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Assessing the adequacy of farmland productivity and cereal yields in combating climate change

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ABSTRACT

Climate change threatens and significantly affects agricultural activities through various mechanisms. One crucial factor is the temperature, which, when exceeding a specific threshold, adversely impacts harvests due to the accelerated pace of plant development. The primary objective of this study is to evaluate the impact of agricultural land, fertiliser inputs per unit of agricultural land, rainfall and temperature on cereal yields in Pakistan using annual data series. Utilizing the Quantile Autoregressive Distributed Lag (QARDL) methodology, we explore the interconnections among these variables in both the short and long-run. The study's findings show that agricultural land dedicated to crop cultivation across various quantiles has a positive impact on cereal yields in both the short and long term. The usage of fertiliser inputs per unit of agricultural land improves cereal yields in the short and long run. However, the effectiveness of this method decreases as the quantiles increase. Furthermore, it has been shown that, over the time, a decrease in cereal yields is connected with low to moderate levels of rainfall, while the influence of rainfall at higher quantiles is insignificant. The effect of temperature on cereal yields in Pakistan varies depending on the temperature level and prevailing circumstances. The study's results suggest a variety of strategies to increase crop yields, including increasing agricultural production, enhancing land utilization and improving farmer access to funding.

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Crops production; climate change; agricultural land; environmental sustainability; fertiliser consumption

1. Introduction

The burning of fossil fuels causes a rise in atmospheric CO₂ emissions and other greenhouse gases, which contributes to climate change. Environmental degradation and climate change in Pakistan are stifling economic growth, worsening the difficulties that poor people confront in achieving their fundamental necessities and obstructing long-term progress. Climate change is mostly caused by manmade causes such as population expansion, unregulated urbanization and reliance on natural resources (GOP, 2022). The success of a country's agricultural sector has a significant influence on its overall economic prosperity. Agricultural techniques are extensively employed in many parts of the globe, allowing farmers to increase agricultural production by using locally available resources (Rehman et al., 2015). The agricultural industry makes significant contributions to the economic success of established economies, as well as to the growth of emerging economies. However, the majority of crops are sensitive to the climatic conditions of their particular regions (Gornall et al., 2010). Climate change has recently gained significant attention as an emerging threat that, when combined with other proven stressors, would have an impact on agricultural productivity in terms of size, scope, geographical and temporal repercussions. This involves tolerating changes in mean temperature or typical precipitation levels. The analysis concludes that in the absence of effective steps to reduce long-term climate change and climatic unpredictability, diversified and location-specific consequences will become more prevalent. Certain characteristics have problems, while others offer benefits. Sometimes the repercussions of particular acts may not appear immediately, allowing producers and policymakers time to make required preparations. The variance in willingness and resources among

economies will produce a wide range of outcomes (Arunrat et al., 2021; Kurukulasuriya & Rosenthal, 2013; Tang, 2019).

Climate change has major implications for agriculture productivity. The farming sector is critical to every country's long-term development and wealth, and it is currently under severe threat from global climate change. Climate change's most evident consequences on agricultural output include weather changes, changing precipitation patterns, storms and hunger. Technological developments in developing economies are expected to mitigate the effects of climate change on crop production. Researchers observed that changes in climate patterns and rising temperatures had a major influence on agricultural production. Climate change has a significant impact on developing countries, while being a global concern. These economies are very vulnerable to and underprepared to deal with the consequences of climate change (Ali et al., 2017; Arunrat, Sereenonchai, Chaowiwat, & Wang, 2022; Chandio et al., 2020; Zhao et al., 2017). The uncontrolled release of greenhouse gases such as fluorinated compounds, carbon dioxide, methane and nitrous oxide causes substantial changes in weather patterns and temperatures, as well as negative consequences on water and land resources, resulting in floods and droughts. Although climate change is a global concern, developing economies are more sensitive to its effects since they have fewer resources and are less equipped to cope with it. The majority of enterprises in developing nations are based on agriculture, which makes them especially sensitive to environmental changes. Climate change is affecting agricultural production in a variety of ways, including rainfall and weather variations, storms, droughts and other negative impacts on water and soil resources (Abbas et al., 2022; Bandara & Cai, 2014; Mendelsohn, 2014).

Increasing global warming is associated with increasingly frequent severe weather occurrences, which are considered as a worldwide abnormality with potentially disastrous consequences. People who live in agricultural regions in emerging economies are more likely to feel the effects of climate change. Many people in South Asian countries depend on the agricultural industry, which is constructed on farmland, rendering them particularly sensitive to the effects of global warming. The ramifications for their cultures, economies and ecosystems are catastrophic (Ahmed & Schmitz, 2011; Calzadilla et al., 2014). Global warming, on the other hand, is one of the most pressing challenges this century. It is characterized as a significant change in the long-term average value of a meteorological element, such as precipitation or temperature. Human activities have altered the global ecosystem, resulting in considerable temperature changes over the last several decades (IPCC, 2007). The production, distribution and consumption of food by humans are significant contributors to global warming and other significant environmental changes at both global and regional levels. Changes in the carbon and nitrogen cycles, biodiversity, ground cover and sediments are some instances of these natural fluctuations. While some locations may benefit from climate change, there is growing concern that global and climatic trends may provide challenges for rising economies in achieving food security. The reason for this is the generally predicted adverse effects on agricultural yield, especially in tropical and temperate regions (Fischer et al., 2001).

Climate change is exacerbating the challenges faced by farmers in meeting the growing food demands of an increasing global population. There is evidence suggesting that agricultural production may decrease in the next decades due to climate change, even if the specific impacts of future climate projections remain uncertain. Temperature, moisture and greenhouse gas emissions are the primary climatic elements that significantly affect insect populations, soil quality, water availability and several other aspects of life in a detrimental manner. Climate change in regions with food scarcity is jeopardizing agricultural productivity, especially in Asian nations. Future weather projections predict significant temperature increases, heightened unpredictability in the intensity of rainfall and changes in the general climatic pattern. This investigation examines the impact of agricultural land, fertiliser inputs per unit of agricultural land, rainfall and temperature on Pakistan's cereal yields within an integrated framework. This is done due to the difficulties that have arisen in Pakistan's agricultural production as a result of climate change, as well as the established tactics to adapt to these problems. Multiple researches have analysed the crossings by using time series and panel data. However, the authors have not seen any prior studies that have used the QARDL model to precisely ascertain the short- and long-term linkages for Pakistan. Therefore, within the context of Pakistan, this research has the capability to provide essential policy interventions that may be used to develop a comprehensive strategy for attaining sustainable agricultural production in Pakistan. These connections are situated within the context of Pakistan. Figure 1 is illustrating the crops production and annual carbonization scenario in Pakistan during the period of 1980 through 2020.

