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Research Article

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Posted Date: April 30th, 2021

DOI: https://doi.org/10.21203/rs.3.rs-469124/v1

Modeling the Impact of Climate and Non-Climatic Factors on Cereal Production: Evidence from Indian Agriculture

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Abstract: The underpinned study examines the effects of climatic and non-climatic factors on Indian agriculture, cereal production, and yield using the country-level time series data of 1965–2015. With the autoregressive distributed lag (ARDL) bounds testing approach, the long-term equilibrium association among the variables has been explored. The results reveal that climatic factors like CO_2 emissions and temperature adversely affect agricultural output, while rainfall positively affects it. Likewise, non-climatic factors, including energy used, financial development, and labor force, affect agricultural production positively in the long run. The estimated long-run results further demonstrate that CO_2 emissions and rainfall positively affect both cereal production and yield, while temperature adversely affects. The results exhibit that the cereal cropped area, energy used, financial development, and labor force significantly and positively impact the long-run cereal production and yield. Finally, pairwise granger causality test confirmed that both climatic and non-climatc factors are significantly

influencing agriculture and cereal production in India. Based on these results, policymakers and governmental institutions should formulate coherent adaptation measures and mitigation policies to tackle the adverse climate change effects on agriculture and its production of cereals.

Keywords: Agricultural output, Climate change, Cereal production, ARDL method, India

Introduction

Climate as a word is specified to explain the global environmental situation, described through temperature variations, rainfall, and humidity. Therefore “climate change” denotes variation in an environmental condition through nature and human involvements. Moreover, rising sea levels, variation in meteorological patterns, global warming, evaporating glaciers, and several further are part of climate change worldwide (Chandio et al. 2020a, Nath &Mandal 2018). Climatic change, also defined as the natural capital, helps economic development; long-term climate patterns determined the specificity of topographical regions. Examples of climate change include the variation in temperature, soil erosion, wind speed, rainfall, typhoons, and the severity of drought and floods (Dulal et al. 2010).

However, environmental changes link with the marketplace, populations, and other socio-economic and demographic components that act concurrently (Palanisami et al. 2010). Populace pressure, expanding industrialization, modern technologies, increasing development, urbanization, and deforestation are the main reasons triggering extra sensitivity in the environment. Also, frequent threats due to climatic variations in economic activities like food and agriculture production, employment, income, and worldwide agriculture-based industries occur in environmental changes (Kumar et al. 2016).

Particularly, climate variation is the more risky natural hazard and severely damages crop production globally (Enete &Amusa 2010, Praveen &Sharma 2019, Wang et al. 2018). On a global level, threatening climatic stratum induce climate change in agriculture sectors and is interlinked with each other, resulting in increased inequality between food production and the world population (Agba et al. 2017). Furthermore, global precipitation and variations in temperature brutally affect agriculture production (Deryng et al., 2014), whereas the frequency of flood and droughts can intensify the upcoming climate change and reduce crops yield (Deryng et al. 2014, Lesk et al. 2016, Lobell et al. 2011).

Agricultural production appears vulnerable to climatic changes and negatively impacts human health, dairy and milk production, agricultural trade, and the price of food-grain goods (Kumar &Parikh 2001b, Praveen &Sharma 2019). Although climate variation is a universal issue, the nocuous impact of climate change on agriculture is more hazardous, especially for emerging countries, mainly Asian and African economics, as they have already higher temperature, lower development, and inadequate policies for development (Dubey &Sharma 2018, Gornall et al. 2010, Hossain et al. 2019, Hussain et al. 2020, Keane et al. 2009, Praveen &Sharma 2019, Van Oort &Zwart 2018). It has been empirically verified that agriculture is the primary source of income in developing countries, and people's livelihood depends on it. Agriculture production is a critical entry-point and more useful for poverty reduction in developing countries (Christiaensen et al. 2011, Liu et al. 2020). Whereas cereal production accounts for nearly one-third of the total caloric intake in the South Asian countries (Mughal and Sers, 2020); thus, considered an essential factor of food security of these economies (Kropff & Morell, 2019). Furthermore, as the population is expected to reach 9.8 billion by 2050; therefore, it is the need of the time to increase cereal production (Godfray et al. 2010). However, despite the increase in production, figures show that recent production is incapable of meeting the required targets (Ray et al. 2013). Other related studies predict the warmer earth with an average temperature of 0.2ºC in the next 30 years. Agriculture and their associated activities are the primary sources of rising GHGs in the atmosphere (Solomon et al. 2007).

In particular to the Asian emerging economy, India, the agriculture sector is still vital in economic development, despite the recent decrease in gross domestic products. This sector is continuously playing a pivotal role in food safety, poverty reduction, and job creation, employing 52 percent of the labor force (Guntukula 2019). The diversity in the agricultural sector is also high, i.e., a massive geographical area like natural resources, crop production management, weather conditions. However, it has become a more fragile and exposed area due to the low level of development and poor adaptation policy (Birthal et al. 2014). Its 30 percent population is poor, and 50 percent of farmers are still at a subsistence level of farming (Kumar et al. 2015), whereas more than 60 percent population relay on agricultural activities (Pattanayak &Kumar 2014). Figure 1 demonstrates the trend of cereal production and yield in India from 1961-2017. Evidence suggests that India is the most pretentious country due to climatic change and natural hazards, insufficient arable land, a considerable population relying on agricultural activities, rainy season depending agricultural, inadequate advanced technology to the adaptation of climatic change (Birthal et al. 2014, Praveen &Sharma 2019). The current climate change forecasts indicate the inclusive increase in temperature by 2 – 4℃, a surge in rainfall during the rainy season, and a 15 – 20 percent rise in precipitation. It will also impact agricultural productivity physically (Gupta et al., 2014); evidence shows that cereal, rice, cotton, sugarcane, sunflower, and wheat production significantly decreased (Gupta et al. 2014, Mall et al. 2006). The surge in temperature by 1 to 2℃ will affect rice production by 3 to 17 percent in India (Aggarwal &Mall 2002). In contrast, the influence of carbon fertilization on agriculture production has predicted a loss for the country by 0-40 percent (Aggarwal (2008).

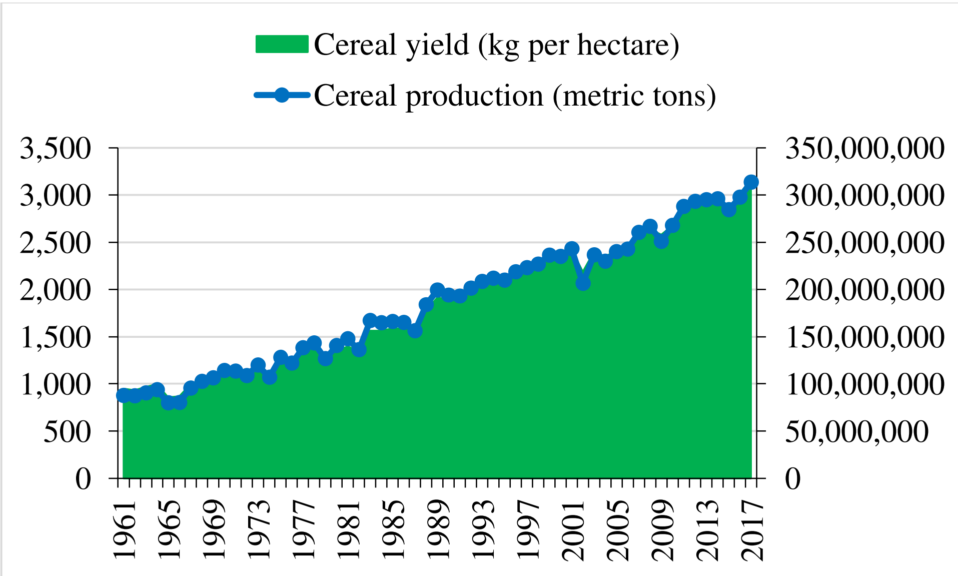

Fig. 1 The trend of cereal production and yield in India.

