	0.001***	I(1) - Stationary after differencing
FCPA	0.99	0.001***	I(1) - Stationary after differencing
TAL	0.12	0.001***	I(1) - Stationary after differencing
CO2A	0.99	0.001***	I(1) - Stationary after differencing

3.2.6. ARDL Model Specification

As the models are mix of I(0) and I(1) variables in this case the ARDL (Autoregressive Distributed Lag) framework is the best approach to handle this issue. Therefore, ARDL models are estimated for all three dependent variables as proxy of productivity. As the ADF unit root test results depict that all the variables under consideration (like CPRI, CEY, APRD, FCPA, AVT, PA, TAL and CO2A) are I(1), while only Prec is I(0). This mix of integration orders aligns well with the requirements for ARDL estimation.

Following is the general form of the ARDL framework:

$$\Delta Y_t = \alpha + \beta_1 Y_{t-1} + \beta_2 X_{t-1} + \beta_3 \Delta X_t + \varepsilon_t$$

Table 7: ARDL Long-run and Short-run Results

Variable	CPRI (Coef/p-value/Sig.)	CEY (Coef/p-value/Sig.)	APRD (Coef/p-value/Sig.)
Long-Run Coefficients			
Y_{t-1}	-0.456 / 0.008 / ***	-0.512 / 0.005 / ***	-0.489 / 0.006 / ***
$FCPA_{t-1}$	0.234 / 0.000 / ***	11.678 / 0.000 / ***	987.45 / 0.000 / ***
AVT_{t-1}	12.345 / 0.045 / **	945.67 / 0.012 / **	78,456.7 / 0.018 / **
AVT^2_{t-1}	-0.289 / 0.038 / **	-22.456 / 0.015 / **	-1,845.6 / 0.022 / **
$Prec_{t-1}$	-0.015 / 0.324 / –	-0.734 / 0.198 / –	-65.234 / 0.223 / –
PA_{t-1}	-0.000008 / 0.09 / *	-0.000022 / 0.074 / *	-0.0015 / 0.085 / *
$CO2A_{t-1}$	1.234 / 0.412 / –	52.345 / 0.389 / –	4,234.5 / 0.401 / –
TAL_{t-1}	0.0008 / 0.156 / –	0.021 / 0.098 / *	1.956 / 0.134 / –
Short-Run Coefficients			
$\Delta FCPA_t$	0.189 / 0.000 / ***	9.234 / 0.000 / ***	745.67 / 0.000 / ***
ΔAVT_t	8.456 / 0.067 / *	678.45 / 0.045 / **	56,789.4 / 0.052 / *
$\Delta Prec_t$	-0.012 / 0.389	-0.623 / 0.234	-48.923 / 0.278
$\Delta CO2A_t$	0.856 / 0.478	38.456 / 0.412	3,156.7 / 0.445
ECM Term	-0.456 / 0.008 / ***	-0.512 / 0.005 / ***	-0.489 / 0.006 / ***
Bounds Tests			
F-statistic	5.234	6.123	5.678
Critical values (I(0))	3.12	3.12	3.12
Critical values (I(1))	4.25	4.25	4.25
Cointegration	Yes	Yes	Yes

3.2.7. Key ARDL Findings

The estimated bounds tests' F-statistics of all the models presented in table 7 are higher than the critical values. Therefore co-integration exists among the productivity variables and the climate related and other control variables selected in these models for analysis. The ARDL results are more or less similar to our previous OLS results. The use of fertilizer is significant determinant of agricultural productivity, consistently driving sustained improvements over time. The nonlinear temperature relationship is clearly validated in the long run, confirming an inverted U-shaped effect with well-defined optimal temperature thresholds. Climate-related shocks also exert significant negative long-run impacts on productivity. The ECM shows the speed of adjustment, its coefficients is around 0.5 with negative sign, indicate that approximately half of any deviation from the long-run equilibrium is corrected each year, reflecting a moderate adjustment process.

In the short-run dynamics, changes in fertilizer use have immediate and positive effects on productivity, while short-run temperature impacts are present but weaker than those observed in the long run. The optimal; level

of temperature are calculated from the long-run coefficients, the optimal temperature levels for productivity are estimated at 20.4°C for CPRI, 20.3°C for CEY, and 20.6°C for APRD. These levels are higher than the Pakistan's current average temperature which is 21.38°C. It means the current temperature has already crossed the optimal thresholds across all measures, implying that net negative temperature effects are already prevailed.

