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FEEDING PAKISTAN'S FUTURE: ASSESSING VULNERABILITIES AND RESILIENCE OF FOOD SYSTEMS AMID CLIMATE SHIFTS

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ABSTRACT

Climate change is dangerous for food security in Pakistan due to its profound impact on agricultural production, especially wheat. The rising temperatures and storm rainfall can adversely affect crop yields and scatter water availability. Indeed, unpredictable weather events, such as floods or droughts, can disrupt farming, leading to food shortages. Addressing these challenges this study investigates the impact of climate change on food security in Pakistan for the data period 1991 to 2021. The results from the ARDL methodology demonstrate adverse effects of rainfall, temperature, and Co2 emission on wheat production whereas inflation exhibits a positive influence on wheat production. Findings show that storm rainfall, high temperatures, and more Co2 emissions substantially decrease wheat production, while high inflation and increase in agricultural technology increase wheat production. Therefore, the empirical analysis recommends the adoption of climate-resilient agriculture crops, a better water management system, the promotion of renewable energy in the agricultural sector, and the formulation of integrated policies for sustainable food production in the face of growing climatic risks

Keywords: Food-grain, Rainfall, Food Security, CO_2 emission, Inflation, Temperature, ARDL

INTRODUCTION

Climate change is recognized as one of the most reflective global challenges of the 21st century. It is driven primarily by the emission of greenhouse gases, resulting from human activities such as the burning of fossil fuels, deforestation, and industrial processes (Yoro et al., 2022). These emissions have led to a sustained increase in global temperatures, variations in weather patterns, and more frequent and severe climatic events (Iturbide., 2020). The consequences of these changes derailed various sectors of human society, with food security being a central concern. Food security, as defined by the Food and Agriculture Organization (FAO), includes the availability, accessibility, and utilization of food for individuals and communities (Rinninella., 2019;). Climate change has a crucial effect on global food security due to its far-reaching impacts on crop yields, livestock production, water availability, and overall food systems (Wheeler., 2015). Variations in temperature and rainfall patterns can disrupt agricultural production, making it challenging for nations to meet the dietary and nutritional needs of their populations. Food security is a pressing global concern, with millions of people facing challenges related to access to safe, sufficient, and nutritious food. According to the Food and Agriculture Organization (FAO), approximately 9% of the world's population (or over 690 million people) experienced undernourishment in 2019. This is compounded by the fact that one-third of all food produced globally, equivalent to 1.3 billion tons, is wasted annually, while at the same time, nearly 820 million people suffer from chronic hunger. In addition, the COVID-19 pandemic exacerbated food insecurity, pushing an estimated 150 million people into acute food insecurity in 2020 (Gul, A., et al

2023) The effects of climate change further exacerbate this issue, with unpredictable weather patterns and extreme events impacting crop yields and livestock production. These facts underscore the urgent need for comprehensive strategies to ensure food security, including improved food production, distribution, and sustainability, especially in the face of growing environmental challenges.

Traditionally, climate change has slight effects on global food production, but these effects are unequally distributed geographically. Most of the losses are suffered in lower-income countries, such as South Asia and Africa (Ali & Liu et al., 2017; Shabeer,& Rasul 2024a). These regions are involved in affluence agriculture and are not technically and financially strong enough to abate the adverse impacts of climate change. Pakistan, part of South Asia, is notably vulnerable to climate change effects due to its diverse geography, ranging from the Himalayan and Karakoram mountain ranges to fertile plains and arid regions. This geographical diversity exposes Pakistan to various climate-related challenges, contributing to a multifaceted challenge in ensuring food security. Additionally, the frequency of extreme weather events, such as floods and droughts, is higher in Pakistan. These events not only destroy crops but also lead to the displacement of communities, further exacerbating the challenge of maintaining a stable food supply (Shoaib et al., 2021; Shabeer & Rasul., 2024b). Given that a substantial portion of the population depends on agriculture for their livelihoods, climate change-induced disruptions in this sector have profound socio-economic implications, contributing to food insecurity (Farooq et al., 2022). Furthermore, the rising temperatures, a consequence of global climate change, pose a direct risk to crop yields and nutritional quality, adding another layer of complexity to the complex web of challenges faced by Pakistan in sustaining its food resources (Shabeer., 2022).