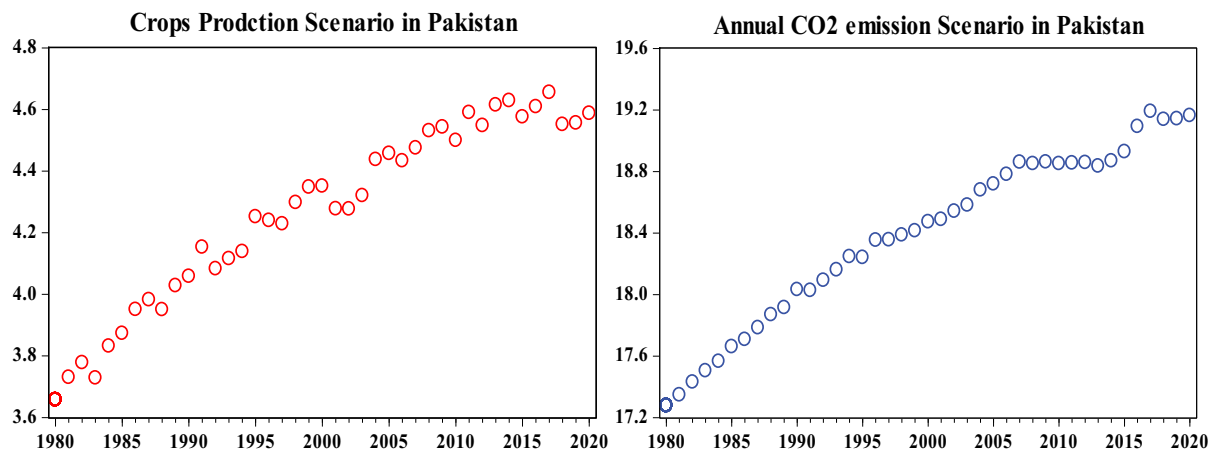


Figure 1. Crops production and annual CO₂ emission scenario in Pakistan (1980–2020).

The paper is structured as specified: in the [section 2](#), a comprehensive literature review is presented on the topic of the interaction between the climatic change and agricultural production. The data collection and the methodology are presented in [section 3](#). The empirical findings and discussion are presented in [Section 4](#), and the concluding remarks are brought to a close in the [Section 5](#), which also contains the policy suggestions.

2. Comprehensive literature review

One of the most important aspects of the global warming is the impact of climate change on agriculture. This is because agriculture is a particularly vulnerable sector of the economy, especially in emerging and transitional economies.

Climate variations, both in terms of geographical location and timing, have a substantial influence on agricultural productivity. The efficiency of all crops is directly correlated with the success of species, which is in turn dependent on climatic conditions. The agricultural output may be positively or negatively impacted by changes in production circumstances resulting from fluctuating weather conditions. Agriculture is essential for human life since it supplies sustenance, livestock feed, textiles and fuel. However, the management of farms also has an influence on other essential ecological processes, like the availability of land and the conservation of clean water (Foley et al., 2011; Lobell et al., 2008). The escalating temperature, alterations in the environment, elevated sea levels and heightened pollution of land and water pose significant obstacles in effectively addressing the mounting demands resulting from the growing need for food and water. To address these challenges, we need to focus on strengthening resilience, enhancing adaptability and building strong food systems that can gradually reduce the effects of climate change through the implementation of new technologies, systems and policies (Anwar et al., 2013; Godfray et al., 2010; Howden et al., 2007). If adequate actions are not implemented to tackle the difficulties posed by increasing temperatures and the frequency of severe weather occurrences, it is expected that the benefits gained from improvements in management and technology would be reduced due to declines in agricultural and livestock productivity. This remains applicable even if those issues are resolved. Furthermore, global warming poses a threat to the productivity of agricultural systems worldwide, and it is expected that climate change will affect many natural processes (Lobell & Gourdji, 2012).

Although increasing productivity is often mentioned as a means to meet investors' need for continuous growth, current evidence suggests that humans have not yet reached the levels of productivity required to fulfil this objective. The complexity of this problem has been exacerbated by the significant decrease in both the fecundity and accessibility of land appropriate for cultivating such commodities. This tendency is expected to continue due to the current agricultural plan. Addressing the effects of climate change on agricultural output is essential for ensuring food security, according to experts (Ray et al., 2013; Tripathi et al., 2016). The global food supply is highly reliant on a small number of events. These crops are cultivated with

the aim of optimizing yield despite limited variations in climate. Moreover, contemporary food security is achieved by the use of significant chemical manufacture. Large agricultural fields are well known for their significant need on synthetic fertilisers and pesticides in order to maintain consistent yields from one season to the subsequent. In the long term, it will result in worldwide transformation. The broad use of modern agricultural technology is necessary in most industrialized countries to provide food security for a growing population and to maintain financial stability in the farming industry. While the negative impact of technology-based grain production systems on the environment has been recognized for many years, the harmful effect of agriculture on the ecosystem has only recently gained significant attention (Kashyap et al., 2017; Kukal & Irmak, 2018; Pareek et al., 2020).

Human activities are responsible for climate change and the resulting unpredictability. The persistence of droughts and storms poses an on-going threat to the existence of the global population, which heavily depends on the land for their fundamental needs. Droughts, floods, heat waves, forest fires and earthquakes are examples of extreme events that may adversely affect the global economy. While earthquakes, tsunamis and volcanic eruptions are not classified as meteorological occurrences, they may nonetheless have an impact on the composition of the atmosphere. Consequently, it is anticipated that there would be a rise in weather-related disasters (Bhattacharya, 2019). Agriculture crops and animals in both wild and farm settings must adapt to changing conditions faster than they were originally intended to adapt. Weather and moisture fluctuations cause communities to migrate, invade and possibly go extinct. Meanwhile, natural calamities such as droughts and storms are lowering agricultural productivity throughout the globe, resulting in declining food supplies. All climate predictions anticipate a decline in global agricultural production. Lower areas will bear the brunt of climate change's impact on agricultural production (IPCC, 2018; Karavolias et al., 2021; Nunez et al., 2019). Natural ecological resilience and responsive actions taken by farmers and other partners will both help to mitigate the overall impact of climate change on human well-being. Agricultural production is heavily reliant on climatic conditions, making it especially sensitive to the effects of global warming (Chen et al., 2016; Fisher et al., 2012).

Global markets, agricultural input and output values, and agricultural policies influencing producer behaviours via enabling tools and legislation are critical to agricultural production development (Mittenzwei et al., 2017). Agriculture and the environment are inextricably linked, with several related factors influencing each other. The agricultural business contributes considerably to the emission of greenhouse gases, which have a warming effect on the Earth's climate. The increasing amounts of greenhouse gases in the atmosphere, along with rising temperatures and changes in precipitation patterns, have a considerable impact on the quantity and quality of agricultural productivity. These elements have an impact on the natural environment in which agriculture takes place (Agovino et al., 2019). Climate change will affect the main economic sector in a variety of ways, including changes in agriculture production patterns, land usage, migration and employment. The consequent transfer of human affluence will have real-world implications for the economy. As part of this process, the costs and related duties of preventative and adaptation efforts, as well as investments, will be shared across socioeconomic groups (Dietz & Atkinson, 2010). Climate change projections are critical for analysing the impact of global warming on the environment, industry and communities, as well as providing post-adaptation policy options. Agriculture is inextricably related to the survival of human civilization and its continuing expansion as a source of livelihood. Climate change has both positive and negative consequences on people at different levels and dimensions (Naab & Koranteng, 2012).

