Climate Change and Food Security in Pakistan: An Empirical Analysis Using Autoregressive Distributed Lag Model

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Abstract

Climate change has profound implications for food security in Pakistan's agrarian economy. This study examines the short- and long-term relationship between climate change and food security in Pakistan by utilizing the Autoregressive Distributed Lag model from 1980 to 2023. The analysis incorporates three key indicators of climate change —namely, temperature, carbon dioxide emissions, and direct flood losses. The bound testing confirms the existence of long-run co-integration between climate change and food security. The results indicate that rising temperatures, high CO_2 emissions, and flood losses significantly compromise food security in both the short and long term. An increase in development expenditures, fertilizer use, and agricultural employment improves food security in the short term; however, overuse of fertilizers and inefficient resource allocation reduce food security in the long term. The authors emphasize the adoption of climate-resilient farming practices, efficient irrigation systems, and adaptive agricultural strategies to address the challenge of food security under increasing climate pressures.

Keywords: Food Security, Temperature, CO_2 emission, Direct Flood Losses, Autoregressive Distributed Lag Model

JEL Classification: O13, Q1, Q19, Q54

1. Introduction

Climate change is a persistent and complex phenomenon that intensifies global food security challenges. It involves long-term alterations in meteorological patterns primarily driven by global warming and environmental degradation (Bokhari, Rasul, Ruane, Hoogenboom, & Ahmad, 2017). Since 1975, the global average temperature has risen, and Pakistan has been one of the most severely affected nations by global warming and natural disasters. GHG emissions, particularly carbon dioxide (CO_2) from human activities, are the main drivers of global warming (Canton, 2021). The energy sector's heavy reliance on fossil fuels such as oil, coal, and gas has led to a rapid increase in CO_2 emissions in recent decades (Lin & Raza, 2019). Although total historical emissions remain lower than in industrialized countries, the growth rate is high. Between 1986 and 2020, CO_2 emissions from final energy use increased from 43.32 million tons to 206.27 million tons, representing an average annual growth rate of 4.76% (Lin & Raza, 2021b). Natural calamities have become intense and more frequent in the country over the past three decades (Shrestha & Takara, 2008). The extreme monsoon rains of June 2022 in Pakistan resulted in catastrophic flooding (Otto et al., 2023). Between 1950 and 2022, the country experienced an average of one flood every three years, with 29 extreme events recorded. The 2010 floods were among the most destructive before 2022. The country also experienced rising temperatures, with minor fluctuations.

CC tends to create food insecurity. Extreme climate patterns have enormously threatened agricultural productivity. As a result, the country failed to achieve food security (FS) for its rapidly expanding population. FS refers to a broader concept encompassing the availability, access, utilization, and stability of food. Previous studies evaluated CC's effect only on specific crops and fruits (Islam, Okubo, Islam, & Sato, 2021; Abrar & Maryiam, 2023). Thus, the impact of CC on the comprehensive FS index has not yet been analyzed.

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This study is unique in the following ways. First, the study aims to investigate the impact of CC on FS in Pakistan, using a multidimensional index of FS. This FS index encompasses four key dimensions: access, availability, utilization, and stability. Second, the study accounts for three different indicators of CC. Most previous studies in the literature consider only temperature and CO2 emissions as indicators of CC and assess their impact on FS (Menhas, Shumaila, & Shabbir, 2016; Gul et al., 2022). This study also accounts for flood losses measured through direct losses, in addition to temperature and CO_2 emissions. Thus, the authors expect that the study will provide valuable insights for the Ministry of Climate Change and Environmental Coordination to address the hazards posed by CC. It benefits farmers and agricultural workers who face climate impacts by enhancing their resilience and productivity through improved knowledge and resources, as well as through the adoption of innovative agricultural practices.

2. Literature Review

FS determinants operate across multiple levels: global, national, regional, household, and individual. CC emerges as a major cross-cutting factor for FS in Pakistan. Empirical evidence shows that fluctuations in temperature, CO_2 emissions, and climatic events such as floods and droughts significantly affect agricultural productivity and infrastructure, thereby undermining FS (Molnar, 1999; Nazli & Hamid, 1999).

