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Nexus between Climate Change and Cereal Production in India - An ARDL Approach

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ABSTRACT
Cereal production remains a critical global concern, particularly in India, where it is increasingly affected by the adverse impacts of climate change. This study investigates the influence of actual rainfall, average temperature, and agricultural credit on cereal production in India, utilizing time series data spanning from 1990–91 to 2020–21. The analysis is conducted using the Autoregressive Distributed Lag (ARDL) model to assess both short-run and long-run relationships between climate variables—actual rainfall (ARF) and average temperature—and the non-climate variable, agricultural credit, in relation to cereal production. The findings reveal that actual rainfall (ARF) has a positive but statistically insignificant impact on cereal production in the long run, while it exhibits a significant positive relationship in the short run. Average temperature is found to have a consistently negative effect on cereal production in both the long and short term. Agricultural credit demonstrates a positive and significant influence on cereal production in the long run, whereas in the short run, its impact is negative. These results underscore the importance of targeted policy interventions. It is recommended that the government provide subsidies and that policymakers prioritize investment in climate-resilient crop varieties and advanced agricultural technologies to mitigate the adverse effects of rising temperatures on cereal production in India.

Keywords- Actual Rainfall, Average Temperature, Agriculture Credit, Cereals Production, ARDL Model.

1. INTRODUCTION

Agriculture remains the backbone of many economies worldwide, especially in developing countries where a significant portion of the population relies on farming for their livelihoods (FAO, 2021). Cereals, including wheat, rice, maize, barley, and millet, are staple foods vital for food security and economic stability (World Bank, 2020). The production of cereals is influenced by several factors, including climatic conditions, access to financial resources, and advancements in agricultural technology (Schlenker & Roberts, 2009). Among the climatic factors, actual rainfall and average temperature are critical determinants of agricultural productivity (IPCC, 2019). Rainfall is essential for irrigation, soil moisture retention, and overall plant growth, while temperature influences plant metabolism, growth cycles, and yield potential (Lobell et al., 2011). Climate variability and extreme weather conditions, such as droughts and floods, can significantly impact cereal production, leading to fluctuations in food supply and prices (Nelson et al., 2010). In addition to climatic variables, access to agricultural credit plays a crucial role in determining production levels. Agricultural credit facilitates the purchase of essential inputs such as high-yielding seeds, fertilizers, pesticides, and modern irrigation techniques (Zeller & Sharma, 2000). It also enables farmers to invest in mechanization and adopt improved farming practices that enhance productivity. However, small and marginal farmers often face challenges in accessing adequate financial resources, limiting their ability to optimize cereal production (Khandker & Samad, 2018). Given the importance of cereals in ensuring food security and sustaining rural livelihoods, it is crucial to analyse the impact of key factors such as actual rainfall, average temperature, and agricultural credit on cereal production. This study aims to provide empirical insights into how these variables interact and influence agricultural output, thereby assisting policymakers, agricultural stakeholders, and financial institutions in making informed decisions to enhance productivity and sustainability. This objective aims to assess how variations in rainfall patterns affect crop growth, yield, and overall productivity. Other objectives of the study are to examine the relationship between agricultural credit, average temperature, and cereal production in India. Comment This objective is asymmetric and follows a zigzag-pattern. The novelty of this study lies in its application of the ARDL model to explore both short- and long-term dynamics between climate change variables and cereal production in India—an area with limited empirical investigation. It also uniquely integrates agricultural credit as a moderating factor, offering a comprehensive view of how financial access and environmental shifts jointly impact food security. The structure of this paper is organized into five key sections: the first section presents the introduction, the second provides a review of relevant literature, the third outlines the data and research methodology, the fourth discusses the results and their interpretation, and the fifth concludes the study with key findings and implications.