The implications of global transformation are substantial. Climate irregularities are becoming prevalent, with alterations in weather and transportation patterns, a rise in temperature and an elevation in CO₂ levels. The current state of agricultural production practices and their anticipated future in both established and developing countries have several implications for achieving desired outcomes. The impact of climate change on agricultural productivity is a significant cause for worry among industry experts and policymakers. The urgency of this challenge is growing due to the impact of global warming on agricultural productivity and the generation of essential resources (Zaied, 2013). The phenomenon of global warming is not a new development. The warming of the earth's surface and atmosphere is causing many consequences such as sea level rise due to melting glaciers, hurricanes, stronger winds, hailstorms, pollution, earthquakes and floods. These indicators together demonstrate the undeniable reality and occurrence of climate change. This phenomenon may arise spontaneously, although it is often intensified by human activities. The anticipated consequences of climate change have already increased in various countries as a result of human activity,

including population expansion, fast urbanization, intensified industrialization, usage of advanced technological innovation, economic development, transportation, construction and deforestation. As a result, these economies are already experiencing the effects of climate change (Ahmad et al., 2011; Kumar & Gautam, 2014). Climate change has intricate and diverse effects on agricultural productivity, which are influenced by characteristics including size, severity and the presence or absence of natural farming limitations in a particular region. The impact of temperature on phenology and other temperature-dependent metabolic processes, such as maintenance, which affect the accumulation of net biomass, are two instances of the well-recognized and substantial impacts of climate change variables and extreme weather events on crops. Increasing atmospheric CO₂ levels may enhance photosynthetic activity and water usage efficiency in plants. However, the extent of these responses is expected to vary significantly depending on the specific cultivars and environments (Eitzinger et al., 2013; Fuhrer, 2003).

Climate change poses a threat to agricultural productivity. The enhanced accuracy in forecasting future climate impacts on crucial global agricultural production has significant implications for developing cultivars and local resilience methods to ensure the future food supply for the world's growing population. The diminished effectiveness is a direct consequence of the increasing temperature, and it is expected to have significant and adverse repercussions for crop yield. In this work, we have examined the effects of agricultural land, fertiliser inputs per unit of agricultural land, rainfall and temperature on cereal yields in Pakistan by employing the QARDL approach. As a consequence, the proposed hypotheses of this investigation are enumerated as: **H1**: Climate change is positively impacted the yields production; **H2**: Agricultural land used for the crops productivity significantly increases the cereal yields; and **H3**: Fertiliser inputs per unit of agricultural land affect the cereal yields positively.

3. Methods and data

3.1. Data sources

The primary objective of this study was to assess the impact of agricultural land, fertiliser inputs per unit of agricultural land, rainfall and temperature on cereal yields in Pakistan. Data on dependent and independent variables is obtained from two primary sources, namely WDI and Our World in Data. For all variables, the units of measurements for cereal yields are (tonnes per hectare) as follows: agricultural land (% of land area), fertiliser inputs per unit of agricultural land (kilograms per hectare of agricultural land), rainfall (mm) and temperature (Celsius), respectively. Data on all variables have been collected from 1980 through 2020. Figure 2 depicts the trends of the data series for all variables for the selected time period. Additionally, Figure 3 displays the research variables and methodological framework.

3.2. Model for the variables

Several studies have been performed to investigate the correlation between climate change and agricultural production in various geographic regions. Aryal et al. (2020) examined the influence of climate change on crop yields and explored the primary strategies that the agricultural industry might use to adjust to climate change. One of the main findings was that there are techniques for farming that may assist in adapting to climate change in agriculture. However, the present regulatory structure for adopting and spreading these technological solutions has to be reinforced. Furthermore, Warsame et al. (2021) examined the influence of climate change on agricultural output by using the ARDL technique, specifically focusing on the variables rainfall, temperature and CO₂ emissions. The empirical findings demonstrated that long-term rainfall positively influenced crop yields but negatively affected crop yields in the short term. Conversely, temperature had a detrimental effect on crop output in both the long and short term. Ahsan et al. (2020) explored the influence of CO₂ emissions, energy consumption, cultivated land area and labour on cereal crop output in Pakistan. The research findings indicated that cereal crop output was positively influenced by CO₂ emissions, energy consumption, cultivated land area and workforce. Ali et al. (2023) demonstrated that cereal crops, such as wheat, rice and maize, have a crucial function in supplying food for the world's population and are especially significant as staple foods in Pakistan. Nevertheless, the cultivation of these fundamental cereal crops in Pakistan has been