Although, Pakistan, is a developing and agricultural country. Grapples with the dual challenge of poverty and hunger, with 21% of its GDP dependent on the agricultural sector (Gul et al., 2022). The agriculture sector, employing 43% of the total workforce, remains a crucial source of income. Despite a 1.9% growth in population and is the fifth most populous country globally yet aims for food security by 2025 (Pakistan Economic Survey, 2021). This aligns with the UN Sustainable Development Goal of achieving zero hunger globally by 2030. While global efforts have lifted nearly 200 million people out of hunger since 1990-2010, Pakistan faces alarming challenges due to consistent climatic vulnerabilities. Since 2013, the country has witnessed five floods, affecting 35 million people, with the floods in 2010, 2013, 2015 and 2022 being the most severe. Pakistan ranks 40th in the Climate Risk Index for 2016, 77th overall, and 17th in the Pacific and Asian regions for food security (Khurshid & Abid 2024). The situation underscores the urgent need for resilient policies to address the impact of climate change on food security in Pakistan. Despite our agricultural prowess, Pakistan is ranked 164th in the Human Development Index (HDI) with an HDI score of 0.540, reflecting significant food insecurity for 49.8% of the population (Pakistan Economic Survey, 2023). Climate change emerges as a pivotal factor influencing food security in Pakistan, impacting aspects such as food production, access, distribution, use, and cleanliness (Farooq et al., 2022)

Despite Pakistan's vulnerability to climate change and its profound implications for food security, there is a need for more in-depth research that specifically investigates the impacts of climate change on food insecurity in Pakistan. The existing studies have often focused on wheat production, rice production, or soil erosion but no one has assessed the relationship between food grain and climate change. At the same time, the study also assesses a sustainable food crop without climate change effects. To safe consecutive production of wheat and achieve food security in Pakistan.

1. LITERATURE REVIEW

In earlier studies, various analyses have been done from diverse angles to assess the effects of climate fluctuations on food security, specifically, Wagan et al. (2015) examined the present state and expansion of rice cultivation in Sindh. Their objective was to empirically analyze and predict the potential climate change threats to food security, particularly about rice production for the data period 1994-2021. The results of the VAR model revealed a negative correlation between temperature precipitation and rice production. Moreover, the utilization of hybrid seeds and adaptive varieties emerged as potential measures to safeguard staple crops in the Sindh region. Similarly, another study by Xu et al. (2019) measured the impacts of climate change and human interventions in agriculture production. This study investigated how climate change, sown area, amount of fertilizer uses, and population influenced food security and agriculture production for the data ear 1990-2015. The OLS model was used to check the econometric relation between dependent and independent variables. The study finds more than one-fourth of counties have been experiencing a high risk of food insecurity. While about 19.4–27.4% of countries have been experiencing severe or moderate per capita food insufficiency since 1990.

Likewise, Bocchiola et al. (2019) investigated the relationship between climate change and food security in the Himalayas, specifically focusing on agricultural production. The aim was to assess the current and future productivity of three primary staple cereals: wheat, maize, and rice. Data spanning the years 1981-2010, including daily weather variables (temperature, rainfall, and solar radiation), population data, and nutritional indices, was collected. Econometric analysis was conducted using Poly Cop and GCM models. The findings indicated that assuming constant conditions, wheat yield decreased by 25%, rice by 42%, and maize by 46%. Moreover, the results suggested that adapting land use at higher altitudes would lead to a 38% decline in wheat yield, while rice and maize yields would experience only slight reductions. However, overall, the food security index in Pakistan exhibited a decline.

In contrast, Hertel et al. (2016) investigated the impact of trends in agricultural products and climate change on the future of global food security. The partial equilibrium model of global agriculture was employed as an econometric technique. The findings indicated positive developments in global food security from 2006 to 2050. Despite population growth and heightened demand for biofuels the anticipated increases in agricultural productivity result in a 24% increase in global average dietary energy intake. The study concluded that the occurrence of malnutrition experiences an 84% reduction, lifting over half a billion people out of extreme hunger. It is crucial to note that these positive outcomes are subject to sustained growth in agricultural productivity. The influence of climate change introduces uncertainty to these projections, with the outcomes heavily dependent on the impact of increasing CO_2 concentrations on crop yields. In the same way, Kralovec (2020) also analyzed the influence of climate change, economic development, and conflict on food. The research inquired into the various aspects posing a threat to the food security situation in Nigeria, employing a mixed-methods approach. The findings revealed that each of the three factors—climate variation, economic progress, and war—can contribute to food insecurity, explaining the observed food security challenges in Nigeria.