2. LITERATURE REVIEW

The agriculture sector is a major sufferer of climate change, both globally and in India. Cereals account for about 92% of India's total food grain output, and climate change significantly influences cereal production (Singh et. al., 2024). Cereal crops, including wheat, rice, millet, and maize, are important both globally and in India. Cereal production is heavily influenced by climate change, irrigation, and fertilizers. Climate change results in a reduction in cereal production, which contributes to food insecurity both worldwide and in India (Wang et al. 2018). According to Kumar et al. (2021), climate change has affected cereal production in underdeveloped and developing countries. This study uses time series data from 1971 to 2016 and employs the Fully Modified OLS (FMOLS) and Dynamic OLS (DOLS) methods. The climate factors examined include average temperature, rainfall, and CO2 emissions, while other variables include rural population and cultivated land dedicated to cereals. The findings indicate that CO2 emissions and rainfall are positively related; however, average temperature has an adverse effect on cereal production. The relationship between climate change and cereal production in India shows both positive and negative trends in different crops. This study is based on time series data from 1966 to 1999. The findings indicate that rice crops are very sensitive to climate variables such as temperature and rainfall, while millet is less affected by climate change (Gupta et al. 2014). The productivity of Kharif crops, such as rice, maize, jowar, and bajra, as well as rabi crops like wheat and barley, decreased with an increase in temperature or a decrease in solar radiation above normal levels. However, the productivity of various Kharif and rabi crops increased under expected enhanced CO2 concentrations. The highest productivity loss occurred in barley during the rabi season (40.7%), while the smallest loss was observed in rice during the Kharif season (5%) with an increase of 3.0 °C in temperature compared to normal. Conversely, maximum productivity loss in the rabi season was also noted in barley (5.0%), while the minimum was in jowar during the Kharif season (1.8%) with a decrease of 2.5% in solar radiation from normal levels (Yadav et al. 2015). Abbas et al. (2016) examine the relationship between climate and non-climate factors in cereal production in India, using time series data from 1965 to 2015. The climate inputs considered are CO_2 emissions, rainfall, and temperature, while non-climate variables include electricity, agricultural credit, and agricultural labour. In this study, the researchers employ the ARDL method, and the findings indicate that, in the long run, climate factors such as temperature and CO_2 emissions are negatively related to cereal production, while rainfall is positively related. Among the non-climate factors, agricultural labour, energy, and credit are all significantly and positively related to cereal production and yield. According to Amber et al. (2022), rice production has both positive and negative relationships with climate and non-climate factors. This study is based on time series data from 1970 to 2020 and employs the ARDL method. The findings reveal that annual temperature has a negative relationship with rice production in the long run, while CO_2 emissions are positively related. Additionally, non-climate factors such as fertilizers, water availability, and labour are positively related to rice production in Pakistan. Ahmed et al. (2023) state climate change impacts food security. This study is based on time series data from 1990 to 2019 and employs the ARDL model. The study identifies several factors that impact food grain production, including energy, CO_2 emissions, N_2O, rainfall, and temperature. Findings indicate that energy, methane emissions, and rainfall are positively related in the long and short run. In contrast, other variables, such as N_2O and temperature, are negatively related in the long and short run. This study examines the impact of climate change on cereal production in Bangladesh. It utilizes time series data from 1988 to 2014 and implements the ARDL model. The main climate factors considered are annual mean rainfall, mean temperature, and CO_2 emissions, while other influential factors include the rural labour force and energy consumption. The findings indicate that rainfall is positively and significantly related to cereal production in both the long and short run. However, CO_2 emissions are significantly negatively related to cereal production in both time frames. Temperature adversely impacts cereal production in the short run. Additionally, other variables such as cereal crop area, energy consumption, the rural labour force, and financial development are positively and significantly related to cereal production (Chandio et. al., 2022). Despite extensive research on the effects of climate change and non-climate factors on individual cereal crops such as wheat, rice, maize, barley, millet, sorghum, oats, and rye, there is a notable gap in studies examining aggregate cereal production at the global level, with very limited research conducted in India. Furthermore, the influence of climate and non-climate factors, such as annual average temperature, annual actual rainfall, and agricultural credit, has not been sufficiently addressed. In this study, we focus on the effects of climate and non-climate factors on cereal production in India from 1991 to 2020. This research aims to fill the identified gap in both the short and long term, using the autoregressive distributed lag (ARDL) model. In this study, our objective is to identify the significant relationships between climate change and cereal production, as well as between agricultural credit and cereal production.