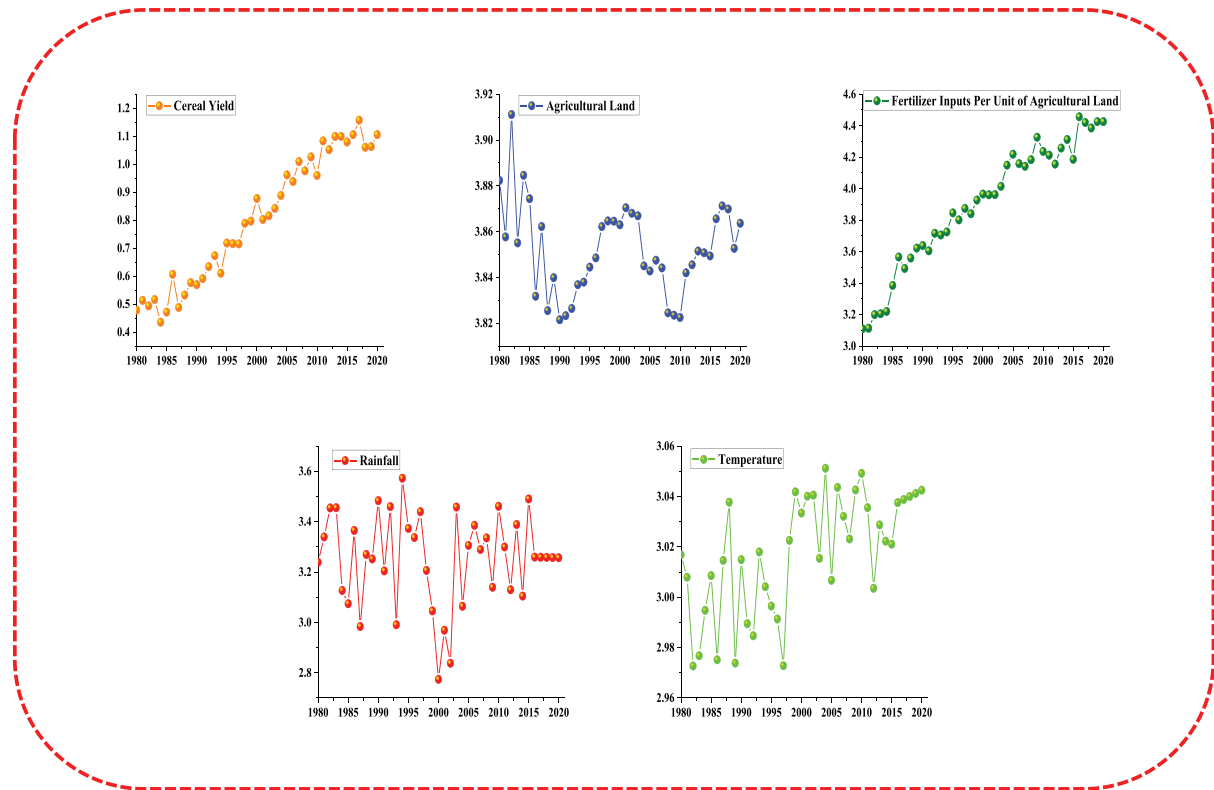


Figure 2. Time sequence annual tendency of variables.

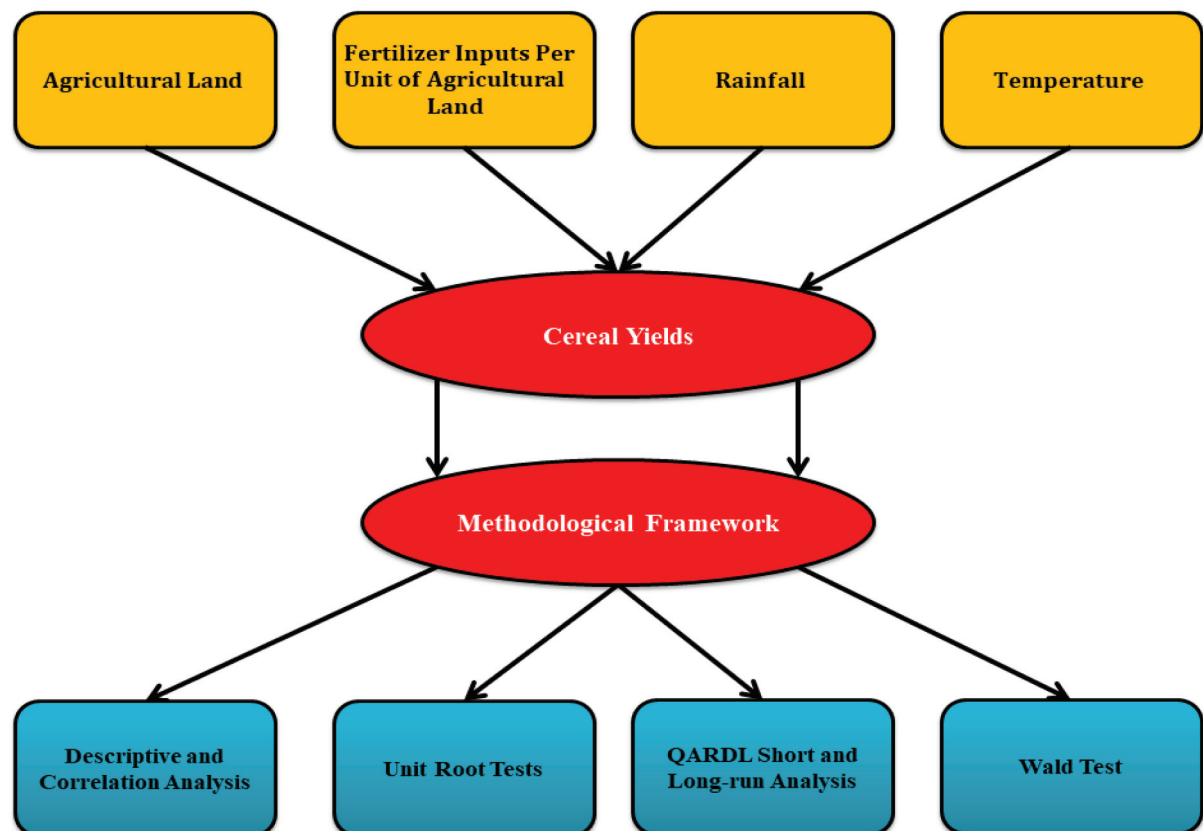


Figure 3. Study mechanism and methodological framework.

negatively impacted by significant changes in climatic conditions and an assortment of other variables. However, the research conducted by Kar et al. (2024) indicated that climate change would have detrimental effects on agricultural output and food security on a worldwide scale. The sudden fluctuations in climatic factors may impact the output of crops, efficiency, livestock, dairy and fisheries, thereby having a negative impact on food security and the worldwide economy. But the current study aimed to examine the impact of agricultural land, fertiliser inputs per unit of agricultural land, rainfall and temperature on cereal yields. To reveal the connection between variables, the following model can be stated:

$$\text{Cereal Yields} = f \left(\begin{matrix} \text{Agricultural Land, Fertilizer Inputs Per Unit of Agricultural Land,} \\ \text{Rainfall, Temperature} \end{matrix} \right) \quad (1)$$

In order to interact the nexus of variables including cereal yields, fertiliser inputs per unit of agricultural land, rainfall and temperature in Pakistan, this investigation used time series data varies from 1980 to 2020. Thus, the econometric form of the above function can be as follows:

$$CY_t = \tau_0 + \tau_1 LA + \tau_2 FL + \tau_3 RF + \tau_4 TE + u_t \quad (2)$$

Where CY indicates the cereal yields, LA is used for agricultural land, FL indicates fertiliser inputs per unit of agricultural land, RF indicates the rainfall, and TE is for the temperature; where u_t is the residual term in Equation (2).

3.3. Econometric procedure

Using the standard ADF testing approach described by Dickey and Fuller (1979), we identified the integration order for the given prescription. The issue of serial correlation is addressed by the Augmented Dickey–Fuller (ADF) test, which incorporates a higher order regression process into the model. The ADF test assumes that the variables are level-stationary only if they do not have a unit root and that they have a unit root if there is one present. The ADF test can be expressed mathematically as

$$\Delta y_t = \theta + \lambda T + \rho y_{t-1} + \sum_{i=1}^k \alpha_p \Delta y_{t-i} + u_t \quad (3)$$