Recently, Abrar et al, (2023) also investigated the Climate change impact on food security. The primary objective of this study was to investigate the impact of climate change on food security, specifically focusing on wheat yield in the Punjab province. The data period for analysis was taken from 1990 to 2022. The analysis utilized the ARDL Bound test to examine the co-integration among these variables. The findings suggest that a one-degree Celsius increase in the mean minimum temperature during the sowing phase is associated with an 8.879016 kg decrease in wheat yield, demonstrating a significant relationship between these variables. Similarly, during the vegetation phase, a one-degree Celsius rise in mean maximum temperature corresponds to a significant decrease in wheat yield, amounting to 13.705017 kg. Conversely, during the maturity phase, a one-degree Celsius increase in mean maximum temperature is linked to a 1.073163 kg increase in wheat productivity. Furthermore, adequate rainfall, leading to an increased wheat yield of 70.921702 kg, was identified as having a significant impact. In conclusion, the study underscores that climate change plays a pivotal role in affecting wheat yield throughout the various stages of wheat development.

Moreover, Abbas et al (2022) conducted a comprehensive study examining the impact of climate change on food security in Pakistan, with a focus on per capita wheat availability. The study employed the OLS estimation technique for the data period from 1980-2012. The findings highlighted the negative impact of rising temperatures in certain months on wheat production in irrigated regions, contrasting with positive correlations between minimum temperatures and production in specific months. Non-irrigated areas were also affected, with minimum temperatures and March rainfall influencing wheat yield. Projections indicated a future decline in per capita wheat availability, exacerbated by population growth in Punjab, Pakistan. In a parallel study, Hassan et al (2021) explored the consequences of climatic variations on food security in Pakistan, emphasizing the interconnectedness of climate change and diminishing natural resources. Utilizing a diverse dataset, the analysis uncovered the substantial effects of climate variations on regional temperature, precipitation, evaporation, irrigation water availability, and glacier melting. The study specifically addressed water crises, food shortages, inflation in food items, and transboundary water conflicts. Results indicated shifts in farming practices, reduced crop yields due to a shortened sowing season, and altered rainfall patterns resulting from increased temperatures causing evaporation. The study also highlighted the contribution of rising average temperatures to glacier melting, leading to an increased frequency of floods in mountainous areas. These interconnected issues collectively contributed to a decline in staple food output, intensifying the challenge of meeting the needs of the growing population.

Similarly, Hina et al (2019) examined the economic impact of Climatic Change Sensitivity in the Rice-Wheat Cropping System of Pakistan Cross-sectional data were gathered from 210 farmers across seven distinct strata in Punjab, Pakistan. Climate data for both the baseline period (1980-2010) and future projections (2039-2040) were utilized. Five global circulation models, namely DSSAT and APSIM, incorporated these climate scenarios, and Economic analysis was conducted using the Tradeoff Analysis Model for Multidimensional Impact Assessment (TOA-MD) for estimation. The crop modeling outcomes, employing different GCMs and RCPs, revealed a detrimental impact of climate change on the yields of major crops, namely rice and wheat. A comparison of the two crop simulation models indicated that APSIM demonstrated higher percentage losses compared to DSSAT. Economic indicators, including net returns, per capita income, and poverty, exhibited a declining trend in both RCPs (4.5 and 8.5) and all five GCMs. Poverty in the study area increased with climate change. The APSIM crop model showed the highest increase in poverty under hot-dry conditions. The study highlights the necessity to update agronomic practices and develop adaptation strategies to ensure food security, alleviate poverty, and minimize the risks associated with climate change. Other scholars who have worked on the subject matter are Shabeer et al., 2021a, 2021b; Arshed et al., 2021; Zubair et al., 2023; Wang et al., 2023; Huang et al., 2023; Shabeer et al., 2024; Abedeen et al., 2024).

Furthermore, Bilali (2019) carried a Research on agro-food sustainability transitions. The main outcome of sustainable agro-food systems is food and nutrition security. Nevertheless, about half of the global population is affected by food insecurity and malnutrition, a symptom of the dysfunctions of the current food system. This paper provides a review of the state of research on the sustainability of agro-food transitions, and the extent to which and in what ways such research examines food and nutrition security. A search carried out on Scopus in January 2018 yielded 771 documents; 120 of these were included in the systematic review. Agro-food represents a small share of the sustainability transitions research field. Most of the available research focuses on crops and the production stage. In general, it is assumed that a transition to sustainability in the agro-food arena would lead to increased food availability, improved food access, better food utilization, and increased food system stability and resilience. However, scholars also point out that the quest for food security (especially through intensification) may undermine the transition towards sustainable agriculture and food systems.