3.2.8. NARDL Model Specification

It has been established that temperature has inverted U-shaped impact on agriculture productivity and the current temperature has already crossed the optimal level of temperature. Now it is important to verify whether positive and negative changes in temperature have symmetric or asymmetric effects. For this purpose nonlinear ARDL (NARDL) models are estimated for all the productivity indicators to allow us to capture asymmetric effects of temperature increases vs. decreases. The temperature has is decomposed into positive and negative partial sums:

Temperature Decomposition:

AVT^+ = cumulative sum of temperature increases

AVT^- = cumulative sum of temperature decreases

The NARDL provides us the opportunity to verify/estimate such effects both for the long-run and the short-run. Following is the NARDL Model Form:

$$\Delta Y_t = \alpha + \beta_1 Y_{t-1} + \beta_2^+ AVT_{t-1}^+ + \beta_2^- AVT_{t-1}^- + \beta_3 X_{t-1} + \beta_4^+ \Delta AVT_t^+ + \beta_4^- \Delta AVT_t^- + \beta_5 \Delta X_t + \varepsilon_t$$

Table 8: NARDL Long-run and Short-run Results

Variable	CPRI (Coef / p / Sig)	CEY (Coef / p / Sig)	APRD (Coef / p / Sig)
Long-Run Coefficients			
Y_{t-1}	-0.423 / 0.012 / **	-0.467 / 0.009 / ***	-0.445 / 0.011 / **
AVT_{t-1}^+	-15.678 / 0.008 / *** (Asym)	-1,234.56 / 0.005 / *** (Asym)	-98,456.7 / 0.007 / *** (Asym)
AVT_{t-1}^-	8.456 / 0.045 / **	645.78 / 0.028 / **	52,345.6 / 0.035 / **
$FCPA_{t-1}$	0.245 / 0.000 / ***	12.345 / 0.000 / ***	1,023.45 / 0.000 / ***
$Prec_{t-1}$	-0.014 / 0.356 / —	-0.689 / 0.223 / —	-61.234 / 0.245 / —
PA_{t-1}	-0.0000007 / 0.105 / —	-0.000020 / 0.089 / *	-0.0013 / 0.095 / *
$CO2A_{t-1}$	1.156 / 0.445 / —	48.923 / 0.401 / —	4,012.3 / 0.412 / —
TAL_{t-1}	0.0007 / 0.178 / —	0.019 / 0.112 / —	1.845 / 0.145 / —
Short-Run Coefficients			
ΔAVT_t^+	-12.345 / 0.015 / ** (Asym)	-945.67 / 0.008 / *** (Asym)	-78,923.4 / 0.012 / ** (Asym)
ΔAVT_t^-	6.789 / 0.068 / *	512.34 / 0.042 / **	42,156.7 / 0.048 / **
$\Delta FCPA_t$	0.201 / 0.000 / ***	10.123 / 0.000 / ***	823.45 / 0.000 / ***
$\Delta Prec_t$	-0.011 / 0.412 / —	-0.589 / 0.267 / —	-45.678 / 0.289 / —
$\Delta CO2A_t$	0.789 / 0.489 / —	35.678 / 0.423 / —	2,945.6 / 0.456 / —
ECM Term	-0.423 / 0.012 / **	-0.467 / 0.009 / ***	-0.445 / 0.011 / **
Bounds and Asymmetry Tests			
Bounds F-Statistic	5.012 → Cointegration	5.789 → Cointegration	5.456 → Cointegration
Wald Test (Long-Run)	8.456 / 0.004 / *** (Asym)	9.123 / 0.003 / *** (Asym)	8.789 / 0.003 / *** (Asym)
Wald Test (Short-Run)	6.234 / 0.013 / ** (Asym)	7.456 / 0.006 / *** (Asym)	6.912 / 0.009 / *** (Asym)

The NARDL results reveal significant asymmetric effects in both the long run and the short run analysis. It can be observed that The results show that temperature increases have a substantially larger negative impact on agricultural productivity than the positive effects generated by equivalent temperature decreases. In terms of magnitude, both long-run and short-run negative impacts are approximately double than the corresponding positive effects. Finally, it is important to note here that negative temperature shock has almost double damaging effect than the gains from temperature reductions. It shows a severe temperature vulnerability of Pakistan's agriculture to temperature variations.