At the household level, socio-economic conditions such as family size, income, employment status, food prices, and mobility also determine FS outcomes (Sharkey, Johnson, Dean, & Horel, 2011). Agricultural productivity is particularly sensitive to climatic conditions. Studies have highlighted that farm size, fertilizer use, quality seeds, labor input, and education all enhance rice yields, whereas limited credit and poor extension services constrain production (Khan et al., 2020). Climate-induced disruptions, such as heavy rainfall during harvest seasons, have damaged crops and infrastructure, with future projections indicating that rising temperatures and irregular rainfall will further reduce wheat yields unless adaptive measures are adopted (Janjua, Samad, Khan, & Nasir, 2010). Research consistently shows that higher temperatures and altered rainfall patterns reduce yields in major crops, including wheat and rice, while irrigation inefficiencies, high production costs, and technological gaps exacerbate vulnerabilities (Huang, 2014; Ahmad, Hussain, & Brooks, 1995; Tariq, Tabasam, Bakhsh, Ashfaq, & Hassan, 2014).

Gender dynamics also shape FS. Women's education, employment, and decision-making power correlate positively with household FS (Hazarika & Khasnobis, 2005). CC-driven water scarcity has worsened nutritional insecurity and contributed to malnutrition, particularly child stunting (Menhas et al., 2016). Time-series analyses confirm that high temperatures reduce FS, while agricultural credit and fertilizer use can partially offset these effects (Munir, Kiani, & Baig, 2016; Gul et al., 2022). Other studies note that CO_2 emissions can sometimes boost yields, although their long-term effects remain complex and context-dependent (Khurshid & Abid, 2024). At the global scale, CC has already reduced maize and wheat yields, necessitating the development of climate-resilient crop varieties and adaptive practices (Lobell, Schlenker, & Costa-Robertset, 2011). The projected mid-century temperature rises and rainfall variability are likely to intensify production risks in Pakistan and South Asia. The authors call for climate-smart agriculture, efficient water management, and targeted policy interventions (Ahmed & Schmitz, 2011; Rahman, Iftikhar, Khattak, & Ali, 2021).

Existing empirical research provides diverse insights into the relationship between CC and crop productivity in Pakistan, with a predominant focus on major staple crops. Rahman et al. (2017) analyzed rice production in Punjab and Sindh using multivariate linear regression. They found that moderate increases in temperature and rainfall could enhance yields, though the optimal thresholds remained undetermined. In contrast, Mahmood et al. (2019) applied the framework of Just and Pope (1978) to analyze the impact of climate vulnerability on wheat yields, using farm-level data from 1980 to 2017. They found that high temperatures significantly reduced productivity. At the same time, increased rainfall improved it, highlighting the importance of climate-resilient farming practices in rain-fed areas and the need for targeted interventions to mitigate climate risk among smallholder farmers. Similarly, Sonia, Sadozai, Khan, Jan, and Hameed (2019) observed significant adverse effects of both TEM and precipitation on wheat yields in Khyber Pakhtunkhwa, advocating for the development of heat-tolerant varieties and the implementation of adaptive policies.

Few researchers validated the detrimental effects of CC for broader crops. For instance, Ali et al. (2017) argued that climate vulnerability affects the three major crops —namely, wheat, rice, and maize — in Pakistan. They applied Feasible Generalized Least Squares (FGLS) and HAC techniques, considering data from 1980 to 2015. The authors document modest short-term but severe long-term reductions in yields. The study recommends climate-resilient agricultural practices, investment in drought- and heat-resistant crop varieties, and improved irrigation systems to mitigate the impacts of climate change on crop yields. Regional studies, such as those by Joyo, Ram, and Magsi (2018) and Chandio, Magsi, and Ozturk (2020), have further emphasized rice's vulnerability to elevated temperatures, recommending hybrid seeds, improved irrigation, and farmer training as adaptation measures.

Despite these contributions, notable gaps exist in the existing literature. Most of the literature relies on a single-dimensional FS indicator, which fails to assess FS comprehensively. Moreover, literature focuses on the impact on major crops and fruits, overlooking the aggregate impact on the state of FS. The impact of flood losses is rarely analyzed in the context of FS. Addressing these limitations, the present study relies on a multidimensional FS index. It further enhances understanding of climatic impacts by evaluating the effects of temperature, CO_2 emissions, and flood-induced damage on FS in Pakistan.