Likewise, it is assumed that a transition towards sustainable food systems implies changes in dietary patterns and nutrition habits. Nevertheless, food security and nutrition are still marginal topics in the literature on agro-food sustainability transitions. Furthermore, the transformation of food systems, which should guide agro-food sustainability transitions, is the exception rather than the rule in the research field. This systematic review represents a useful contribution to research on transitions towards sustainability in agriculture and food sectors and provides insights into how such research can contribute to addressing the grand challenges of food insecurity and malnutrition. The paper suggests the need to move beyond silos by fostering cross-sectorial collaboration and the integration of the agro-food sustainability transitions and food security research fields.

Hence, the study examined earlier work and found that wheat production reveals a negative relation between climate change and food production contributing to decreased food security. Contrary findings by Lantz et al. and Kralovec suggest positive developments in global food security, contingent on sustained agricultural productivity growth. Additionally, Abrar et al. examine climate change's impact on wheat yield in Punjab, identifying significant relationships between temperature, rainfall, and productivity. In conclusion, there is a need to assess with another angle of wheat production to understand the need for adaptation strategies to ensure food security amidst climate challenges.

3. METHODOLOGY AND DATA SOURCES

The study used time series data analysis to examine the climate change on food security in Pakistan for the data period 1991 to 2021. Data has been sourced from different sources such as the Economic Survey of Pakistan (ESP), the World Development Indicator (WDI), Pakistan agricultural statistics, and the Pakistan Metrological Department (PMD). The Wheat production measure in (million tons) is the dependent variable while Rainfall (millimeters annual), Temperature (share of temperature change from greenhouse gases in Celsius), Inflation (consumer prices annual %), and agricultural machinery are used as a proxy for technology via number of tractators per square km of arable area and CO_2 emission (kg per 2017 PPP $ of GDP) are independent variables.

Model Specification And Justification Of Variables

Each crop likely needs certain conditions for growth and existence, such as soil moisture (water), optimal temperature, and adequate rainfall. According to one study, temperature enhances photosynthesis as it increases and leads to an increase in crop yield (Wijewardene et al., 2021) However, it was stated that extremely high temperature negatively affects the process of metabolism in plants, such as protein stability and reactions (enzymatic) in cells, leading to metabolic imbalance. In addition, high temperature also affects photosystem II and RuBisCO function and causes a reduction in photosynthesis. On the other side, the extremely low temperature may lead to injury by chilling in plants. In the monsoon season, intense rainfall can be a serious problem for the farmers. It can lead to soil erosion, washing out of the soil surface, and depletion of nutrients in the soil. Devastating floods can destroy crops, leaving no food for farmers to eat and sell, and thus can trigger production and food security problems. Wang et al., (2019). Similarly, CO_2 emissions are significant contributors to climate change, impacting food-grain production in several ways. Elevated CO_2 levels can alter temperature and precipitation patterns, affecting crop growth and yield. Climate changes can lead to water scarcity, increased prevalence of pests and diseases, and shifts in optimal regions for cultivation, all of which can result in reduced food-grain productivity. Mitigating CO_2 emissions and implementing sustainable agricultural practices are vital to address these challenges and minimize losses in food-grain production. In light of the above deliberations, this study estimates the following model econometrics model to meet the objectives of the study (Hina et al (2019). The other variable of analysis is inflation, which plays a multifaceted role in an economy (Khan, A. W., et al., 2023) In some cases, moderate inflation may incentivize farmers to produce more as they expect higher returns for their crops. The anticipation of rising prices can encourage agricultural investment and efforts to expand cultivation. Conversely, high and unpredictable inflation can have detrimental effects. Inflationary pressures may increase input costs such as fuel, fertilizers, and machinery, making farming more expensive. This, coupled with uncertainty about future prices, can discourage farmers from investing in agricultural activities and adopting advanced technologies (Khan, M. R., et al (2018).