Source: World Development Indicators (2017)

Thus, as farmers lack proper financial resources to mitigate the effects of the environment on agriculture, climate change is becoming a severe challenge for economists, agriculturists, and policymakers to develop an advanced technique to alleviate the effects of climate on agriculture activities (Singh et al. 2017). Besides, most literature is found in developed countries, raising the concern for the country's food security (Adger et al. 2003).

Several previous studies have combined assessed the impacts of climate variations and agricultural labor force, cereal cultivated area, and energy usage on agricultural output and cereal production in developing countries. Specifically, this study aims (i) to assess the impacts of climate change and other important inputs on agricultural value added, to identify climatic and non-climatic factors that affects cereal production, and (iii) also evaluating the combined effects of climatic and non-climatic factors on cereal yield. The present comprehensive study significantly contributes to the existing literature as we are the pioneer in exploring the short- and long-term impacts of climate change and other important input factors on agricultural value added, cereal production and cereal yield in the case of India using the ARDL framework and Granger causality tests. Figure 2 demonstrates the conceptual framework presenting climatic and non-climatic factors that may affect Indian agriculture, cereal production and cereal yield.

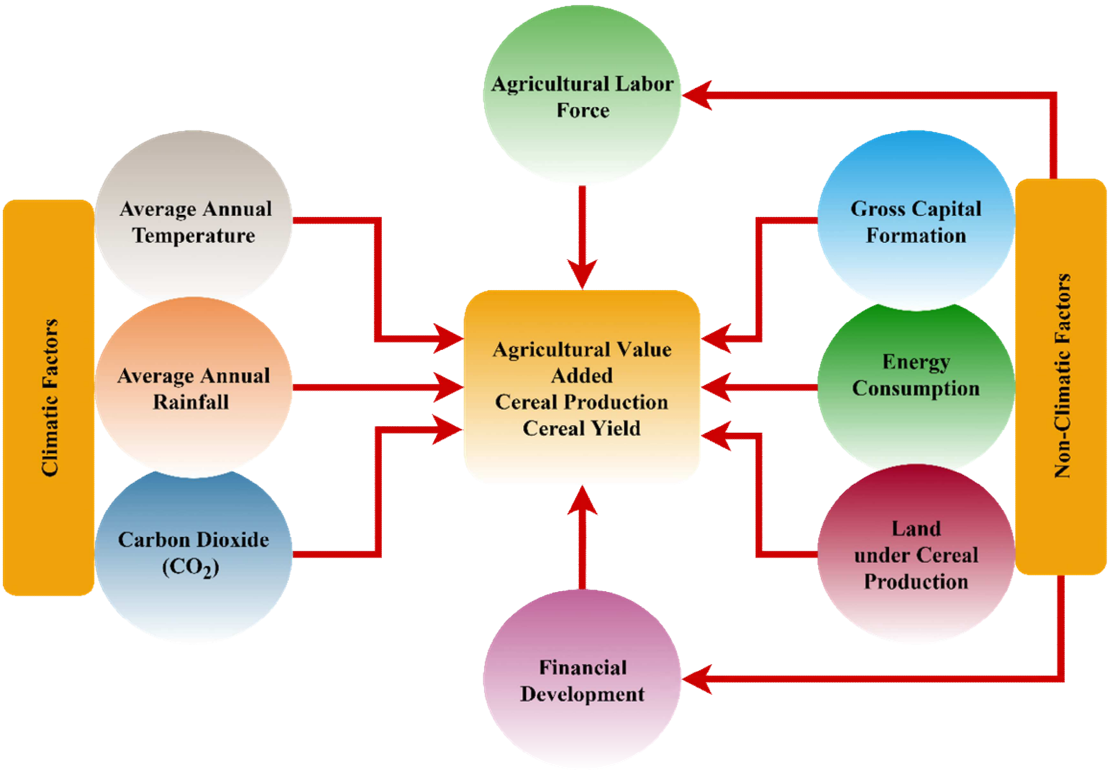

Figure 2. Conceptual framework of the study

This remaining part of this paper includes the critical literature review in section two, the source of data and research methodology in section three, section 4 empirically describes results and discussion, and the conclusion and suggestions for policy implication in the last part.

Related Literature Review

The contemporary climatic change effect and inconsistency in agriculture attract scholars around the world. Gbetibouo et al. (2005) mentioned that economically and physically, the agriculture sector is more vulnerable than any other sectors due to climatic change. Other studies also noticed that change in the climate negatively affects the productivity of agriculture. A study conducted by Bosello andZhang (2005) suggest that climatic change is a complex issue, and increasing temperature also affects agriculture production. Deressa et al. (2005), based on South African production of sugarcane, also predicted that change in climate adversely affects the sugarcane, understandably, impacting the 40% of worldwide land used for agriculture production. Several researchers investigate the weather and change in climate on crop and agricultural productivity, employing different econometric techniques. These include (Agba et al. 2017, Attiaoui &Boufateh 2019, Sarker et al. 2014, Sbaouelgi 2018, Zhang et al. 2017). These researchers estimated the relationship between the change in the climate and the yields of the crops by primarily using three approaches including (a) the production function approach, (b) the Ricardian approach, and (c) the econometric approach (Guiteras 2009, Sarker et al. 2014). Nevertheless, there is a gap in exploring the impact of these climatic and non-climatic factors on the agricultural sector, particularly the cereal yield, keeping the fact that world emerging economies like India face the worst climatic effects, which also questions the food security of the country (Kropff & Morell, 2019). Further, Pathak et al. (2003) confirm that the cereals yield are more vulnerable to climatic change. Keeping the above-defined notion in view, researchers provide a substantial consensus between climatic change and crop modeling studies across the world and might be some differences in estimated regions (Kim et al. 2015, Tan &Shibasaki 2003, Valizadeh et al. 2014). Srivastava andRai (2012) elaborated to conduct more research to check the impact of change in climate on Indian cane production. In the case of food grain production, researchers also predicted the adverse impact of climate change on grains like Saseendran et al. (2000) observed that rice production temperature has a negative influence. Also, a 5ºC change in temperature can decrease rice production, a one-degree increment in temperature can decrease the 6 percent Kerala rice production. Hundal (2007) investigated through a simulation model in the Indian state of Punjab and pointed out that the 1ºC increase in temperature can decrease wheat and rice production by 3 and 10 percent. Kar and Kar (Kar &Kar 2008) checked the effect of rainfall on Jowar production in Orissa India. The authors used the annual rainfall variable as a climate change and conclude that low rain hurts poor farmers' income and Jowar production, also indicate that more investment in the irrigation department can improve the income of poor farmers' in Orissa.