3. Methodology

This section outlines the conceptual framework, data, and econometric procedure for assessing the CC-FS nexus in Pakistan.

3.1 Conceptual Framework

This study builds on the Climate Change and Food Security (CCFS) framework developed by FAO (2008). The CCFS framework is a foundation for global efforts to align climate action with food security goals under the Sustainable Development Goals (SDGs). It links key climatic variables, such as temperature (TEM), carbon dioxide (CO_2) emissions, and flood incidence (DFL), to FS outcomes. These FS outcomes/dimensions are food availability (FAV), access (FAC), utilization (FUT), and stability (FST), which are aggregated to build a composite food security index (FSI) following Rahman et al. (2021).

CC exerts *direct* and *indirect* pressures on FS, significantly undermining Pakistan's capacity to meet the dietary needs of its growing population. The *direct impacts* are observed through altered weather patterns, including elevated TEM, irregular precipitation, floods, and droughts, all of which reduce yields of staple crops such as wheat, rice, and maize (Chandio et al., 2020). For instance, elevated temperatures in southern Punjab and Sindh have shortened the growing season for crops. At the same time, recurrent floods in Sindh and Balochistan have destroyed agricultural output, livestock, and storage infrastructure, diminishing food availability (Citaristi, 2022).

Indirect impacts of CC refer to disruptions in food access (FAC) and food stability (FST) by triggering production declines that elevate market prices, thereby disproportionately affecting low-income households. These shocks erode the purchasing power of rural farmers, who rely on agriculture for their livelihoods, thereby limiting their ability to access adequate food (Ali et al., 2017). Furthermore, climate-induced disasters damage transportation networks and market systems, impeding the equitable distribution of food across regions. Collectively, these pathways underscore CC's multifaceted threat to FS.

3.2 Data and Econometric Procedure

This study uses time series data for Pakistan from 1980 to 2023. Table 1 lists the variables, their measurement, and data sources for CC and FSI.

Table 1. List of Variables, Measurement, and Data Source for Regression Analysis

Variables	Description/Measurements of Variable	Data Sources
Dependent Variable		
Food Security Index (FSI)	Composite index based on dimensions of FAV, FAC, FUT, and FST.	Author's Construction using Data from WDI and FAO
Independent Variable		
Climate Change (CC)	Mean Temperature (TEMP) CO2 emissions metric tons per capita. Direct Flood Losses % (DFL)	Climate Change Knowledge Portal (CCKP) and Pakistan Economic Survey (PES).
Control Variables[‡]		
Development Expenditure (DEXP)	Measured as % of GDP	WDI, WB
Fertilizer consumption (FU)	Measured as kilograms per hectare of arable land	WDI, WB
Agricultural employment (AEMP)	Measured as % of total employment	WDI, WB

To assess the impact of CC on FS, the study employs the Autoregressive Distributed Lag (ARDL) model proposed by Pesaran and Shin (1999) and further refined by Pesaran, Shin, and Smith (2001). This method has several advantages. It provides a consistent estimate even in the small samples and irrespective of the variables having either I (0) or I(1), or frictionally integrated. The models specified are as follows (equation 1 to 3):

$$FSI_t = a_0 + a_1 TEM_t + a_2 DEXP_t + a_3 FU_t + a_4 AEMP_t + u_t \quad \textbf{(1)}$$

$$FSI_t = b_0 + b_1 CO_{2t} + b_2 DEXP_t + b_3 FU_t + b_4 AEMP_t + v_t \quad \textbf{(2)}$$

$$FSI_t = c_0 + c_1 FLD_t + c_2 DEXP_t + c_3 FU_t + c_4 AEMP_t + w_t \quad \textbf{(3)}$$