In light of the above discussions, this study estimates the following econometrics model to meet the objectives of the study:

$$WT_{it} = \lambda o + \lambda_1 Rain_{it} + \lambda_2 Tep_{it} + \lambda_3 Inf_{it} + \lambda_4 CO_{2it} + \lambda_5 TCN_{it} + \varepsilon_{it} \quad \text{......... (1.1)}$$

where WT_{it} = Total wheat production in million tons annually, a λ_i coefficient to be estimated; Rain represents annual rainfall in mm; Inf= inflation GDP; Tem= Share of temperature change from greenhouse gases; CO_2= emission of greenhouse gases and TCN reveals agricultural technology, ε_{it} is the error term. Now the study takes a log of all the variables to shrink the data for smooth estimation. According to Gul (2023), log transformations are employed for simplifying mathematical expressions, linearizing relationships, and handling percentage changes effectively. They aid in stabilizing variance, facilitating interpretation, and transforming exponential relationships into additive ones, making them valuable tools in statistical modeling. Hence equation, 1.1 is given below;

$$LnWT_{it} = \lambda o + \lambda_1 LnRain_{it} + \lambda_2 Tep_{it} + \lambda_3 Inf_{it} + \lambda_4 CO_{2it} + \lambda_5 TCN_{it} + \varepsilon_{it}$$
…………… (1.2)

Given that none of our variables exhibit a unit root at the order I(2), we can employ the ARDL methodology established by (Pesaran et al., 2001).To do this, we must transform Equation 1.1 into an ARDL model as demonstrated below:

$$\Delta \ln FG_t = \lambda_0 + \sum_{i=1}^{n1} \lambda_1 \Delta \ln FG_{t-i} + \sum_{i=0}^{n2} \lambda_2 \Delta \ln RF_{t-i} + \sum_{i=0}^{n3} \lambda_3 \Delta Tep_{t-i} + \sum_{i=0}^{n4} \lambda_4 \Delta Inf_{t-i} + \sum_{i=0}^{n5} \lambda_5 \Delta CO_{2_{t-1}} + \sum_{i=0}^{n6} \lambda_6 \Delta TCN_{2_{t-1}} + \delta_1 \ln FG_{t-1} + \delta_2 \ln RF_{t-1} + \delta_3 Tem_{t-1} + \delta_4 \ln Inf_{t-1} + + \delta_5 CO_{2_{t-1}} + \delta_6 TCN_{2_{t-1}} + \varepsilon_t$$
… (1.3)

The ARDL model (Equation 1.3) allows for short-term and long-term estimates with effectiveness in limited sample sizes. Model selection follows the Schwarz Information Criterion (SIC), emphasizing a balance between fit and complexity. The Error Correction Term (ECT) in the ECM model assesses how quickly adjusts to long-term equilibrium with independent variables. Validating results, an essential step per Khan, A.W et al. (2023), involves examining the ECT values in the ECM model, which incorporates the first differences of the variables.

$$\ln FG_{t-1} = \lambda_0 + \sum_{i=1}^{n} \lambda_i \Delta \ln RF_{t-1} + \sum_{t=1}^{n} \lambda_i \Delta Tem_{t-1} + \sum_{i=1}^{n} \lambda_i Inf_{t-1} + \sum_{i=1}^{n} \lambda_i \Delta CO_{2_{t-1}} + \sum_{i=1}^{n} \lambda_i \Delta TCN_{2_{t-1}} + \gamma ECM_{t-1} + \varepsilon_t$$
……. (1.4)

The above equation 1.4 depicts ECM $_{t-1}$ as the lag value of ECT, which captures the convergent to the long-term equilibrium and γ is the coefficient of the ECT, indicating how quickly the variables are correct. Besides, conducted diagnostic tests in research are essential to objectively assess and validate hypotheses, ensuring the reliability and credibility of research findings. Several commonly employed Diagnostic examinations, including the BPG test to assess heteroscedasticity, the Jarque-Bera test for normality/ familiarity, the BG test for autocorrelation, and the CUSUM test for stability, are utilized. These are the essential tools to assess model specification and estimate quality, ensuring the reliability of econometric findings.

4. RESULT AND DISCUSSION

Table 1: Descriptive statistics

	WHT	ATC	TMP	INF	CLI	RNF
Mean	9.935451	4.892333	-0.485747	2.152670	-1.719358	3.235661
Median	9.960693	4.957313	-0.476445	2.152104	-1.700457	3.250285
Maximum	10.22063	5.259190	-0.281038	3.650970	-1.610331	3.563117
Minimum	9.569098	4.425929	-0.709277	1.181299	-1.833488	2.771531
Std. Dev.	0.196625	0.268107	0.130316	0.541353	0.062006	0.210706
Skewness	-0.334052	-0.200382	-0.137212	0.403668	-0.292687	-0.410908
Kurtosis	1.816565	1.592717	1.810772	3.425670	1.926686	2.341455
Jarque-Bera	2.462510	2.854743	1.986096	1.110651	1.992889	1.478749
Probability	0.291926	0.239939	0.370446	0.573885	0.369190	0.477412
Sum Sq. Dev.	1.198499	2.228326	0.526451	9.084945	0.119189	1.376308
Observations	32	32	32	32	32	32