Null hypothesis: The analysis reveals that there is no statistically significant impact of climate change variables on cereal production in the study period.

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3. DATA AND METHODOLOGY

3.1 DATA

The purpose of this study is to evaluate both the short-term and long-term impacts of climatic and non-climatic factors on cereal production in India. The study utilizes time series data from 1991 to 2020. The dependent variable is cereal production, while the independent variables include annual actual rainfall, annual average temperature, and agricultural credit. Data on actual rainfall is sourced from Agricultural Statistics 2022, average temperature data is obtained from the Indian Meteorological Department (IMD), and the data on agricultural credit is taken from the Reserve Bank of India Handbook.

Table-1- List of study variables selected for analysis

Variable Types	Variable	Abbreviation	Units	Time	Resources
Output Variable	Cereal Production	CP	Lakh Tonnes	1991-2020	RBI
Input Variables	Actual Rainfall	AR	MM	1991-2020	IMD
	Average Temperature	AT	Celsius	1991-2020	IMD
	Agricultural Credit	AC	Crore	1991-2020	RBI

3.2 METHODOLOGY

The association between climate, non-climate factors and cereals production was examined using the following functional model, This study employs the Auto-Regressive Distributed Lags (ARDL) model, which is recommended by several studies for examining this type of sample data. The ARDL model is suitable for exploring the relationships among the variables in the dataset.

$$CP = f(AR, AT, AC) \text{ ---------------------------(1)}$$

$$CP = \alpha + \alpha_1 AR + \alpha_2 AT + \alpha_3 AC + €t \text{ ----------------(2)}$$

Equation (2) can be expressed as follows: α denotes the intercept term, and ε_t represents the stochastic error term. By applying the natural logarithm to both sides of the equation, the variables are transformed as follows—LNCP, LNAR, LNAT, and LNAC denote the natural logarithms of cereal production, actual rainfall, average temperature, and agricultural credit, respectively.

$$LNCP_t = \alpha + \alpha_1 LNCP_t + \alpha_2 LNAR_t + \alpha_3 LNAT_t + \alpha_4 LNAC_t + €t \text{--------------------(3)}$$

In this study, Formula (3) requires additional refinement to determine the short- and long-term relationships between climate and non-climate factors affecting cereals productivity in India.

$$\Delta LNCP_t = \alpha + \alpha_1 LNCP_{t-1} + \alpha_2 LNAR_{t-1} + \alpha_3 LNAT_{t-1} + \alpha_4 LNAC_{t-1} + \sum_{t=1}^{p} \beta \Delta LN\, CP_{t-1} + \sum_{t=1}^{p} \beta 1\, \Delta LN\, AR_{t-1} + \sum_{t=1}^{p} \beta 2\, \Delta LN\, AT_{t-1} + \sum_{t=1}^{p} \beta 3\, \Delta LN\, AC_{t-1} + et \text{-----}(4)$$

Equation (4) illustrates that the Auto Regression Distribution Lag (ARDL) model comprises components that address both long-term and short-term dynamics. By isolating certain parts, it facilitates long-term analysis, while another section focuses on short-term behaviour.

$$\Delta LNCP_t = \sum_{t=1}^{p} \beta \Delta LN\, CP_{t-1} + \sum_{t=1}^{p} \beta 1\, \Delta LN\, AR_{t-1} + \sum_{t=1}^{p} \beta 2\, \Delta LN\, AT_{t-1} + \sum_{t=1}^{p} \beta 3\, \Delta LN\, AC_{t-1} + et ----- (5)$$

As a result, the ARDL model is employed to create the error correction model (ECM), enabling a more precise assessment of the short-term relationship between the variables. The specific formula is provided, with the short-term relationship illustrated in equation 5.