where FSI denotes food security index, three different measures of CC used in Models (1) to (3) are temperature (TEM), carbon dioxide emissions (CO_2), and direct flood losses (DFL). The control variables are development expenditures (DEXP), fertilizer consumption (FU), and Employment in agriculture (AEMP). Rose and Adil (2021) argued that development expenditure (DE) primarily focuses on state-funded social infrastructure and public services alongside policy programs that indirectly influence FS. These investments represent a vital engine for boosting agricultural productivity while fighting poverty and securing vital resources that generate better FS results. The study of Iqbal et al. (2015) stated that fertilizer consumption (FU) plays a significant role in enhancing FS in Pakistan by boosting agricultural productivity and improving crop yields. Fertilizers provide essential nutrients like nitrogen, phosphorus, and potassium that are necessary for plant growth. These nutrients are vital in Pakistan's farming system. By boosting crop yields, FU helps bridge the gap between food demand and supply, increasing FAV in the market and ensuring FS. AEMP plays a crucial role in enhancing FS in Pakistan. It is directly linked to the livelihood of a large portion of the population, particularly

[‡] Initially, the authors considered six control variables. However, data on agricultural land (AL), modern farming technologies (MFT), and research & development (R&D) is not available before 2000. This compelled to drop them from analysis.

in rural areas where agriculture remains the primary source of income. By securing AEMP, individuals and families can earn wages that improve their purchasing power, allowing them to buy food. This directly enhances economic access to food (Ahmed et al., 2017).

The ARDL representations of Model (1) to Model (3) are as follows (equations 4 to 6);

$$\Delta FSI_t = \alpha_0 + \sum_{i=1}^{n} \alpha_{1i}\, \Delta FSI_{t-i} + \sum_{i=0}^{n} \alpha_{2i}\, \Delta TEM_{t-i} + \sum_{i=0}^{n} \alpha_{3i}\, \Delta DEXP_{t-i} + \sum_{i=0}^{n} \alpha_{4i}\, \Delta FU_{t-i} + \sum_{i=0}^{n} \alpha_{5i}\, \Delta AEMP_{t-i} + \lambda_1 FSI_{t-1} + \lambda_2 TEM_{t-1} + \lambda_3 DEXP_{t-1} + \lambda_4 FU_{t-1} + \lambda_5 AEMP_{t-1} + \varepsilon_t \quad \textbf{(4)}$$

$$\Delta FSI_t = \beta_0 + \sum_{i=1}^{n} \beta_{1j}\, \Delta FSI_{t-i} + \sum_{i=0}^{n} \beta_{2i}\, \Delta CO_{2t-i} + \sum_{i=0}^{n} \beta_{3i}\, \Delta DEXP_{t-i} + \sum_{i=0}^{n} \beta_{4i}\, \Delta FU_{t-i} + \sum_{i=0}^{n} \beta_{5i}\, \Delta AEMP_{t-i} + \delta_1 FSI_{t-1} + \delta_2 CO_{2_{t-1}} + \delta_3 DEXP_{t-1} + \delta_4 FU_{t-1} + \delta_5 AEMP_{t-1} + e_t \quad \textbf{(5)}$$

$$\Delta FSI_t = \gamma_0 + \sum_{i=1}^{n} \gamma_{1i}\, \Delta FSI_{t-i} + \sum_{i=0}^{n} \gamma_{2i}\, \Delta FLD_{t-i} + \sum_{i=0}^{n} \gamma_{3i}\, \Delta DEXP_{t-i} + \sum_{i=0}^{n} \gamma_{4i}\, \Delta FU_{t-i} + \sum_{i=0}^{n} \gamma_{5i}\, \Delta AEMP_{t-i} + \tau_1 FSI_{t-1} + \tau_2 FLD_{t-1} + \tau_3 DEXP_{t-1} + \tau_4 FU_{t-1} + \tau_5 AEMP_{t-1} + \mu_t \quad \textbf{(6)}$$

The coefficients attached to the difference operator in models (4) to (6) measure short-run dynamics, and the terms with the first lag denote the long-run relationship. The following null hypothesis can test the existence of long-run relationship between FSI and all explanatory variables:

$$\lambda_1 = \lambda_2 = \lambda_3 = \lambda_4 = \lambda_5 = 0$$
$$\delta_1 = \delta_2 = \delta_3 = \delta_4 = \delta_5 = 0$$
$$\tau_1 = \tau_2 = \tau_3 = \tau_4 = \tau_5 = 0$$