Pathak et al. (2003) estimated the climate change effects on cereals yield and found that these are more vulnerable to the change. The effects of climatic change on rice across India and revealed that an upsurge of 1 to 2ºC in temperature could reduce crop productivity by 3 to 17 percent in different zones of India (Aggarwal &Mall 2002). Kumar et al. (2011a) estimated the impact of change in climate on the Indian rice cultivated from the irrigated and rain-fed water. The authors found that rice production is reduced by 10 percent in the rain-fed northeast areas. Kalra et al. (2008) analyzed Punjab, Haryana, Rajasthan, and Uttar Pradesh of India and concluded that, due to increasing seasonal temperature, chickpea, wheat, barley, and mustard production is decreased. Kapur et al. (2009) revealed that precipitation could decrease the production of crops by 30 percent by the mid of 21st century, and mean arable land could diminution; thus, extra pressure would be on agriculture productivity. Large-scale changes in a climate significantly reduce the rice and wheat yield by 2060. Also, it can impact the nation's food security (Kumar &Parikh 2001a). Haris et al. (2010) predicted reducing Indian rice productivity by 30 percent at the end of 2080 due to the adverse climatic impacts. The authors also predicted a reduction in paddy and maize production in the Utter Pradesh state due to climate change. Kumar et al. (2011b) determined that climatic change has shifted the meteorological conditions, which affect the regular crops and lessened the growing time of rice and sugarcane yields in India. Geethalakshmi et al. (2011) mentioned that a 4ºC increase in temperature could decline rice production by 41percent in Tamil Nadu, India. Kumar et al. (2011b) also claimed that arable land might decline due to climate change to produce maize, rice, mustard, and wheat. Gupta et al. (2014) investigated the effect of climatic changes on crop production by using average temperature and precipitation of crops growing time; this study reveals that climate change reduces the rice, millet, and sorghum crop production in leading states of India.

Mukherjee and Huda (2018) suggested that crop productivity can improve by adopting new technology and temperature tolerant seeds. Multiple studies explored the effects of change in climate on the production of crops with the help of the Ricardian approach. Likewise, Mendelsohn et al. (1999) evaluated the association between the revenue from agricultural land and variables of agro-climate. Kumar (2009)) suggests that climate change reduces 9 percent of agriculture revenues in India. The author employed the Ricardian cross-sectional regression model to examine the climatic sensitively impact on agriculture revenue in India, and used minimum and maximum temperature, precipitation of all seasons. Kumar (Kumar 2014) also employed the Cobb-Douglas production to examine the non-climatic and climatic constraints on Indian grain production. The study includes the mean, highest, and lowest temperature and precipitation as factors in crop production affected by climatic variations. The empirical results show that gram, wheat, rice, and barley yields decline due to a mean minimum temperate surge.

Appiah et al. (2018) explored the association among productivity of agriculture, growth of the economy, energy consumption, population, and CO_2 emission in India, South Africa, Brazil, and China from 1971 to 2013. Estimated results revealed that a 1 percent surge in the country's economy, production of the crop, and livestock output are predicted to cause a surge of 16, 27, and 28 percent carbon dioxide emission, respectively. In Ghana, researchers analyzed the long-run association between carbon dioxide emission and agriculture productivity from 1961 to 2012. The outcome showed the presence of association among variables in the long-run. Results further suggested that CO_2 emission affects agriculture production with cocoa bean, fruit, vegetables, and livestock (Asumadu-Sarkodie and Owusu, (2016).

Summarizing the above-discussed literature, researchers here conclude that the nocuous impact of climate change on agriculture is more hazardous, especially for emerging economies in Asia and Africa. They already face higher temperatures, lower development, and inadequate policies for development (Dubey and Sharma, 2018; Hossain et al., 2019; Hussain et al., 2020; Praveen and Sharma, 2019. Further, the increase in temperature and decrease in rainfall are adversely impacting cereal production globally; thus, impacting food security and farmers' income. More specifically, the Indian agricultural production system is also facing the adverse effects of climate change. Therefore, it is imperative to explore the effect of climate and non-climate related variables on agriculture and cereal production in India.

Data and Methodology

Data

The current study used time series data (annual) for India from 1965 to 2015. The study used three dependent variables, such as agricultural value-added (AVA) in (constant 2010 US$) for model I, cereal production (NCP) in (metric tonnes) for model II, and cereal yield (CY) in (kg per hectare) for model III. While climatic and non-climatic independent variables include emission of carbon dioxide (CO_2) expressed in (million tonnes), average annual temperature (TP) expressed in (ºC), average annual rainfall (RF) expressed in millimeter (mm), energy consumption (EC) expressed in (million tonnes oil equivalent), land under cereal production (LUC) expressed in (hectares), financial development (FD) measured by domestic credit to the private sector as a share of GDP, gross capital formation (GCF) as a share of GDP, and rural population is used as a proxy of the agricultural labor force (LAB) as a percentage of the total population. The description and data source of all the variables are presented in Table 1. Whereas, the trend of logarithmically transformed all the variables is shown in Figure 3.

Table 1. Variables' description and source of data

Variables		Measurement unit	Source
Dependent variables			
Agricultural value added	(Model I)	Constant 2010 US$	WDI, 2015
Cereal production	(Model II)	Metric tonnes	-
Cereal yield	(Model III)	Kg per hectare	-
Climatic variables			
CO_2 emissions		Million tonnes	BP, 2015
Average annual temperature		ºC	WDI, 2015
Average annual rainfall		Millimeter	-
Non-climatic variables			
Energy consumption		Million tons of oil equivalent	BP, 2015
Gross capital formation (GCF)		% of GDP	WDI, 2015
Land under cereal production		Hectares	-
Domestic credit to private sector		% of GDP	-
Rural population		% of total population	-