In this investigation, we also employed the Phillips and Perron unit root testing (Phillips & Perron, 1988). Although it varies from ADF in that it does not allow for serial correlation in test regression, it nonetheless produces reliable findings when dealing with heteroscedasticity. The estimated equation for this test is as follows:

$$\Delta y_t = \theta + \rho y_{t-1} + u_t \quad (4)$$

Cho et al. (2015) created an enhanced version of ARDL called QARDL, which we employed for a variety of purposes to investigate the cointegration connection among both endogenous and exogenous variables. In some cases, this strategy allows for distribution-based asymmetry because the parameters may change depending on where the dependent variable is located within the restrictive dissemination. Furthermore, unlike NADRL, where the nonlinearity threshold is zero (Shin et al., 2014), QARDL intensity is determined using data-driven techniques, and this model surpasses all of them. The ARDL fundamental equation is

$$\begin{aligned} \Delta CY_t = & \beta_0 + \beta_1 CY_{t-1} + \beta_2 LA_{t-1} + \beta_3 FL_{t-1} + \beta_4 RF_{t-1} + \beta_5 TE_{t-1} + \sum_{i=1}^n \gamma_{1i} \Delta CY_{t-i} + \sum_{i=0}^p \gamma_{2i} \Delta LA_{t-i} \\ & + \sum_{i=0}^q \gamma_{3i} \Delta FL_{t-i} + \sum_{i=0}^r \gamma_{4i} \Delta RF_{t-i} + \sum_{i=0}^s \gamma_{5i} \Delta TE_{t-i} + u_t \end{aligned} \quad (5)$$

Where u_t indicates $CY_t - E[CY_t / \sigma_t - 1]$, and $\sigma_t - 1$ is the smallest σ -field generated by $\{CY_t, LA_t, FL_t, RF_t, TE_t, CY_{t-1}, LA_{t-1}, FL_{t-1}, RF_{t-1}, TE_{t-1}\}$. Furthermore, β shows the long-run effects, while γ show the dynamics in the short term. Equation (5) may be expressed in quantile form as follows:

$$\begin{aligned} QCY_t = & \alpha(\tau) + \sum_{i=1}^n \gamma_{1i}(\tau) \Delta CY_{t-i} + \sum_{i=0}^p \gamma_{2i}(\tau) \Delta LA_{t-i} + \sum_{i=0}^q \gamma_{3i}(\tau) \Delta FL_{t-i} + \sum_{i=0}^r \gamma_{4i}(\tau) \Delta RF_{t-i} \\ & + \sum_{i=0}^s \gamma_{5i}(\tau) \Delta TE_{t-i} + \beta_1(\tau) CY_{t-1} + \beta_2(\tau) LA_{t-1} + \beta_3(\tau) FL_{t-1} + \beta_4(\tau) RF_{t-1} + \beta_5(\tau) TE_{t-1} + u_t(\tau) \end{aligned} \quad (6)$$

In Equation (6), $u_t(\tau) = CY_t - Q_{CYt}(\frac{\tau}{u_{t-1}})$ that is proposed by the authors Kim and White (2003); where $0 < \tau < 1$ indicates quantile values.

By following Equation (6), this may be used to uncover the ECM version of the QARDL model:

$$QCY_t = a(\tau) + \sum_{i=1}^n \gamma_{1i}(\tau) \Delta CY_{t-i} + \sum_{i=0}^p \gamma_{2i}(\tau) \Delta LA_{t-i} + \sum_{i=0}^q \gamma_{3i}(\tau) \Delta FL_{t-i} + \sum_{i=0}^r \gamma_{4i}(\tau) \Delta RF_{t-i} + \sum_{i=0}^s \gamma_{5i}(\tau) \Delta TE_{t-i} + \beta_1(\tau) CY_{t-1} + \beta_2(\tau) LA_{t-1} + \beta_3(\tau) FL_{t-1} + \beta_4(\tau) RF_{t-1} + \beta_5(\tau) TE_{t-1} + u_t(\tau) \quad (7)$$

The effects of the asymmetrical integrations across different quantiles have been examined using the Wald test in relation to both the long- and short-term outcomes.

4. Empirical findings and discussion

Prior to conducting the empirical analysis in this study, we performed a descriptive analysis to examine the distribution and structure of the data. The results of this analysis are provided in Table 1. All variables, with the exception of TE and LA, exhibited considerable deviations from the mean value. Furthermore, each variable exhibited a distribution that was negatively skewed. Except RF, all variables have a kurtosis value below 3, indicating that they are not normally distributed.

Table 2 demonstrates the correlation between agricultural land, fertiliser inputs per unit of agricultural land, rainfall and temperature, and cereal yields. The findings suggest that there is an interaction between all parameters.

The ARDL model is expanded by incorporating QARDL in this study, which possesses nearly identical prerequisites with ARDL. In order to prevent the inclusion of our model's variables in the second order, we conduct subsequent validation and confirm stationarity before using QARDL. This study employs both the Augmented Dickey–Fuller (ADF) and Phillips–Perron tests to provide proof of the time-varying characteristics of the series. A stationarity test was conducted on all variables, and the results of the tests are reported in Table 3. None of the independent variables were found to exhibit stability at the second level of variation.

Table 4 displays the estimated values of the long-term, short-term and error-correction variables in the QARDL model. According to Cho et al. (2015), the error-correction element is substantial, except for the first quantile. Furthermore, the element has a negative correlation with every quantile. This indicates that the variables are converging towards a stable equilibrium over an extended period of time. However, the rate at which they adjust differs based on the quantiles. The constant's value can be disregarded when analysing high quantile values due to its insignificance.

The coefficient of agricultural land over the quantiles indicates that land has positively impacted on cereal yields in both short and long run. Increasing the land under cultivation can lead to an upsurge in the total area of land available for cereal production. This, in turn, can increase the overall cereal productivity in the short run, as more land is available to grow crops. Additionally, the increased cultivation of land can lead to higher agricultural productivity, a consequence of the fact that producers are able to generate more sustenance using the same quantity of resources (such as labour and fertiliser). This increase in productivity can further boost cereal production in the short run. However, in the long run, increasing the agricultural

Table 1. Descriptive analysis.

Variables	Mean	Max.	Min.	S.D	Skew.	Kurt.
CY	0.802	1.157	0.434	0.230	−0.055	2.469
LA	16.337	16.408	16.172	0.080	−0.096	2.168
FL	3.895	4.456	3.109	0.396	−0.475	2.369
RF	3.253	3.572	2.773	0.189	−0.663	3.119
TE	3.017	3.051	2.972	0.023	−0.519	2.025

Table 2. Correlation among the variables.

	CY	LA	FL	RF	TE
CY	1.000	−0.122	0.957	−0.033	0.625
LA	−0.122	1.000	−0.226	−0.235	−0.046
FL	0.957	−0.226	1.000	−0.050	0.637
RF	−0.033	−0.235	−0.050	1.000	−0.365
TE	0.625	−0.046	0.637	−0.365	1.000

Table 3. Unit root test.

[Variables]	[ADF test]		[Phillips-Perron test]	
	I(0)	I(1)	I(0)	I(1)
CY	-0.568 (0.860)	-10.734*** (0.000)	-0.432 (0.767)	-8.521*** (0.000)
LA	2.010 (0.988)	-7.030*** (0.000)	1.622 (0.578)	-5.695*** (0.000)
FL	-2.114 (0.229)	-6.663*** (0.000)	-2.354* (0.091)	-7.019*** (0.000)
RF	-3.007** (0.043)	-13.234*** (0.000)	-3.797** (0.049)	-8.088*** (0.000)
TE	-5.859*** (0.000)	-8.859*** (0.000)	-6.160*** (0.000)	-3.017** (0.046)

*, **, *** show at 1%, 5% and 10% level of significance.