The computed F-statistics for these null hypotheses will be compared with the critical bound values from Pesaran et al. (2001). A long-run relationship between FSI and its explanatory variables will be confirmed if the null hypothesis is rejected. Once the long-term relationship is confirmed, the next step in the ARDL model is to estimate the short-term dynamics and check the stability of the equilibrium relationship through the error-correction models (equations 7-9);

$$\Delta FSI_t = \theta_0 + \sum_{i=1}^{n} \theta_{1i}\, \Delta FSI_{t-i} + \sum_{i=0}^{n} \theta_{2i}\, \Delta TEM_{t-i} + \sum_{i=0}^{n} \theta_{3i}\, \Delta DEXP_{t-i} + \sum_{i=0}^{n} \theta_{4i}\, \Delta FU_{t-i} + \sum_{i=0}^{n} \theta_{5i}\, \Delta AEMP_{t-i} + \varpi ECT_{t-1} + \varsigma_t \quad \textbf{(7)}$$

$$\Delta FSI_t = \phi_0 + \sum_{i=1}^{n} \phi_{1i}\, \Delta FSI_{t-i} + \sum_{i=0}^{n} \phi_{2i}\, \Delta CO_{2_{t-i}} + \sum_{i=0}^{n} \phi_{3i}\, \Delta DEXP_{t-i} + \sum_{i=0}^{n} \phi_{4i}\, \Delta FU_{t-i} + \sum_{i=0}^{n} \phi_{5i}\, \Delta AEMP_{t-i} + \rho ECT_{t-1} + \xi_t \quad \textbf{(8)}$$

$$\Delta FSI_t = \psi_0 + \sum_{i=1}^{n} \psi_{1i}\, \Delta FSI_{t-i} + \sum_{i=0}^{n} \psi_{2i}\, \Delta FLD_{t-i} + \sum_{i=0}^{n} \psi_{3i}\, \Delta DEXP_{t-i} + \sum_{i=0}^{n} \gamma_{4i}\, \Delta FU_{t-i} + \sum_{i=0}^{n} \psi_{5i}\, \Delta AEMP_{t-i} + \bar{y} ECT_{t-1} + \eta_t \quad \textbf{(9)}$$

where ϖ , ρ, and $\bar{y}$ denote the coefficient of lagged error correction terms. Pesaran et al. (2001) refer to these coefficients as the speed of adjustment towards the long-run equilibrium after a shock hits, causing disequilibrium in the short run. These coefficients are expected to be negative, indicating convergence towards equilibrium.

4. Result and Discussion

One of the preconditions for applying the ARDL model is that none of the variables be I (2) as it invalidates the F-statistics (Pesaran et al., 2001). F-statistics will be valid only if the variables under consideration are either I (0) or I (1). Table 2 reports the result of the Dickey-Fuller Generalized Least Squares test (DF-GLS) proposed by Elliott, Rothenberg, and Stock (1996).

The results indicate that none of the variables is I (2). This makes a strong case for applying ARDL for estimating short-run and long-run coefficients of models (4) to (6). Selecting the lag length for ARDL bounds testing is crucial: taking too few lags may fail to capture the model's dynamics, while taking too many may lead to issues with degrees of freedom. The lag lengths on first difference for models (4) through (6) are determined using the Akaike Information Criterion (AIC).

Table 2. Result of DF-GLS Unit Root Test

Variables	Level	First Difference	Decision
FSI	2.519	-5.890***	I(1)
TEM	-0.608	-8.651***	I(1)
CO_2	-1.708	-5.027***	I(1)
DFL	-6.507***	---	I(0)
DEXP	-2.007	-7.752***	I(1)
FU	-0.895	-7.383***	I(1)
AEMP	-1.138	-10.530***	I(1)

Note: *** refers to significance at 1 %.

To make the long-run coefficient meaningful, it is essential to demonstrate that the variables of interest exhibit a long-term relationship. The ARDL bound test checks for co-integration between variables, even when some variables are I (0) and others are I (1). Table 3 documents the result for the Bounds test proposed by Pesaran et al. (2001).