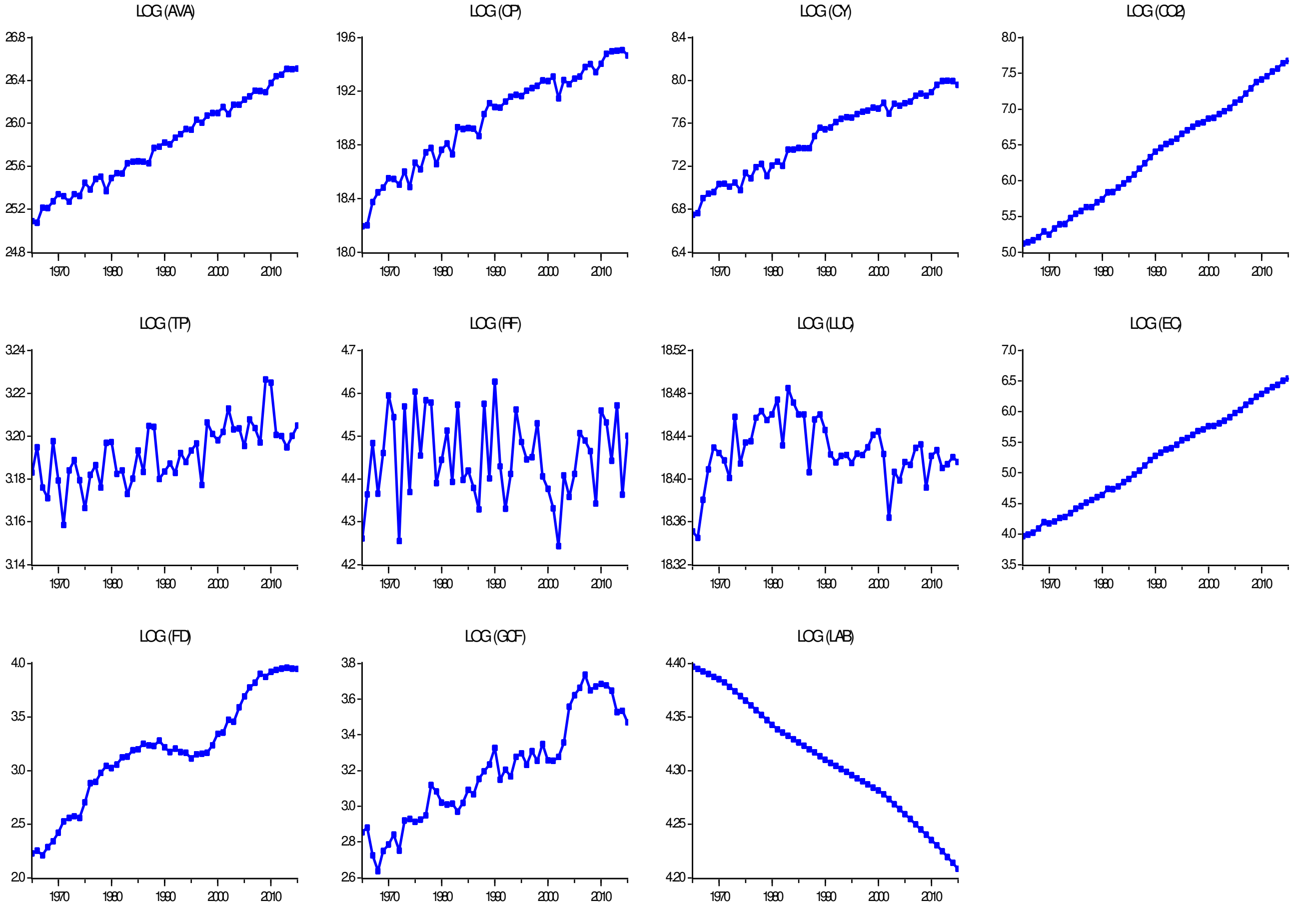

Fig. 3 Trend of all the study variables in their natural log form.

Model specification

Following the previous comprehensive studies of Chandio et al. (2020a), Pickson et al. (2020), and Warsame et al. (2021), this study explore the both short-term and long-term effects of climatic factors, such as carbon dioxide emission, average temperature, and average rainfall on agricultural output, cereal production and cereal yield in the case of India. In addition, this study also examine the impacts of non-climatic factors including land under cereal production, energy consumption, financial development, gross capital formation, and agricultural rural labour on agricultural output, cereal production and cereal yield. Financial development (FD) is expected to boost agricultural output as the easy supply of agricultural credit to rural households' increases cereal production. The FD improves the financing constraints by increasing domestic saving, institutional credit and investment activities in the agricultural sector and hence increases the agricultural productivity. Previous studies suggest that FD significantly boots agricultural output (Chandio et al. 2020d, Shahbaz et al. 2013, Zakaria et al. 2019).

Capital formation provides infrastructure for agricultural sector, which helps to enhance the agricultural productivity in the country. The contribution of capital formation is observed as one of the leading engines of agricultural development (Looney 1994; Janjua and Javed 1998). Agricultural rural labour (ARL) increases agricultural output (Chisasa &Makina 2015, Iqbal et al. 2003) But, overutilization of agricultural rural labour has an adverse impact on agricultural output (Tijani 2006).
The first part of the study examines the climatic and non-climatic factors' impact on agricultural value-added. The linear relationship between the variables for model 1 is expressed as follows:

$$\log(AVA)_t + \alpha_0 + \alpha_1 \log(CO_2)_t + \alpha_2 \log(TP)_t + \alpha_3 \log(RF)_t + \alpha_4 \log(LUC)_t + \alpha_5 \log(EC)_t + \alpha_6 \log(FD)_t + \alpha_7 \log(GCF)_t + \alpha_8 \log(LAB)_t + \varepsilon_t \tag{1}$$

The second part of the study inspects the impact of climatic and non-climatic factors on cereal production. The linear association among the variables for model 2 is expressed as follows:

$$\log(CP)_t + \beta_0 + \beta_1 \log(CO_2)_t + \beta_2 \log(TP)_t + \beta_3 \log(RF)_t + \beta_4 \log(LUC)_t + \beta_5 \log(EC)_t + \beta_6 \log(FD)_t + \beta_7 \log(GCF)_t + \beta_8 \log(LAB)_t + \varepsilon_t \tag{2}$$

The third part of the study investigates the impact of climatic and non-climatic factors on cereal yield. The linear linkage among the variables for model 3 is expressed as follows:

$$\log(CY)_t + \delta_0 + \delta_1 \log(CO_2)_t + \delta_2 \log(TP)_t + \delta_3 \log(RF)_t + \delta_4 \log(LUC)_t + \delta_5 \log(EC)_t + \delta_6 \log(FD)_t + \delta_7 \log(GCF)_t + \delta_8 \log(LAB)_t + \varepsilon_t \tag{3}$$

This underpinned paper employs the ARDL approach for testing the relationship among the study variables in the long-run. The conditional ARDL model for Eq. (1) can be expressed as follows:

$$
\begin{aligned}
\Delta \log(AVA)_t = \psi_0 & \\
& + \sum_{i=1}^{m} \psi_1 \, \Delta \log(AVA)_{t-i} \\
& + \sum_{i=1}^{m} \psi_2 \, \Delta \log(CO_2)_{t-i} \\
& + \sum_{i=1}^{m} \psi_3 \Delta \log(TP)_{t-i} + \sum_{i=1}^{m} \psi_4 \Delta \log(RF)_{t-i} + \sum_{i=1}^{m} \psi_5 \, \Delta \log(LUC)_{t-i} \\
& + \sum_{i=1}^{m} \psi_6 \, \Delta \log(EC)_{t-i} + \sum_{i=1}^{m} \psi_7 \, \Delta \log(FD)_{t-i} + \sum_{i=1}^{m} \psi_8 \, \Delta \log(GCF)_{t-i} \\
& + \sum_{i=1}^{m} \psi_9 \Delta \ \log(LAB)_{t-i} + \varphi_1 \ \log(AVA)_{t-1} + \varphi_2 \ \log(CO_2)_{t-1} \\
& + \varphi_3 \log(TP)_{t-1} + \ \varphi_4 \log(RF)_{t-1} + \varphi_5 \log(LUC)_{t-1} \\
& + \varphi_6 \log(EC)_{t-1} + \varphi_7 \log(FD)_{t-1} + \varphi_8 \log(GCF)_{t-1} \\
& + \varphi_9 \log(LAB)_{t-1} + \varepsilon_t \qquad (4)
\end{aligned}
$$