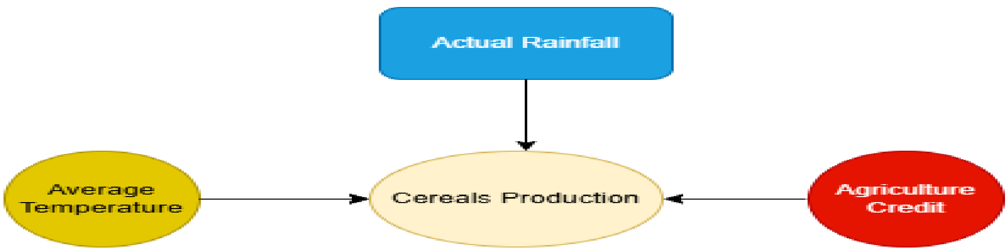


Figure- 1: Framework of the Study

4 RESULT AND DISCUSSION

4.1 DESCRIPTIVE ANALYSIS

Table 2 outlines cereals productivity (CP) as the dependent variable being measured, while other variables are independent, including actual rainfall (AR), average temperature (AT), and agriculture credit (AC). The average value of Cereals production is 3.30, while the independent variables show mean values of 3.05 for actual rainfall, 5.16 for average credit, and 1.39 average temperature. The standard deviation (S.D.) of cereals production is 0.07, indicating comparatively little variance. The standard deviation values of the independent variables are as follows: 0.036 for actual rainfall, 0.705 for agriculture credit, and 0.005 for average temperature. The standard deviation of agriculture credit, at 0.705, shows a higher deviation compared to the other variables. The skewness of the dependent variable is 0.165, while the skewness of the other variables—actual rainfall, agriculture credit, and average temperature—are -0.105, -0.042, and 0.081, respectively. The kurtosis of the dependent variable is 1.877, while the kurtosis values for the other variables are as follows: actual rainfall is 2.23, agriculture credit is 1.622, and average temperature is 3.201. Although the probability is highest for average temperature at 0.959, the probabilities for the other variables are as follows: 0.67 for actual rainfall, 0.30 for agriculture credit, and 0.42 for the dependent variable.

Table-2(Dependent and Independent Variables)

Variables	LCP	LAR	LAC	LAT
Mean	3.309	3.059	5.166	1.395
Median	3.299	3.058	5.218	1.395
Maximum	3.439	3.123	6.197	1.406
Minimum	3.194	2.988	4.049	1.384
Std. Dev.	0.07	0.036	0.705	0.005
Skewness	0.165	-0.105	-0.042	0.081
Kurtosis	1.877	2.231	1.622	3.201
Jarque-Bera	1.712	0.794	2.382	0.084
Probability	0.425	0.672	0.304	0.959

Author's calculation in E-Views-10

4.2 RESULT OF AUGMENTED DICKEY FULLER TEST

A model known as the Auto Regression Distribution Lags (ARDL) is also developed in the study. Using this model requires all variables to be stationary at either I(0) or I(1). This is a necessary condition for ARDL analysis. To assess whether the data has a unit root, the ADF test. The ADF test is applied, along with data characteristics, to detect the presence of a unit root in each variable. The test results are displayed in Table 3. LNCP, LNAR, LNAT, and LNAC are integrated at I(I) and I(0), according to the A.D.F. test (1). All the variables are stationary, either at I(0) or I(I)

Table-3 (Dependent and Independent Variables)

Variables	Level		1st Difference		
	t-value	**p-value**	**t-value**	**p-value**	**Decision**
Average Temperature	-3.21***	0.02	-7.24***	0	I(0)
Cereals Production	0.30**	0.91	-10.82**	0	I(I)
Actual Rainfall	-5.03***	0	-6.75***	0	I(0)

Agri-Credit	-0.81**	0.79	4.54**	0	I(I)

Note 1%, 5%, show the *, ** Author's calculation in E-Views-10**

The findings in Table 3 show that half of the variables exhibit significant evidence of stationarity at the 1% level for the ADF test. The variables average temperature and actual rainfall are stationary at I(0), while other variables, such as cereals production and agriculture credit, are stationary at the first difference, I(1).