Table 4. Outcomes of QARDL estimates.

Variables	Long-run estimates					Short-run estimates				
	C	LA	FL	RF	TE	D(LA)	D(FL)	D(RF)	D(TE)	ECM(-1)
0.1	-1.638 (0.364)	0.727 (0.243)	0.452* (0.000)	-0.108*** (0.062)	0.169 (0.630)	0.251 (0.753)	0.459* (0.003)	0.004 (0.942)	0.452 (0.444)	-0.011 (0.769)
0.2	-1.647 (0.321)	0.821*** (0.061)	0.436* (0.000)	-0.071 (0.131)	0.240 (0.695)	1.158 (0.198)	0.337 (0.114)	0.001 (0.653)	-0.241 (0.702)	-0.399** (0.024)
0.3	-2.323** (0.028)	0.905* (0.000)	0.414* (0.000)	-0.063* (0.009)	0.108** (0.015)	1.216* (0.009)	0.317** (0.019)	-0.069** (0.024)	-0.218 (0.433)	-0.753* (0.000)
0.4	-1.554** (0.023)	1.116* (0.002)	0.354* (0.000)	-0.085** (0.036)	0.235** (0.029)	1.211* (0.010)	0.326* (0.010)	-0.058** (0.038)	-0.141 (0.609)	-0.709* (0.000)
0.5	-2.909** (0.032)	1.130* (0.003)	0.389* (0.000)	-0.110*** (0.064)	0.315* (0.000)	0.868** (0.012)	0.323** (0.019)	-0.046*** (0.068)	-0.210 (0.331)	-0.567** (0.026)
0.6	-1.984 (0.134)	1.552** (0.015)	0.232*** (0.075)	-0.027 (0.760)	0.040*** (0.064)	0.804** (0.034)	0.240*** (0.064)	-0.054** (0.042)	-0.334* (0.009)	-0.317 (0.400)
0.7	-1.776** (0.032)	1.304*** (0.021)	0.267 (0.212)	0.032 (0.732)	0.748 (0.462)	0.882** (0.021)	0.251** (0.050)	-0.057** (0.041)	-0.285* (0.003)	-0.270*** (0.095)
0.8	-1.144*** (0.077)	1.181 (0.159)	0.242 (0.159)	0.109 (0.498)	1.822 (0.291)	1.299** (0.016)	0.105 (0.345)	-0.109** (0.030)	-0.078*** (0.077)	-0.213*** (0.058)
0.9	-1.824 (0.831)	1.100 (0.137)	0.272*** (0.093)	0.151 (0.376)	2.101 (0.553)	1.443* (0.009)	0.105 (0.264)	-0.102** (0.032)	-0.017*** (0.098)	-0.346* (0.000)

*, **, *** show at 1%, 5% and 10% levels of significance.

land can also lead to improvements in soil quality and fertility. Farmers who plan to keep their property in production for several decades typically make investments in soil conservation techniques like crop rotation and the use of organic fertilisers. This, in turn, can increase the long-term productivity of the land, leading to sustained increases in cereal production over time. However, it is imperative to indicate that the effect of increasing land under cultivation on cereal production may diminish at higher quantiles. This is because, as more land is cultivated, the marginal returns to additional cultivation may decrease. In other words, the increase in cereal production may not be as great for each additional unit of land that is cultivated as it was for previous units. Therefore, while increasing the land under cultivation can have an imperative influence on cereal production, it is important to consider the optimal level of cultivation that maximizes the benefits of the land. Most people around the world rely on cereals like wheat, maize and rice for their daily nutrition. Productivity growth is often cited as a solution to keeping up with rising consumer demand, but actual numbers demonstrate that we're still far from where we need to be. The problem is compounded by the fact that traditional agricultural methods have severely reduced the amount of land that is appropriate for cultivating these goods and are expected to reduce the amount of land even more in the future. In order to achieve food security, it is crucial to address concerns such as global climate change, which has the capacity to reduce agricultural production. Climate change can have significant impacts on grain production, primarily due to increased heat and water stress. Furthermore, climate change can have an indirect impact on grain production by altering the availability of fertilisers, increasing the occurrence of diseases and influencing the presence of insects (Hawkesford et al., 2013; Molotoks et al., 2021; Porter et al., 2014). Agricultural and food production can be impacted by a wide variety of external influences. Assessing the effects of climate change on agriculture is difficult because of the intricate connections among various elements within agricultural systems. The impact of climate on food production is a crucial factor in

determining the agricultural techniques employed at the local and regional levels. Fluctuations in atmospheric carbon dioxide concentrations, along with the associated alterations in weather patterns and precipitation trends, might potentially exert a substantial influence on crop productivity. According to experts, farming has an impact on the environment by altering the output of harmful gases and the utilization of land. The resilience of crops to withstand the effects of climate change will be pivotal in guaranteeing worldwide food security in the coming decades (K. F. Ahmed et al., 2015).

Results show that fertiliser inputs per unit of agricultural land affects cereal yields in Pakistan positively in both the long run and short run; however, the effectiveness reduces at higher quantiles. Fertilisers provide essential nutrients to crops that are necessary for their growth. The usage of fertilisers can help to upsurge the yields of cereal crops in the short run by ensuring that crops have access to the necessary nutrients. This can be particularly important in areas where soil fertility is low or where crops are grown intensively. In the long run, the use of fertilisers can also lead to improvements in soil fertility. As crops absorb nutrients from the soil, the soil can become depleted over time. Fertilisers can help to replenish the soil's nutrient levels and maintain its fertility, which can lead to sustained increases in cereal production over time. However, the effect of increasing fertiliser use on cereal production may diminish at higher levels of fertiliser use. This is because excessive use of fertilisers can lead to environmental problems such as soil erosion, groundwater pollution and nutrient imbalances. Additionally, as the amount of fertiliser used increases, the marginal returns to additional fertiliser use may decrease. Therefore, while increasing fertiliser use can have a constructive consequence on cereal production, it is imperative to deliberate the optimal level of fertiliser use that maximizes the benefits while minimizing the negative environmental impacts. In contrast, the growth in soil N_2O emissions has become a serious concern in recent years, limiting the use of nitrogen fertilisers to improve agricultural production and sustainability (Arunrat, Sereenonchai, Chaowiwat, Wang, & Hatano, 2022; Kotuš et al., 2022).