The conditional ARDL model for Eq. (2) expressed as follows:

$$
\begin{aligned}
\Delta \log(CP)_t = \lambda_0 & \\
& + \sum_{i=1}^{m} \lambda_1 \, \Delta \log(CP)_{t-i} \\
& + \sum_{i=1}^{m} \lambda_2 \, \Delta \log(CO_2)_{t-i} \\
& + \sum_{i=1}^{m} \lambda_3 \Delta \log(TP)_{t-i} + \sum_{i=1}^{m} \lambda_4 \Delta \log(RF)_{t-i} + \sum_{i=1}^{m} \lambda_5 \, \Delta \log(LUC)_{t-i} \\
& + \sum_{i=1}^{m} \lambda_6 \, \Delta \log(EC)_{t-i} + \sum_{i=1}^{m} \lambda_7 \, \Delta \log(FD)_{t-i} + \sum_{i=1}^{m} \lambda_8 \, \Delta \log(GCF)_{t-i} \\
& + \sum_{i=1}^{m} \lambda_9 \Delta \ \log(LAB)_{t-i} + \Upsilon_1 \ \log(CP)_{t-1} + \Upsilon_2 \ \log(CO_2)_{t-1} \\
& + \Upsilon_3 \log(TP)_{t-1} + \ \Upsilon_4 \log(RF)_{t-1} + \Upsilon_5 \log(LUC)_{t-1} \\
& + \Upsilon_6 \log(EC)_{t-1} + \Upsilon_7 \log(FD)_{t-1} + \Upsilon_8 \log(GCF)_{t-1} \\
& + \Upsilon_9 \log(LAB)_{t-1} + \varepsilon_t \qquad (5)
\end{aligned}
$$

The conditional ARDL model for Eq. (3) expressed as follows:

$$
\begin{aligned}
\Delta \log(CY)_t = \phi_0 &+ \sum_{i=1}^{m} \phi_1 \Delta \log(CY)_{t-i} \\
&+ \sum_{i=1}^{m} \phi_2 \Delta \log(CO_2)_{t-i} \\
&+ \sum_{i=1}^{m} \phi_3 \Delta \log(TP)_{t-i} + \sum_{i=1}^{m} \phi_4 \Delta \log(RF)_{t-i} + \sum_{i=1}^{m} \phi_5 \Delta \log(LUC)_{t-i} \\
&+ \sum_{i=1}^{m} \phi_6 \Delta \log(EC)_{t-i} + \sum_{i=1}^{m} \phi_7 \Delta \log(FD)_{t-i} + \sum_{i=1}^{m} \phi_8 \Delta \log(GCF)_{t-i} \\
&+ \sum_{i=1}^{m} \phi_9 \Delta \log(LAB)_{t-i} + \gamma_1 \log(CY)_{t-1} + \gamma_2 \log(CO_2)_{t-1} \\
&+ \gamma_3 \log(TP)_{t-1} + \gamma_4 \log(RF)_{t-1} + \gamma_5 \log(LUC)_{t-1} \\
&+ \gamma_6 \log(EC)_{t-1} + \gamma_7 \log(FD)_{t-1} + \gamma_8 \log(GCF)_{t-1} \\
&+ \gamma_9 \log(LAB)_{t-1} + \varepsilon_t \qquad (6)
\end{aligned}
$$

Following the cointegration tests based on Equations (4), (5), and (6), the error correction models (ECM) for the agricultural value-added, cereal production, and cereal yield specifications, for the present study, are specified as follows:

$$
\begin{aligned}
\Delta \log(AVA)_t = \psi_0 &+ \sum_{i=1}^{m} \psi_1 \, \Delta \log(AVA)_{t-i} \\
&+ \sum_{i=1}^{m} \psi_2 \, \Delta \log(CO_2)_{t-i} \\
&+ \sum_{i=1}^{m} \psi_3 \Delta \log(TP)_{t-i} + \sum_{i=1}^{m} \psi_4 \Delta \log(RF)_{t-i} + \sum_{i=1}^{m} \psi_5 \, \Delta \log(LUC)_{t-i} \\
&+ \sum_{i=1}^{m} \psi_6 \, \Delta \log(EC)_{t-i} + \sum_{i=1}^{m} \psi_7 \, \Delta \log(FD)_{t-i} + \sum_{i=1}^{m} \psi_8 \, \Delta \log(GCF)_{t-i} \\
&+ \sum_{i=1}^{m} \psi_9 \Delta \; \log(LAB)_{t-i} + \theta ECT_{t-1} + \varepsilon_t \qquad (7)
\end{aligned}
$$

$$
\begin{aligned}
\Delta \log(CP)_t = \lambda_0 &+ \sum_{i=1}^{m} \lambda_1 \, \Delta \log(CP)_{t-i} \\
&+ \sum_{i=1}^{m} \lambda_2 \, \Delta \log(CO_2)_{t-i} \\
&+ \sum_{i=1}^{m} \lambda_3 \Delta \log(TP)_{t-i} + \sum_{i=1}^{m} \lambda_4 \Delta \log(RF)_{t-i} + \sum_{i=1}^{m} \lambda_5 \, \Delta \log(LUC)_{t-i} \\
&+ \sum_{i=1}^{m} \lambda_6 \, \Delta \log(EC)_{t-i} + \sum_{i=1}^{m} \lambda_7 \, \Delta \log(FD)_{t-i} + \sum_{i=1}^{m} \lambda_8 \, \Delta \log(GCF)_{t-i} \\
&+ \sum_{i=1}^{m} \lambda_9 \Delta \; \log(LAB)_{t-i} + \theta ECM_{t-1} + \varepsilon_t \qquad (8)
\end{aligned}
$$

$$
\begin{aligned}
\Delta \log(CY)_t = \phi_0 & + \sum_{i=1}^{m} \phi_1 \Delta \log(CY)_{t-i} \\
& + \sum_{i=1}^{m} \phi_2 \Delta \log(CO_2)_{t-i} \\
& + \sum_{i=1}^{m} \phi_3 \Delta \log(TP)_{t-i} + \sum_{i=1}^{m} \phi_4 \Delta \log(RF)_{t-i} + \sum_{i=1}^{m} \phi_5 \Delta \log(LUC)_{t-i} \\
& + \sum_{i=1}^{m} \phi_6 \Delta \log(EC)_{t-i} + \sum_{i=1}^{m} \phi_7 \Delta \log(FD)_{t-i} + \sum_{i=1}^{m} \phi_8 \Delta \log(GCF)_{t-i} \\
& + \sum_{i=1}^{m} \phi_9 \Delta \log(LAB)_{t-i} + \theta \mathrm{ECT}_{t-1} + \varepsilon_t \qquad (9)
\end{aligned}
$$

Results and discussions

Descriptive statistics and results of the ADF and PP unit root tests are presented in Table 2. The Jarque-Bera test statistics indicate that agriculture value-added (AVA), cereal production (NCP), cereal yield (CY), CO_2 emissions, annual average temperature (TP), annual average rainfall (RF), land under cereal production (LUC), energy consumption (EC), financial development (FD), gross capital formation (GCF), and labor force (LAB) have normal distribution allied with constant variance, respectively. Before applying the ARDL approach, we checked the orders of integration of the series. The examined series is mixed orders of integration, as observed in the estimated outcomes of both unit root tests include ADF and PP (see Table 2). The estimated outcomes of both unit root tests suggested that the ARDL approach can be used for examining the long-run and short-run interrelationships among variables.