4.3 ARDL BOUND CO-INTEGRATED TEST

The co-integration test assesses whether the variables maintain a stable long-term relationship. A long-term co-integrated relationship between the variables is suggested when the F-statistic is 5.94 exceeds the upper bound I (1) 4.37 at a given 5% level of significance.

This demonstrates that, over the long term, at the 5% level, LNAR, LNAT, and LNAC are co-integrated with LNCP. These findings enable a more detailed examination of the short- and long-term relationships within the ARDL model.

Table 4: ARDL Bound Test Cointegration

F-Bound Test

Test Statistic	**Value**	**Signif.**	**I(0)**	**I(1)**
F-statistic	5.9456	10%	2.72	3.77
K	3	5%	3.23	4.37
		2.50%	3.69	4.89
		1%	4.29	5.61

Sources: (Calculated by the author using the EViews-10 software)

Table 5: ARDL Bound test and Long Run Analysis

Variable	**Coefficient**	**Std. Error**	**t-Statistic**	**Prob.**
LARF	0.03	0.18	0.16	0.88
LAC	0.10	0.01	11.76	0.00
LAT	-2.37	1.45	-1.64	0.12

LCP = (0.0283*LARF + 0.1037*LAC -2.3712*LMT)

Source- Author's Calculation through EViews

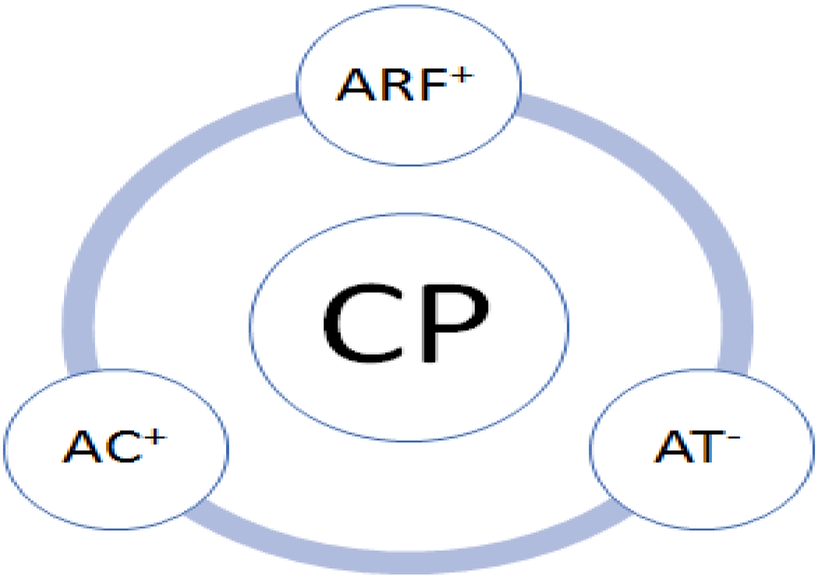


Figure 2 Summary of result

It is crucial to carry out the ARDL Bound test to determine the long run and short run relationship between variables to confirm the existence of co-integration. The ARDL bound test used in the current study to investigate the long run relationship between LNCP, LNAR, LNAT and LNAC. The finding in the table 5**,** show that there is a long run relationship. The study findings show that LARF has a positive and insignificant influence on the cereals production over the long-run. As the 1% increase the actual rain fall, the cereal production will increase the 0.028%. A study by Lobell et al. (2011) indicates that while rainfall variability influences cereal yields, factors such as soil moisture conservation and agronomic practices can mitigate these effects, making the statistical relationship weak or insignificant. According to Mendelsohn & Dinar (2009), the impact of rainfall on cereal production varies by region and over time, sometimes making its relationship insignificant when other climatic and non-climatic factors dominate. Agriculture credit is positive and significantly related with the cereals production in India. As the agriculture credit (AC) increases 1%, then cereals production increases the 0.10%. According to Yadav et. al., (2024), institutional agricultural credit has a statistically significant positive impact on crop productivity. The empirical results from the bounding *F*-test indicate a statistically significant relationship between agricultural credit and the yield of total cereals, millets, and rice at the 1% level, confirming the long-run equilibrium relationship in the models. The long-run impact of crop loans positively affects the yield of total cereals and rice, while there is no statistically significant effect on the yield of millets (Mahapatra & Jena, 2023). The average temperature is negatively related to cereal production. As the average temperature increases by 1%, total cereal production decreases by 2.37%. According to Singh (2017), climate change, and cereals production is negatively related, production of paddy crops is expected to decline by 15.04 percent in plains farms and by 12.83 percent in hill farms by the turn of this century. According to Kumar et. al., (2014) the production of wheat, a crop sensitive to weather, may be influenced by climate change. The regional vulnerability of wheat production to climate change in India was assessed by quantifying the impacts and adaptation gains through a simulation analysis using the Info Crop-WHEAT model. Negative impacts of climate change are projected to be less severe in low-emission scenarios compared to high-emission scenarios. Differences in sowing time are one of the major reasons for the variable impacts on yield, with late-sown areas projected to suffer more than those sown on time.

4.4 ERROR CORRECTION MODEL

The table 6 shows the ARDL Error Correction Model (ECM), error correction model represents the short run relationship between the cereals production dependent variable, and other independent variables such as actual rainfall (ARF), agriculture credit (AC) and average temperature (AT). Table 6 illustrates that the first difference of the log-transformed variable ARF has a coefficient of 0.196, indicating a positive relationship between D(LARF) and the dependent variable cereals productivity. However, the associated t-statistic (5.21) and p-value (0.0216) suggest that this relationship is statistically significant at conventional levels (e.g., 5%). Although the agriculture credit (AC) is negatively and insignificantly related with cereals production in India. However, the t-statistics is (-0.138807), and probability is p= 0.8909. The coefficient of average temperature is -1.546918, that represent the negative correlation between average temperature and cereals production in India. The t-value is -1.958496, and the probability is 0.063.

Table 6: Short run ARDL Model

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	5.8	1.11	5.22	0
D(LARF)	0.2	0.08	2.48	0.02
D(LAC)	-0.01	0.1	-0.14	0.89
D(LAT)	-1.55	0.79	-1.96	0.06
Coint. Eq. (-1) *	-0.97	0.19	-5.21	0

Source- Author's Calculation through EViews

4.5. DIAGNOSTIC AND STABILITY TEST OF THE ARDL MODEL

This study employs the CUSUM and CUSUM of squares tests to assess the stability of the ARDL model. The CUSUM and CUSUM of Squares (CUSUMSQ**)** diagnostic tests use graphical plots to detect structural breaks or instability in regression models. The CUSUM (Cumulative Sum) test in the graph assesses the stability of a regression model's parameters over time. The blue line represents the cumulative sum of recursive residuals, while the red dashed lines indicate the 5% significance level. If the CUSUM line remains within these boundaries, the model's parameters are considered stable. Conversely, if it crosses the boundaries, it suggests structural breaks or instability in the model. In the given graph, the CUSUM line fluctuates within the red boundaries, indicating no significant structural changes. This test is widely used in econometrics to detect parameter instability in time series and regression model.