The coefficient of rainfall indicates that in the long run, low to intermediate level of rainfall is affecting cereal production negatively, while the effect of rainfall at higher quantile is insignificant. However, in the short run, low level of rainfall has an insignificant effect on cereal production whereas rainfall at median to higher quantile affects cereal production negatively. Rainfall coming out in the low-to-medium range has the potential to negatively affect crop production in Pakistan over the long term. This is because prolonged periods of low rainfall can lead to soil moisture stress, which can affect the growth of crops over time. Additionally, low rainfall can reduce the availability of water for irrigation, which can further limit crop growth and yield. Conversely, the long-term effect of abundant rainfall on cereal production in Pakistan is negligible. This is because while excess rainfall can provide water for crop growth, it can also lead to waterlogging, soil erosion and other negative environmental impacts that can ultimately limit cereal production. In the short run, the impact of rainfall on cereal production can be different. In the near term, low rainfall may not have much of an effect on cereal yields because cereals may still have access to enough wetness for growth and development. However, moderate-to-high levels of rainfall in the short run can negatively impact cereal production, as excessive rainfall can lead to flooding, soil erosion and other environmental problems that can damage crops and reduce yields.

The influence of temperature on cereal productivity in Pakistan can vary depending on the specific temperature level and whether the analysis is for the short run or long run. In the long run, temperature at low quantiles is affecting cereal production insignificantly, while impact of moderate temperature has an imperative influence on cereal production and at higher quantiles; temperature has an insignificant impact on dependent variable. Further, in the short run, low-to-moderate temperature has an insignificant effect on cereal production, while high level of temperature negatively affects cereal production. When deciding on how to adapt to climate change, it is vital to understand the connection between a variety of environmental characteristics and agricultural production. Separating and quantifying the impact of various environmental conditions on agricultural production is required to put these strategies into action. For example, adjusting to a change in weather requires a different set of procedures than adjusting to a change in precipitation. According investigations, even slight temperature changes can have a significant impact on agricultural yields, and locations for plants experiencing heat stress have been identified around the world (Challinor et al., 2014; Teixeira et al., 2013). Reduced greenhouse gas emissions from farms could make a significant contribution to climate change mitigation in the future. The effects of global warming on crops are severe. As a result, implementing more energy-efficient and green technologies is the single most effective way to

reduce pollution in farming environments. Future agricultural growth will need the production and seeding of green agriculture, which will become a pattern useful in achieving sustainable green and low carbon goals (Cui et al., 2021; Elahi et al., 2022; van Veelen, 2021).

Low temperatures may not have a major effect on Pakistan's grain output in the long term. However, grain output can benefit from mild temperature because they support agricultural growth and development. This is because moderate temperatures can provide optimal conditions for crop growth, such as reducing heat stress and increasing photosynthesis rates. On the other hand, high levels of temperature in the long-run may not have an important impact on cereal production in Pakistan. This is because crops can adapt to higher temperatures over time through changes in their physiology and development. In the short run, low to moderate levels of temperature may not have a significant influence on cereal yields, as crops may still have access to enough heat for growth and development. However, high levels of temperature in the short-run can lead to heat stress in crops, which can cause wilting, reduced photosynthesis rates and reduced yield. Climate change presents a threat to agricultural productivity. To ensure global food security, it is crucial for agronomists, policymakers and crop growers to have a thorough knowledge of climate change, specifically regarding increased temperatures. Optimal conditions can greatly enhance crop growth. Elevated temperatures exert the most significant impact on plant physiological systems, including photosynthesis, transpiration, respiration and production. The decline in agricultural productivity is a significant cause for concern, and the increase in temperatures is a major factor contributing to the reduction in yields of crucial food crops. Rising temperatures have a detrimental impact on plants at every stage of their development, resulting in reduced crop yields. Most of the decline in agricultural productivity occurs during the reproductive phase, which is also the most susceptible stage of a plant's life cycle due to seed generation taking place at this time (Hein et al., 2021; Schauburger et al., 2017; Zhao et al., 2017). Crops are vulnerable to the effects of increasing atmospheric CO₂ levels, as well as fluctuations in temperature and precipitation. Climate models provide more accurate predictions of temperature variations in specific regions compared to fluctuations in precipitation. Among the predicted changes, temperature rises are the most probable factor that will negatively impact agricultural productivity (Anderson et al., 2020; Rosenzweig et al., 2014).

The findings of a Wald test conducted for the short and long term are reported in Table 5. The Wald test is a statistical technique used to evaluate distributional asymmetry by examining nonlinearities in both short- and long-term components (Cho et al., 2015). The results of the Wald test indicate the presence of asymmetric correlations between the dependent variable and all independent factors in the long term. In the short term, all independent variables, except for temperature, exhibit indications of nonlinearity. The Wald test's null hypothesis is rejected for the ECT parameter as well; therefore, we can draw the conclusion that there is asymmetry in the ECT term.

Moreover, Figures 4 and 5 depict the distinct representation of the long- and short-term constraints throughout the chosen quantiles. The comparison between static linear parameters and projected coefficients reveals a noticeable alteration in the coefficient values, providing evidence of the existence of asymmetric patterns in these variable coefficients. The computed values are presented in a vertical orientation, whereas the quantiles of 0.1, 0.3, ..., 0.9 are presented in a horizontal orientation on the graphs.

Table 5. Wald test results.

(Study variables)	(Wald-test)
ECT	4.208***
Long-run findings (Parameters)	
LA	5.890***
FL	3.048**
RF	3.499***
TE	2.934***
Short-run findings (Parameters)	
LA	1.916*
FL	2.022*
RF	5.133***
TE	1.156

*, **, *** show at 1%, 5% and 10% level of significance.