Table 3. Results for Bounds Test

Models	F Statistics	Critical value at significance level of 5%	
		Lower Bound	Upper Bound
Model (4)	6.727	3.23	4.35
Model (5)	4.667	3.79	4.60
Model (6)	6.209	3.79	4.85

The study also used the Chow (1960) structural break test to detect a structural break in the floods of 2010 and 2022. The F-statistic value is 7.264 for the 2010 floods, confirming the rejection of the null hypothesis of no structural change. Thus, we incorporate the flood dummy in Model (6) to capture a structural break.

4.2 Long and Short Run Estimates of the ARDL Model

The last step in ARDL analysis is to estimate the model parameters. Table 4 presents the long-run relationship between various indicators of CC and FS for Pakistan over the period 1980-2023. Results for models 4 to 6 are presented in columns (2) to (4), respectively. Model (4) presents the long-run estimates of the TEMP-FSI nexus for the period 1980-2023.

A unit increase in temperature tends to lower FS by 0.137 units. The coefficient is statistically insignificant at the 1% level. Heat stress reduces crop yield and exacerbates water scarcity. These factors cumulatively reduce agricultural productivity, thereby reducing FS. Our findings align with those of Abbas, Kousar, and Khan (2022) and Sossou, Igue, and Diallo (2019). DEXP, the first control variable, has a positive and statistically significant impact on FSI at 5% significance level. A % increase in DEXP results in a 0.078-unit increase in FSI, as these expenditures help fund various agricultural, forestry, and infrastructural initiatives, including investments in irrigation systems, the provision of quality seeds, the cultivation of climate-resilient varieties, and the adoption of innovative agriculture practices. The second control variable is FU. A unit increase in FU causes a 0.031unit increase in FS by enhancing crop yield, reducing GHG emissions, thereby enhancing FS. The coefficient is significant at 5% significance level. The finding is consistent with Prasad (2009). The last control variable is AEMP. A 1% increase in AEMP enhances food security by 0.287 units, and the impact is highly significant at 1% level. The increase in AEMP enhances households' income and purchasing power, thereby improving FAC and, consequently, FS. These findings align with those of Fan et al. (2024).

Table 4. Long-Run Estimates from ARDL Model

Dependent Variable: FSI	Model 4	Model 5	Model 6
Regressors	ARDL (1,1,1,0,3)	ARDL (1,1,1,2,2)	ARDL (1,1,0,2,1)
TEM	-0.1366*** (3.6702)	-	-
CO_2	-	-0.2318* (1.2548)	-
DFL	-	-	-0.127** (0.0010)
DEXP	0.0780** (2.1808)	0.0813* (1.9820)	0.1058** (2.1036)
FU	0.031* (1.9479)	0.3108** (2.1550)	-
AEMP	0.2871*** (4.8307)	0.3719*** (3.5127)	0.131** (3.1245)
Dum2010	-	-	-0.2789*** (4.2152)
Constant	1.1001 (0.6970)	0.9427 (0.7125)	1.0688 (0.6102)
R^2	0.9579	0.9318	0.9461
Adj R^2	0.9565	0.9309	0.9449

Note: Food Security Index (FSI) is a dependent variable in all models. The climate indicators are temperature (TEM) in Model 4, CO_2 emissions in Model 5, and direct flood losses (DFL) in Model 6. The control variables are development expenditure (DEXP), fertilizer consumption (FU), and agricultural employment (AEMP). Dum2010 is a dummy variable capturing the impact of the 2010 flood. Parentheses () values indicate t values. *, **, and *** show 10%, 5% and 1% significance levels.