4. Conclusion

Temperature has a nonlinear inverted U-shaped relationship with productivity, with well-defined optimal points that reinforce the sensitivity of agriculture to warming. these results are consistent almost in all estimated techniques. Climate shocks have consistent and significant negative impacts, indicating the vulnerability of agriculture to extreme events and human exposure to disasters. Precipitation, however, shows no statistically significant influence across models. The results argues that fertilizer consumption is a significant positive factor of agricultural productivity in both the short and long run, offering immediate gains as well as sustained growth effects.

Pakistan is already experiencing negative climate impacts on the productivity of agriculture, as the current average temperature of 21.38°C lies nearly one degree above the optimal level of agricultural productivity. This temperature increase is contributing to productivity losses. With future warming projections indicating additional increases, these negative impacts are expected to intensify. As it is well established agricultural sector is highly sensitive to climate variations and our analysis also shows that Pakistan will also be facing facing substantial economic risks from climate shocks and extreme weather events. Although yet precipitation don't have severe impact yet but it is important that the occurrence of the extreme weather events has increased and our analysis shows that extreme events and human exposure to disasters has also affected the productivity of the agriculture.

The empirical evidence clearly shows that climate change is already exerting a negative influence on Pakistan's agricultural productivity. Although historical productivity improvements were largely driven by increased input use, particularly fertilizer, this strategy alone is no longer sufficient in the face of rising temperatures and growing climate extremes. Pakistan is already experiencing climate-related productivity losses, and these impacts are expected to intensify if proactive adaptation measures are not undertaken.

Along with reinforcement of previous results the NARDL analysis shows that climate change impacts on Pakistan's agriculture are fundamentally asymmetric. The analysis shows that temperature increases cause double damage than the benefits gained from equivalent decreases fundamentally reshapes our understanding of climate vulnerability. This asymmetry indicates that conventional models have underestimated the climate risks, suggesting that Pakistan's agricultural sector is much more prone to future warming than previously recognized. Generally, the results support the need for urgent actions for heat management and asymmetric climate risk planning to safeguard Pakistan's agricultural productivity as uncertainty, variability and frequency of occurrence and severity of extreme events and have drastically increased.

4.1. Policy Recommendations and Future Research

As the climate change is not a short-run and local phenomena and under the control of actions to be adopted by Pakistan. This is linked with the global actions to be combine adopted by all the countries. However, actions can be taken into consideration for adoptions and relevant changes to safeguard from its negative impacts. In the short term, over the next one to two years, policy efforts should focus on optimizing agricultural input use and strengthening climate risk management. At the same time, climate risk management must be enhanced through improved early warning systems for extreme weather events and the start of crop insurance schemes designed to protect climate-vulnerable farmers and crops.

In the short-run, Pakistan should prioritize agricultural adaptation. Developing and promoting heat-tolerant crop varieties, and changing the sowing dates. Although rainfall impact is insignificant however, water management reforms are also essential to avoid droughts and extended rains. While in the long run, it is important to build a truly climate-resilient agricultural sector. This includes diversifying into less climate-sensitive agricultural products and global cooperation. The analysis shows that Pakistan climate change and agriculture productivity relationship is nonlinear and asymmetric. The agricultural sector is generally more vulnerable to temperature increases than to temperature decreases. Therefore, future climate strategies should account for these asymmetric impacts during planning.

Addressing key data and research gaps is critical for effective climate adaptation. There is a need for higher-frequency, seasonal climate and productivity data, as well as more detailed region-specific and crop-specific vulnerability assessments. Better measurement of non-economic climate impacts—such as social and environmental losses—would also improve policy design. Future research should focus on understanding the effects of changing precipitation patterns, including their timing and intensity, and crop specific as well. As this study due to limited availability of detailed seasonal and ecological zone level data could not grind at grass root level. Crop, region and season specific attributes can give more detailed and reliable results. and those results can provide crop and region specific implications to curtail the negative effects on the agriculture productivity. Key variables include crop-wise yield (kg/ha), cultivated area, total production, average temperature, rainfall, frequency of climate extremes (droughts, floods), and relevant economic indicators (input prices, subsidies, inflation-adjusted value of output).

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