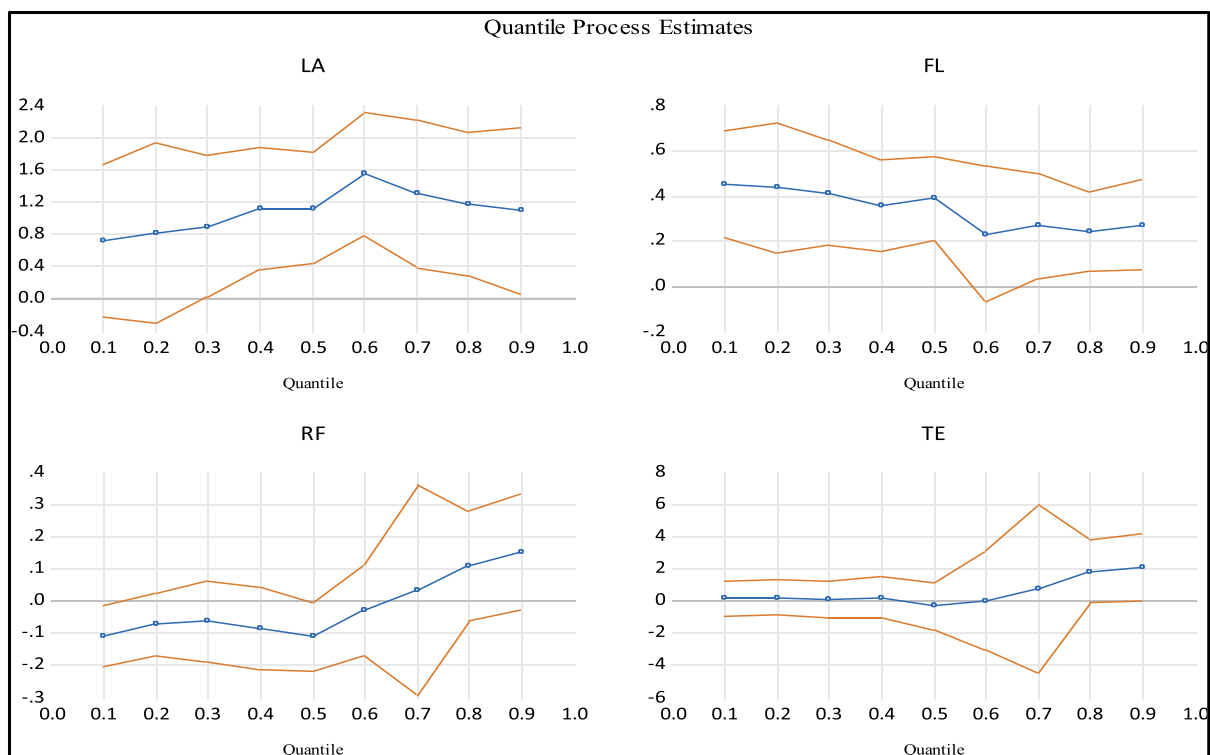


Figure 4. Long-term parameter dynamics across quantiles.

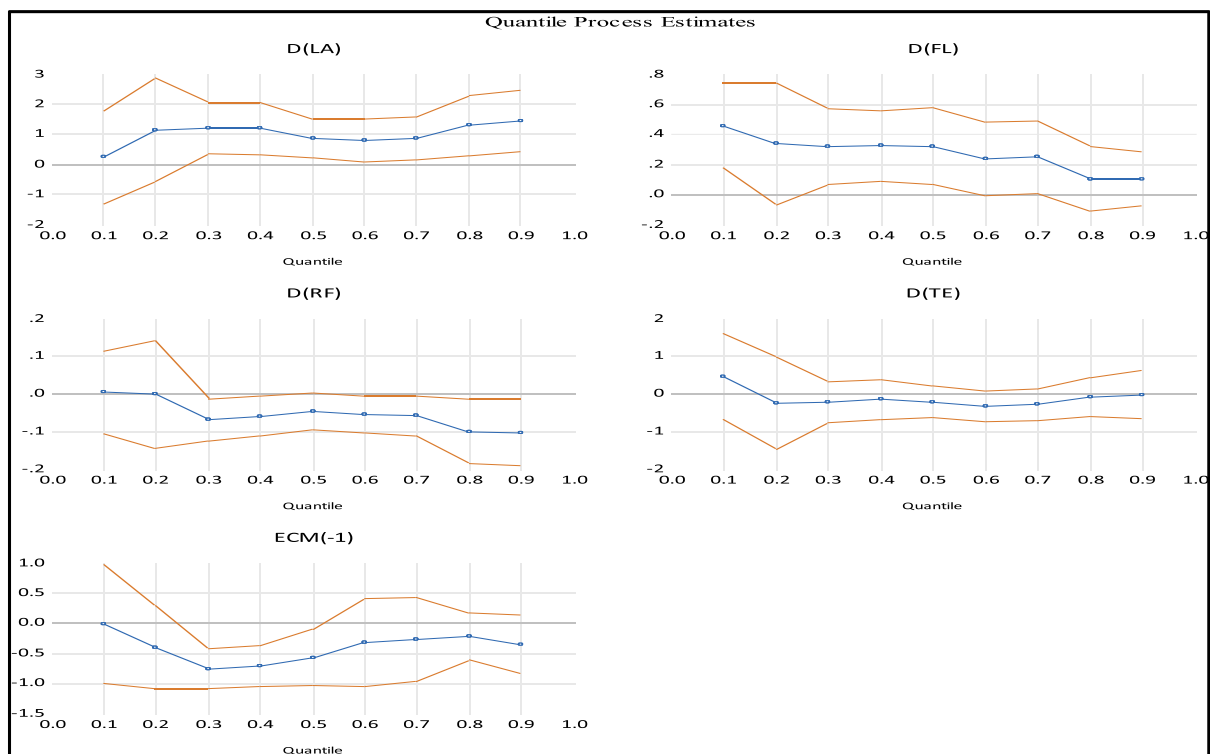


Figure 5. Short-term parameter dynamics across quantiles.

5. Conclusion and policy suggestions

The primary objective of this study was to investigate the influence of agricultural land, fertiliser inputs per unit of agricultural land, rainfall and temperature on cereal yields in Pakistan. The study employed the quantile autoregressive distributed lag (QARDL) method to analyse the impact of variables in both the short and long term. The findings uncover that agricultural land over the quantiles indicates that land has a constructive influence on cereal yields in both the short and long run. Fertiliser inputs per unit of agricultural land affect cereal yields positively in both short and long run; however, the effectiveness reduces at higher quantiles. Furthermore, rainfall indicates that in the long run, low to intermediate level of rainfall is affecting cereal production negatively, while the effect of rainfall at higher quantile is insignificant. Similarly, the effect of temperature on Pakistan's yields production can shift based on the temperature at which the investigation is conducted and whether it is a short- or long-term analysis.

5.1. Policy recommendations

The study concludes with a number of recommendations for improving farming output, site usage and peasant access to funding in order to raise food outputs. It is widely acknowledged that emerging economies expenditures on agriculture, insufficient funding for resilience measures, a worsening average environment and a higher likelihood of severe events make these economies more vulnerable to the impact of climate change compared to more developed countries. Due to the unavoidable nature and significant consequences of climate change, certain regions may experience irreparable damage to their arable land and water resources, leading to severe consequences for local food production. The poorest economies, which have fewer resources to deal with disasters, suffer the most from these losses. Although the global community has made progress towards reducing greenhouse gas emissions, resilience to climate change remains a critical problem that must be addressed in future negotiations. However, the weather plays a major role in farming output, which in turn affects global food sources. Agriculture is especially susceptible to climate change because local weather trends determine which goods and services can flourish in a particular region. Increases in average annual temperatures reduce production due to abbreviate the manufacturing cycle for many goods. In the end, how much of an effect global climatic change has on food security will rely on how well societies are prepared to deal with the situation and how quickly they can recoup. In order to mitigate the susceptibility of agriculture to climate change, it is imperative to effectively manage land, water and wildlife. In recognition of the importance of agriculture, the government encourages the implementation of inventive approaches to financial inclusion in the agricultural sector. This is done with the aim of boosting agricultural production and exports, which in turn stimulates economic growth by fostering rural development. In order to mitigate the impact of climate change on Pakistan's agricultural sector and food supply, it is imperative to undertake initiatives at the global, national, regional and local levels.

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