Table 2. Descriptive statistics and unit root tests

Variables	AVA	CP	CY	CO_2	TP	RF	LUC	EC	FD	GCF	LAB
Mean	25.809	18.988	7.470	6.337	3.191	4.448	18.426	5.218	3.173	3.195	4.310
Median	25.803	19.082	7.558	6.402	3.193	4.444	18.423	5.277	3.171	3.195	4.310
Maximum	26.512	19.505	7.996	7.672	3.226	4.627	18.484	6.536	3.958	3.736	4.397
Minimum	25.072	18.193	6.750	5.122	3.158	4.243	18.345	3.965	2.210	2.637	4.208
Std. Dev.	0.421	0.365	0.363	0.787	0.013	0.096	0.028	0.785	0.506	0.295	0.054
Kurtosis	1.804	2.100	1.832	1.736	3.201	2.232	3.759	1.743	2.340	2.096	1.988
Skewness	0.042	-0.429	-0.285	0.037	0.126	-0.068	-0.538	0.025	-0.174	0.187	-0.104
J-B	3.054	3.286	3.588	3.403	0.221	1.292	3.688	3.358	1.184	2.034	2.267
Prob.	0.217	0.193	0.166	0.182	0.894	0.524	0.1581	0.186	0.553	0.361	0.321
OBS	51	51	51	51	51	51	51	51	51	51	51

Unit root tests	Augmented dickey-fuller (ADF) test		Phillips and Perron (PP) test		Outcome
	level	Δ	level	Δ	
AVA	-5.904***	-5.584***	-5.926***	-16.040***	*I(0)/I(1)*
CP	-3.667**	-5.669***	-4.030**	-14.087***	*I(0)/I(1)*
CY	-2.758	-5.047***	-3.530**	-11.765***	*I(1)/I(0)*
CO_2	-4.337***	-4.883***	-2.937	-8.520***	*I(0)/I(1)*
TP	-2.716	-3.525**	-6.191***	-16.134***	*I(1)/I(0)*
RF	-7.627***	-5.331***	-7.627***	-25.462***	*I(0)/I(1)*
LUC	-4.075**	-6.688***	-3.953**	-12.211***	*I(0)/I(1)*
EC	-2.680	-4.957***	-2.745	-7.944***	*I(1)*
FD	-3.581**	-2.804	-1.738	-6.197***	*I(0)/I(1)*
GCF	-3.957**	-3.178	-3.000	-7.605***	*I(0)/I(1)*
LAB	-2.944	-4.611***	-2.180	-4.588***	*I(1)*

Variables are in their natural log form. *** and ** Indicate statistical significance at 1% and 5% level.

The conventional unit root tests cannot be applied, if structural breaks exists in time series data due to unauthentic and biased results which may lead to suspiciously the null hypothesis rejections (1). To handle that situation, we employ the Lagrange Multiplier (LM) Lee- Strazicich (2) unit root test to capture the one and two structural breaks in the series. The estimated outcomes indicate that some selected study variables are integrated at the I(0) and some of them are integrated at the I(1) (see Table 3). The findings suggesting that the ARDL model can be applied for further estimation.

Table 3. Results of Lee–Strachwich unit root test

@Level				
		t-Statistic	SB1	SB2
AVA		-5.421	1992	1998
CP		-5.641	1979	2001
CY		-5.461	1978	1990
CO_2		-4.874	1986	1999
TP		-7.275***	1996	2003
RF	K&T	-6.281**	1975	1978
LUC		-5.556	1975	1980
EC		-5.366	1986	1999
FD		-6.853***	1982	1988
GCF		-5.911*	1975	2003
LAB		-6.383**	1975	1995
@First difference				
AVA		-7.815***	1994	2009
CP		-7.522***	1975	1985
CY		-7.883***	1975	1980
CO_2		-9.246***	1975	1978
TP		-10.149***	2001	2004
RF	K&T	-11.808***	1975	1979
LUC		-9.869***	1975	1978
EC		-8.605***	1979	2004
FD		-8.139***	1987	2001
GCF		-6.590**	1989	1997
LAB		-6.723**	1979	1999

SB1 and SB2 Denote for one and two structural breaks. ***, **, and * Indicate statistical significance at 1%, 5%, and 10 levels, respectively.

The ARDL-bounds F-statistic is applied for checking the long-term cointegration relationships among the study variables. Estimated results of the bounds test for models (I), (II), and (III) are demonstrated in Table 4, indicating that the calculated F-statistic for the model (I) $F_{AVA}(AVA|CO_2, TP, RF, LUC, EC, FD, GCF, LAB)$ value is 4.741 that is greater than the values of (I1 Bound) at a 1% level of significance. It means that there is a long-term cointegration relationship among the variables. The estimated F-statistic for the model (II) $F_{CP}(CP|CO_2, TP, RF, LUC, EC, FD, GCF, LAB)$ value is 4.904, which is also higher than the values of (I1 Bound) at 1%. It means that CP, CO_2, TP, RF, LUC, EC, FD, GCF, and LAB are co-integrated in the long-run. Also, evidence from Table 3 displays that the calculated F-statistic value for the model (III) $F_{CY}(CY|CO_2, TP, RF, LUC, EC, FD, GCF, LAB)$ is 5.494, accessed the values of (I1 Bound) at 1%. It means that CY, CO_2, TP, RF, LUC, EC, FD, GCF, and LAB are also co-integrated in the long-run. The authors also used the Johansen cointegration approach to check the robustness of the long-term cointegration associations among the study variables. The estimated outcomes of the rest for models (I), (II), and (III) are displayed in Table 5, which shows the robust cointegration exists among the variables in the long-run.