The above table 1, describes a statistical summary related to the concerned variables, where Wheat exhibits a mean of 9.935451 and a slightly negatively skewed distribution, indicating a longer left tail. Agricultural technology has with higher mean of 4.892333 and shows a positively skewed distribution. In contrast, temperature has a negative mean value of -0.485747 and also a negatively skewed distribution. Inflation, with a mean of 2.152670, shows a positively skewed distribution, suggesting a smaller right tail. Moreover, CO_2 emission has a mean of -1.719358 and a relatively low standard deviation, indicating limited variability. Lastly, rainfall has a mean of 3.235661 and a negatively skewed distribution. The Kurtosis values reveal the shapes of the distributions, with higher values indicating heavier tails and sharper peaks. Notably, the Jarque-Bera test identifies RF as significantly departing from normality (Probability = 0.000). In summary, this dataset exhibits varying distributions and diverse characteristics.

Table 2: Correlation

	WHT	ATC	TMP	INF	CLI	RNF
Wheat	1					
Agricultural Technology	0.9587	1				
Temperature	0.9660	0.9815	1			
Inflation	-0.0613	-0.1432	-0.1655	1		
Carbon	-0.2762	-0.383424	-0.37712	0.0441	1	
Rain_fall	-0.1651	-0.0729	-0.1397	-0.0230	-0.1095	1

In Table 2, the correlation matrix reveals the linear relationships between the variables.

Notably, wheat production has a strong and positive relation with both agricultural technology usage and temperature with figures of 0.9587 and 0.9660, respectively. In contrast, negative association between wheat production and both inflation and rainfall. Moreover, wheat production has a negative correlation with carbon dioxide levels, with a coefficient of -0.2762.

In summary, these outcome highlights the complex interaction between environmental and economic elements in influencing wheat production, underscoring the importance of this estimation.

Table 3: Lags selection criteria

VAR Lag Order Selection Criteria						
0	-86.41407	NA	0.000305	6.094271	6.327804	6.168980
1	41.80161	205.1451*	3.22e-07*	-0.786774*	0.614424*	-0.338519*
2	52.34985	13.36110	9.82e-07	0.176677	2.745539	0.998478
3	72.84995	19.13343	2.05e-06	0.476670	4.213196	1.672017

Table 3, depicts the criteria used to assess the trade-off between model fit and complexity. Lower values of AIC, SIC, HQIC, and FPE are generally preferred, indicating a better balance between the goodness of fit and model complexity Gul, A., et al (2021).In this case, for lag 1, the asterisks (*) highlight that the selected lag order is based on the minimum values of AIC, SIC, HQIC, and FPE, suggesting that a lag of 1 is deemed most suitable according to these criteria. The specific values for each criterion provide quantitative measures to guide the selection of the lag order in the VAR model.

Table 4: Long and Short run results

Long run results				
Variables	**Coefficient**	**Std. Error**	**t-statistics**	**Prob.**
Agricultural Technology	1.416119	0.457847	3.092993	0.0060
Temperature	-1.891090	0.484555	-3.902738	0.0008
Inflation	0.042187	0.018233	2.313726	0.0304
Carbon	-1.328602	0.611071	-2.174216	0.0398
Rain_fall	-0.671788	0.283918	-2.366135	0.0268
C	9.391654	0.864284	10.866401	0.0000
R^2	0.620107		F-statistics	15.234
Prob(F-statistics)	0.0000		DW	2.111979
Short-run results				
Variables	**Coefficient**	**Std. Error**	**t-statistics**	**Prob.**
Agricultural Technology	0.536482	0.200930	2.669992	0.0134
Temperature	20.586722	9.051156	2.274485	0.0322
Inflation	0.037539	0.020304	1.848882	0.0768
Carbon	-0.148798	0.204621	-0.727191	0.4741
Rain_fall	-0.020501	0.053978	-0.379811	0.7074
CointEq(-1)	-0.341406	0.107676	-3.170691	0.0041