Source: Authors' Estimates

Column (3) in Table 4 reports the empirical results for the CO_2-FS nexus. A unit increase in CO_2 emissions tends to lower food security by 0.232 units. Increased levels of CO2 lead to excessive mineral concentrations, reduce crop yields, and thus disturb agricultural productivity. Ultimately, these impacts tend to lower FS. The findings are consistent with Gobezie and Boka (2023) and Dakora, Li, and Zhao (2025). The last column documents the impact of DFL on FS in Pakistan. The analysis reveals that a % increase in DFL results in a 0.127 units' decline in FSI. It is statistically significant at 5% significance level. Furthermore, FDL can lead to a substantial reduction in agricultural output, which poses a threat to FS. The finding aligns with that of Yolchi et al. (2024). The R^2 and adjusted R^2 values are high across all models, indicating that the models explain most of the variation in FSI. This suggests that all three models fit the data very well. The long-run results indicate that all climatic variables (TEM, CO_2, and DFL) harm FS. Similar to model (4), DEXP, FU, and AEMP have a positive and significant impact on FS in models 5 and 6. Model 6 also incorporates the impact of the 2010 floods through a dummy variable for floods, capturing structural change. The significant negative coefficient confirms the devastating impacts of the 2010 floods on the FS of Pakistan. Table 5 presents the short-run results for Models 4-6. The findings confirm that the climate indicators have a significant negative impact on all three models.

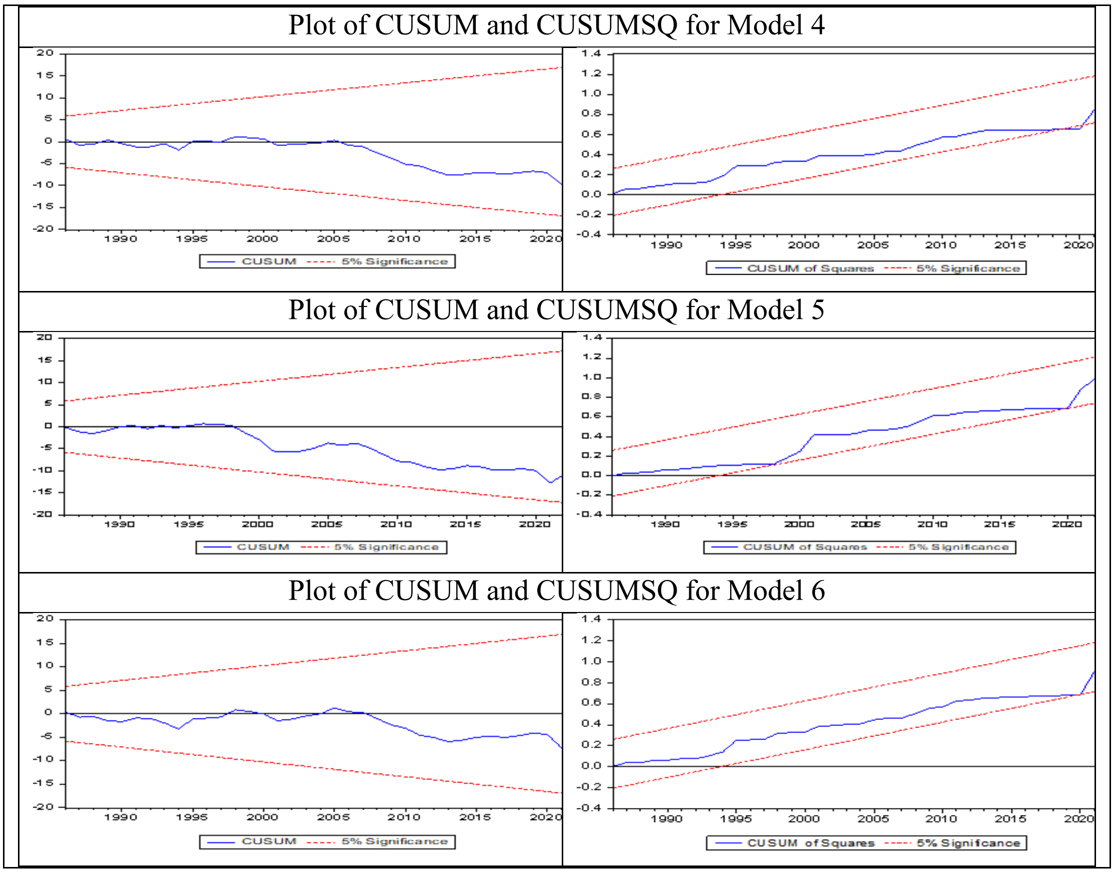
The bottom part of Table 5 presents the results for diagnostic tests. The Breusch-Godfrey-LM test statistics are pretty low, and the p-values are high, confirming the null hypothesis of no serial correlation. Likewise, a low value of the Breusch-Pagan LM test statistic indicates that the models are free of heteroskedasticity. Next, the study applies the parametric stability test. Figure 1 reports the findings of the CUSUM and CUSUMSQ tests. The results of the stability tests indicate that the residual variances are stable, as they lie within the 5% critical line. This confirms the stability of the estimated parameters.