Table 4. ARDL cointegration results for Models I, II, and III

Function	F-statistic	
$F_{AVA}(AVA\|CO_2, TP, RF, LUC, EC, FD, GCF, LAB)$	4.741***	
Critical Value Bounds		
Significance	I(0)	I(1)
10%	1.95	3.06
5%	2.22	3.39
1%	2.79	4.10
Diagnostic tests		
R^2	0.727	
Adj-R^2	0.639	
F-statistic	8.247***	
Serial Correlation	0.280 (0.599)	
ARCH	0.216 (0.806)	
Function	F-statistic	
$F_{CP}(CP\|CO_2, TP, RF, LUC, EC, FD, GCF, LAB)$	4.904***	
Critical Value Bounds		
Significance	I(0)	I(1)
10%	2.26	3.34
5%	2.55	3.68
1%	3.15	4.43
Diagnostic tests		
R^2	0.713	
Adj-R^2	0.556	
F-statistic	4.549***	
Serial Correlation	0.133 (0.717)	
ARCH	0.678 (0.512)	
Function	F-statistic	
$F_{CY}(CY\|CO_2, TP, RF, LUC, EC, FD, GCF, LAB)$	5.494***	
Critical Value Bounds		
Significance	I(0)	I(1)
10%	1.95	3.06
5%	2.22	3.39

1%	2.79	4.10
Diagnostic tests		
R^2	0.638	
Adj-R^2	0.473	
F-statistic	3.878***	
Serial Correlation	0.216 (0.884)	
ARCH	1.118 (0.352)	

*** Indicates the rejection of no cointegration at 1% significance level.

Table 5. Johansen cointegration test results for Models I, II, and III

	$AVA = f(CO_2, TP, RF, LUC, EC, FD, GCF, LAB)$		$CP = f(CO_2, TP, RF, LUC, EC, FD, GCF, LAB)$		$CY = f(CO_2, TP, RF, LUC, EC, FD, GCF, LAB)$	
Hypothesis	Trace statistic test	Max-eigen statistic test	Trace statistic test	Max-eigen statistic test	Trace statistic test	Max-eigen statistic test
$r \leq 0$	246.590***	68.036***	263.307***	59.206**	263.308***	59.192**
	(0.000)	(0.004)	(0.000)	(0.041)	(0.000)	(0.042)
$r \leq 1$	178.553***	49.847	204.101***	55.069**	204.115 ***	55.075**
	(0.003)	(0.088)	(0.000)	(0.025)	(0.000)	(0.025)
$r \leq 2$	128.706**	36.551	149.032***	42.894	149.040***	42.908
	(0.032)	(0.365)	(0.000)	(0.109)	(0.000)	(0.108)
$r \leq 3$	92.154	30.464	106.138***	36.728	106.131***	36.726
	(0.086)	(0.393)	(0.008)	(0.113)	(0.000)	(0.113)
$r \leq 4$	61.690	27.055	69.4102**	29.257	69.405**	29.256
	(0.187)	(0.260)	(0.053)	(0.161)	(0.053)	(0.161)
$r \leq 5$	34.634	20.622	40.152	25.648	40.149	25.648
	(0.467)	(0.299)	(0.217)	(0.086)	(0.217)	(0.086)
$r \leq 6$	14.011	7.669	14.503	9.807	14.500	9.805
	(0.480)	(0.922)	(0.811)	(0.762)	(0.811)	(0.762)
$r \leq 7$	6.342	6.201	4.696	4.384	4.695	4.384
	(0.655)	(0.587)	(0.840)	(0.816)	(0.840)	(0.816)
$r \leq 8$	0.140	0.140	0.311	0.311	0.310	0.310
	(0.707)	(0.707)	(0.576)	(0.576)	(0.577)	(0.577)

** and *** indicate the rejection of no cointegration at the 5 and 1% significance level, respectively.

Table 6 reports the estimated long-and-short-run outcomes of the model (I), and Figure 4 shows the summarized long-run nexus among the variables.

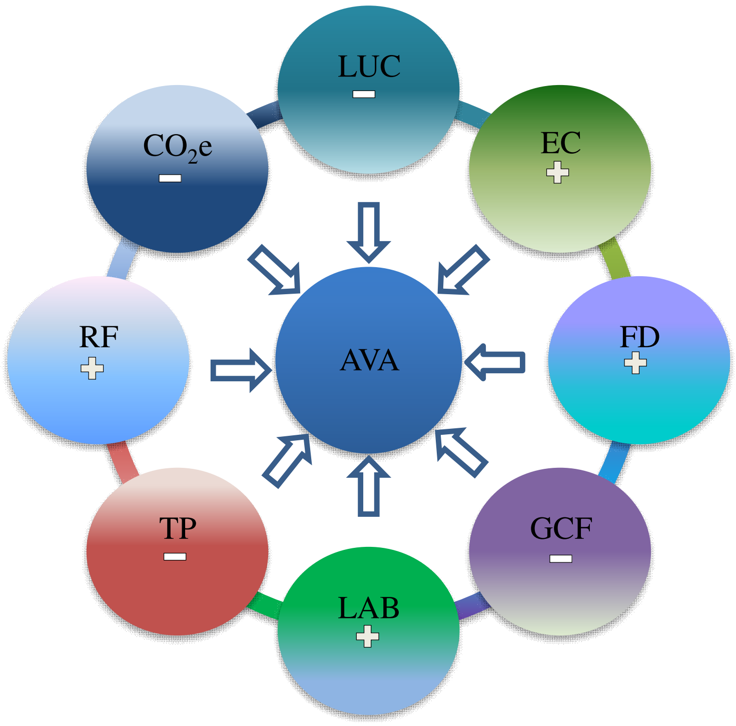

Fig. 4 Association among variables in the long-run – model (I)

The predicted long-and-short-run coefficients for a climate like carbon dioxide and mean temperate are significantly and negatively affecting agricultural value-added. Interpretively, 1% increase in CO_2 emissions and temperature decrease agricultural value added by 0.538%, 0.513%, 1.117%, and 1.065%, respectively. The negative impact of CO_2 and temperature on agricultural value-added appears parallel to the results of (Bannayan et al. 2014, Chandio et al. 2020a, Chandio et al. 2020c, Sarker et al. 2014), who reported that carbon dioxide emissions and temperature negatively affect agricultural production. The Indian economy is primarily based on the agriculture sector, and it plays a greater role in economic development of the country. Around 66.4% of rural population are directly involved with this sector. Moreover, this sector contributes 14.6% to the country's GDP (Bank 2018). In Asian nations like India is most affected nations in terms of climate change and frequently occurring of natural hazards due to its inadequate arable land, vast population, dependence on rainfed farming, and less adoption capacity of technology (Birthal et al. 2014)

Average rainfall positively and significantly affects agricultural value-added with long-and-short-run coefficients of 0.177 and 0.169, respectively. The outcomes depict that the 1% increase in average precipitation increases the agricultural value-added by 0.177% and 0.169%, respectively. These are similar to the outcomes of (Attiaoui &Boufateh 2019, Chandio et al. 2020c, Sarker et al. 2012). Likewise, the long-run cereal cropped area negatively affects the value-added agriculture, and in the short-run positively affects agricultural value-added. The estimated long-and-short-run coefficients of energy consumption, financial development, and labor force have shown significant and positive effects on agricultural value-added. The surge in the consumption of energy, financial development, and labour force will enhance agricultural value added by 1.147%, 0.404%, 0.028%, 0.027%, 0.312%, and 0.298%, respectively. The results are supported by the findings of (Raifu &Aminu 2019, Rehman et al. 2017, Shahbaz et al. 2013, Yazdi &Khanalizadeh 2013). Many previous studies also have documented that energy consumption and financial development have a positive significant association with agricultural output (Ahmad et al. 2020, Anh et al. 2020, Inumula et al. 2020). The dynamic error correction term (ECM) showed adjustments of 95.3% short term shocks into equilibrium in a year. The ARDL model has passed all the diagnostic tests (see below Table 6), and evidence from CUSUM and CUSUM of squares tests revealed that the ARDL model is stable (see Figures 5 and 6).