Table 4 presents the short-run and long-run results of the study. Agricultural technology usage shows a significant positive influence, with a coefficient value of 1.416, showing that higher utilization leads to an increase in wheat production. Conversely, temperature expresses a notable negative connection (-1.891), implying that higher temperatures decreased wheat production. Moreover, both inflation and Co2 emission show significant and positive influence, while rainfall has a significant negative influence on the dependent variable (Wheat). Lastly, (C) shows the intercept term, which indicates the dependent variable's value when all independent variables are zero, showing a considerable positive effect. Therefore, the overall model is statistically significant, as indicated by the high value of F-statistic (15.234). The Durbin-Watson value (DW = 2.112) indicated that there is evidence of the existence of autocorrelation in the residuals. These results collectively shed light on the relationships between the variables and provide valuable insights into their influences on the dependent variable. Moreover, the Error Correction Term (ECT) value of CointEq(-1) -0.341406 in the Error Correction Model indicates the speed and direction of adjustment towards long-term equilibrium after short-term disturbances, with a negative and significant coefficient implying a faster correction towards equilibrium.

Table 5: Bound Test

F- Test	Null Hypothesis		
Test Statistics			
	Significance	I (0)	I (1)
F-stat 6.701744	10%	3.03	4.06
	5%	3.47	4.57
	2.5	3.89	5.07
	1%	4.4	5.72

The above table 5 shows the results of the bound test. A bound test is used to assess the existence of a long-term cointegrating relationship between variables, helping to determine whether a stable equilibrium relationship exists among the variables in a time series. The F-statistic, derived from the bound test, is considered statistically significant when its calculated value exceeds the critical value from the

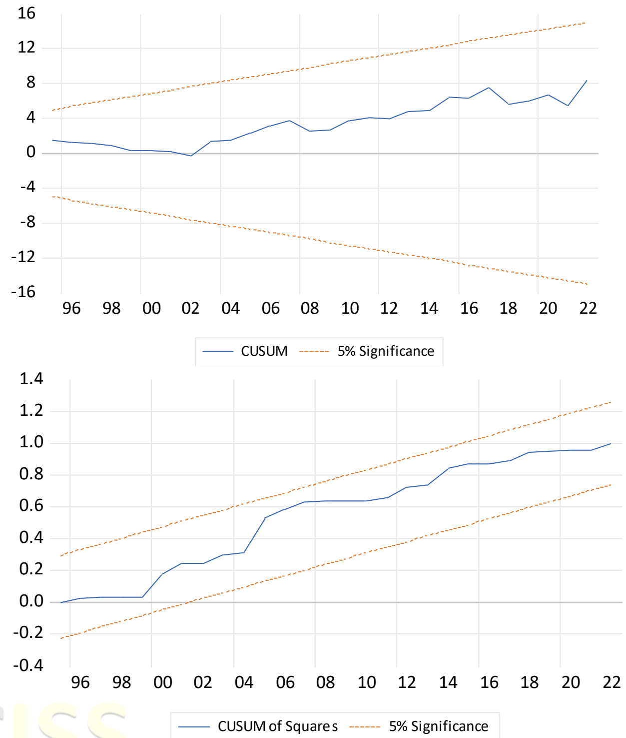
F-distribution table at a chosen significance level (e.g., 5%). If the F-statistic value exceeds the critical value at the 5% significance level, it implies that the overall model is statistically significant at the 5% level of significance. In the provided context, the critical value at the 5% significance level is given as 3.47, exceeding the critical value at the 5% significance level. Therefore, the null hypothesis is rejected, suggesting a statistically significant long-term cointegrating relationship among the variables in the time series analysis.

Table 6: Diagnostic Tests

Heteroskedasticity Test BPG			
F-statistics	1.152391	Prob F-(7,24)	0.3653
Obs*R²	8.049949	Prob. χ2 (7)	0.3282
SE-SS	9.566242	Prob. χ2 (7)	0.2145
BG-Serial Correlation LM Test			
F-statistics	0.894645	Prob F-(2,22)	0.4231
Obs*R²	2.406851	Prob. χ2 (2)	0.3002