Table 5. Short-Run Coefficient Estimates from ARDL Models

Variables	**Model 4** ARDL (1,1,1,0,3)	**Model 5** ARDL (1,1,1,2,2)	**Model 6** ARDL (1,1,2,0,1)
ΔTEM	-0.109431** (0.027)	-	-
ΔCO_2	-	-0.17920** (2.2172)	-
ΔDFL	-	-	-0.0921** (4.82)
ΔDEXP	0.0514 (0.8912)	0.0712 (1.2102)	0.0470 (0.7108)
ΔDEXP(-1)	-	-	0.0810 (1.2517)
ΔFU	-	0.2517** (3.1025)	-
ΔFU(-1)	-	0.1905** (2.1808)	-
ΔAEMP	0.1918** (2.1307)	0.3017* (1.91257)	0.1084* (1.9188)
ΔAEMP(-1)	0.1371 (1.9012)	0.1917** (3.1875)	-
ΔAEMP(-2)	0.2328** (3.1847)	-	-
ECT(-1)	-0.7591*** (4.1490)	0.61287*** (6.1245)	-0.8327*** (5.2157)
$\chi^2_{GF\ LM}$	0.256 (0.4570)	0.3471 (0.8125)	0.8412 (0.6187)
$\chi^2_{BP\ Het}$	0.06971 (0.9125)	0.2817 (0.6811)	0.0918 (0.9301)
F-Statistics	6.1324*** (0.000)	5.1846*** (0.000)	7.1324*** (0.000)
Observations	44	44	44

Note: The Food Security Index (FSI) is a dependent variable in all models. The independent variables are temperature (TEM) in Model 4, CO_2 in Model 5, and direct flood losses (DFL) in Model 6. The control variables are development expenditure (DEXP), fertilizer consumption (FU), and agricultural employment (AEMP). Parentheses () values indicate standard errors. **, and *** show 5% and 1% significance levels.

Figure 1. Parametric Stability Test



5. Conclusion and Policy Recommendation

The current study aims to assess the short- and long-run impact of CC on FS in Pakistan using the ARDL model for the period 1980-2023. The study considered three indicators of CC, namely TEM, CO_2 emissions, and DFL. The ARDL bound testing of all the models indicates that long-run co-integration exists among the variables. The first indicator of climate change, TEM, has a negative and significant short- and long-term influence on the FSI. The second measure of CC, CO_2 emissions, also shows an adverse effect in both the short and long runs; however, the impact is significant only in the short run. The third indicator of CC is DFL, which indicates a statistically significant and adverse effect on FSI. The control variables show a positive impact in the short run. It plays an important role in enhancing FS nationwide. Development expenditure enhances agricultural infrastructure and market access, alleviating food distribution challenges and fostering a stable supply chain. Fertilizer consumption directly boosts agricultural productivity, ensuring food production meets the growing demand. Meanwhile, increasing employment in agriculture provides income opportunities for rural populations, improving their ability to access and afford nutritious food. These factors strengthen Pakistan's FS by increasing food availability, improving access, and stabilizing the agricultural sector, which is essential for the country's long-term sustainability in addressing FS problems.

The government should encourage climate-resilient farming practices, including water-saving irrigation methods, and introduce drought-resistant and heat-tolerant crop varieties. CC adaptation strategies should be an integral part of agricultural planning, as outlined in the National Food Security Policy, which can forecast and mitigate CC. The study recommends increased spending on agriculture-related development to enhance the agricultural infrastructure necessary for FS. Such activities will enable farmers to respond to sudden climate shifts, including floods and droughts, and maintain a stable food supply. The study can be further improved in the future if long and consistent data on other factors affecting FS are readily available, such as agricultural land, modern farming technologies, and research and development.

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