Figure: 3 CUSUM TEST

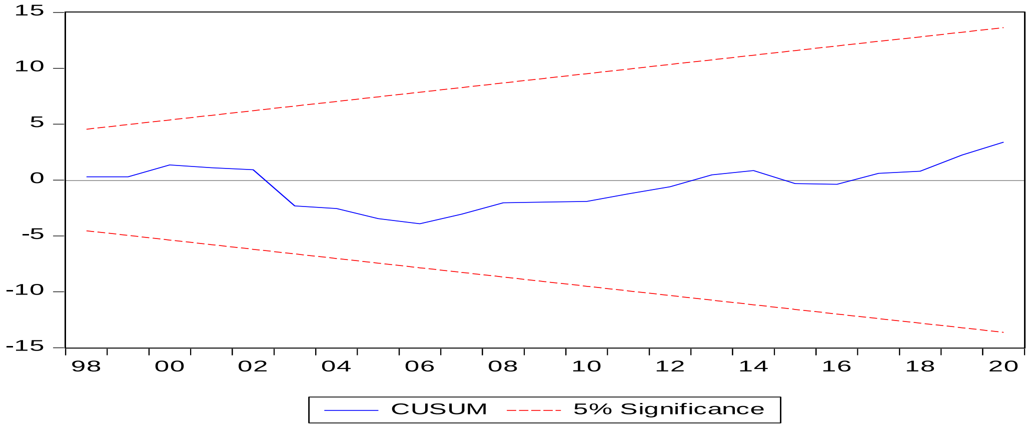
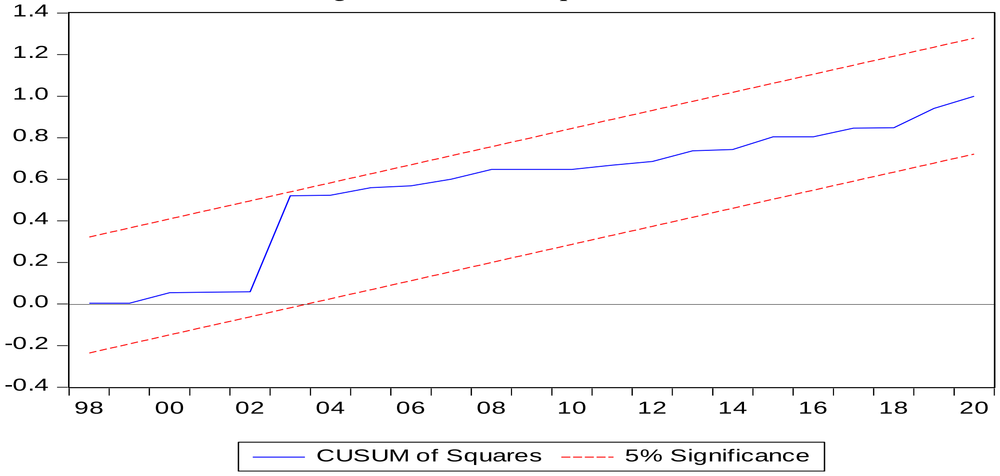


Figure: 45 CUSUM Square TEST



the CUSUM of Squares line remains within the bounds, the model exhibits parameter stability. However, in this graph, the CUSUM of Squares line sharply rises around 2002-2004 and continues to increase, approaching the upper boundary. This suggests possible structural breaks or increasing variance in the model over time, indicating potential instability in the regression parameters.

4. CONCUSION AND POLICY IMPLICATION

The study finds that cereal production is positively influenced by actual rainfall in both the long run and short run. This indicates that adequate and timely rainfall plays a crucial role in enhancing agricultural productivity. However, other factors such as agricultural credit and average temperature exhibit mixed effects. Agricultural credit negatively impacts cereal production in the short run but has a positive effect in the long run, suggesting that farmers may initially struggle with debt repayments or investment inefficiencies before reaping the benefits. Meanwhile, higher average temperatures negatively affect cereal production in the short run and long run, likely due to heat stress and adverse climatic conditions. Average temperature has the negative impact with cereals production, policy maker should investment in climate-resilient seed varieties, and precision farming, that reduced the negative impact the rising average temperature. Although agricultural credit positively affects cereal production in the long run, its short-term negative impact indicates a need for better credit allocation and monitoring. Policies should ensure easy access to credit with favourable repayment terms and offer financial literacy programs to help farmers utilize credit effectively.

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