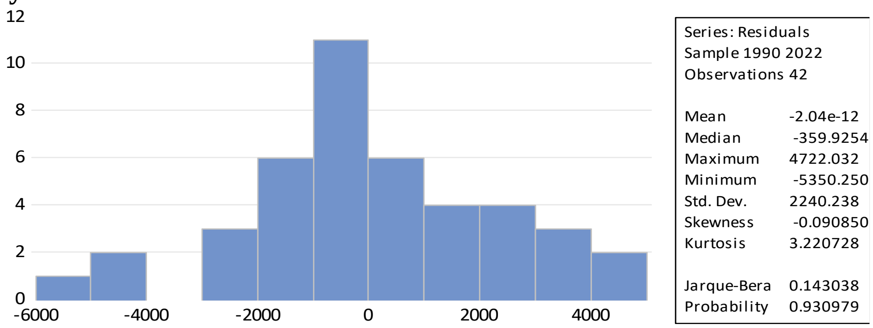
Table 6 shows the result of heteroskedasticity by using the BPG (Breusch-Pagan-Godfrey) test statistics, the F-statistic is 1.152391 with a probability (p-value) of 0.3653. The probability of 0.3653 is relatively high and exceeds common significance levels such as 0.05, suggesting that there is insufficient evidence to reject the null hypothesis of homoskedasticity. Therefore, based on this result, there is no significant indication of heteroskedasticity in the data, implying that the variance of the errors is likely constant across observations in the regression model. The second test is used for serial correlation which is the BG (Breusch-Godfrey) Serial Correlation LM Test, the F-statistic is 0.894645 with a probability (p-value) of 0.4231. The relatively high p-value, exceeding common significance levels like 0.05, indicates that there is insufficient evidence to reject the null hypothesis of no serial correlation. Therefore, based on this result, it suggests that there is no significant indication of serial correlation in the residuals of the regression model.

Figure 1: CUSUM (CUMULATIVE SUM) AND CUSUM SQUARE



CUSUM (Cumulative Sum) and CUSUM square tests are statistical methods used to monitor the process of stability, detecting shifts or changes over time in mean and variance, respectively. The CUSUM test monitors cumulative changes, while the CUSUM Square test enhances sensitivity by incorporating squared deviations. When the blue line in both tests consistently falls within the red lines on their respective charts, it indicates a lack of significant structural change in the data. This stability suggests that the observed values align with the expected pattern or reference value, and no substantial deviation or shift is detected over the analyzed period.

Figure 2: Normality of Data



In the context of regression analysis, the Jarque-Bera test is often applied to assess the normality of residuals. The Jarque-Bera test statistic of 0.143038 with a corresponding p-value of 0.930979 suggests that, at the 5% significance level, there is no significant evidence to reject the null hypothesis that the data follows a normal distribution. In this case, the non-significant p-value indicates that the residuals conform reasonably well to a normal distribution. This is crucial for valid statistical inferences in regression models, as it supports the assumption that the errors are normally distributed. Therefore, the provided results imply that the normality assumption holds for the residuals, strengthening the reliability of the regression analysis conducted.

5. Conclusion and Recommendation

The study has empirically scrutinized the impact of climate change on food security in Pakistan for the data period 1990 to 2021. Initially, the ADF unit root test has decided that the ARDL estimation technique is appropriate for this data analysis. The results of the cited estimation method revealed that the use of Agricultural technology exhibits a significant and positive influence on wheat production, while notably temperature indicates a significant and negative impact on Wheat production. It shows that the use of technology in the agriculture field may significantly increase wheat production whereas high temperature adversely affects the dependent variable. Moreover, both rainfall and CO_2 emission express a negative impact on the dependent variable whereas inflation is positively related to wheat production. Undeniably, these results find that substantial inflation leads to more wheat production, in contrast, Co2 emission and heavy rainfall deteriorate and lessen the wheat production.

The analysis empirically investigated the pivotal challenges of climate change on food security in Pakistan, hence the following key recommendations are proposed.

Firstly, the implementation and promotion of climate-resilient agricultural processes, such as drought-resistant crops and sustainable water management, are essential to bolster the adaptive capacity of farmers. Secondly, make rules and regulations to reduce Co2 emissions, especially from agricultural activities such as reduced tillage, agroforestry, and crop rotation. Additionally, the authorities should invest in renewable energy sources associated with agricultural activities. Thirdly, develop and implement a water management system to ensure fluent water availability in extreme temperatures and halt the affluence of rainwater and flood control systems. Lastly, an integrated policy approach, involving collaboration across government agencies, agricultural institutions, and environmental bodies, is crucial for developing comprehensive policies that consider the interconnected dynamics influencing food security.

Future studies could investigate the influence of AI advancements and regional climate vulnerabilities on food production. The long-term research efforts and community-based projects may help understand adaptation strategies and the role of global market dynamics.

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