Table 6. ARDL model I: The impact of climatic and non-climatic factors on agriculture value-added

Model selection method: Akaike information criteria (AIC)				
Selected model: ARDL (1, 0, 0, 0, 1, 1, 0, 1, 0)				
$AVA = f(CO_2, TP, RF, LUC, EC, FD, GCF, LAB)$				
Long-run estimates: AVA as a dependent variable				
Variables	Coefficient	SE	t-Statistic	Prob.
CO_2	-0.538	0.399	-1.345	0.186
TP	-1.117**	0.506	-2.205	0.033
RF	0.177**	0.074	2.388	0.022
LUC	-0.274	0.300	-0.913	0.366
EC	1.147***	0.396	2.891	0.006
FD	0.028	0.071	0.396	0.694
GCF	-0.147**	0.074	-1.987	0.054
LAB	0.312	1.685	0.185	0.853
Constant	28.737***	10.014	2.869	0.006
Short-run estimates: ΔAVA as a dependent variable				
ΔAVA(-1)	0.046	0.136	0.337	0.737
ΔCO_2	-0.513	0.407	-1.260	0.215
ΔTP	-1.065**	0.548	-1.944	0.059
ΔRF	0.169**	0.062	2.691	0.010

ΔLUC	0.328	0.315	1.042	0.303
ΔLUC(-1)	-0.591**	0.231	-2.555	0.014
ΔEC	0.690	0.510	1.352	0.184
ΔEC(-1)	0.404**	0.195	2.067	0.045
ΔFD	0.027	0.068	0.396	0.693
ΔGCF	-0.033	0.071	-0.475	0.637
ΔGCF(-1)	-0.106*	0.063	-1.688	0.099
ΔLAB	0.298	1.603	0.186	0.853
ECM(-1)	-0.953***	0.136	-6.974	0.000
R^2	0.996			
Adj-R^2	0.995			
F-statistic	45.339***			
Diagnostic tests				
Test	F-statistic	Prob.		
Normality	1.787	0.409		
LM Test	0.136	0.872		
ARCH	0.237	0.628		
CUSUM	Stable			
CUSUMSQ	Stable			

***, ** and * indicate statistical significance at 1%, 5%, and 10% level.

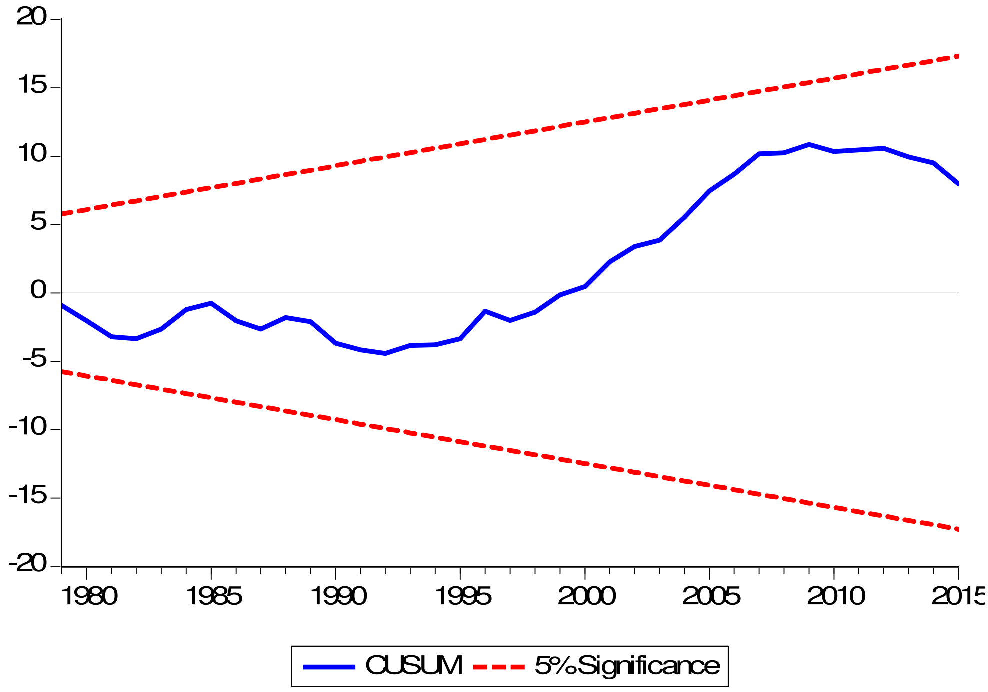

Fig. 5 The plot of the cumulative sum of recursive residual (CUSUM) test for model agricultural value-added

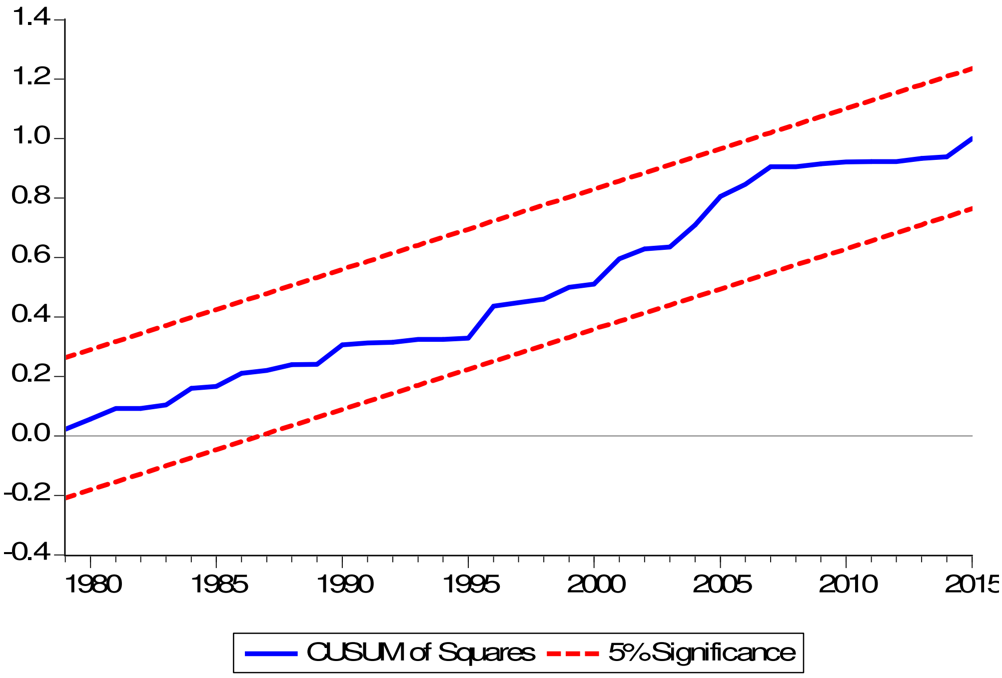

Fig .6 The plot of cumulative sum of squares of recursive residuals (CUSUMS) test for model agricultural value-added

Table 7 reports the estimated long-and-short-run outcomes of Model (II) and Figure 7 shows the summarized long-run association among variables.

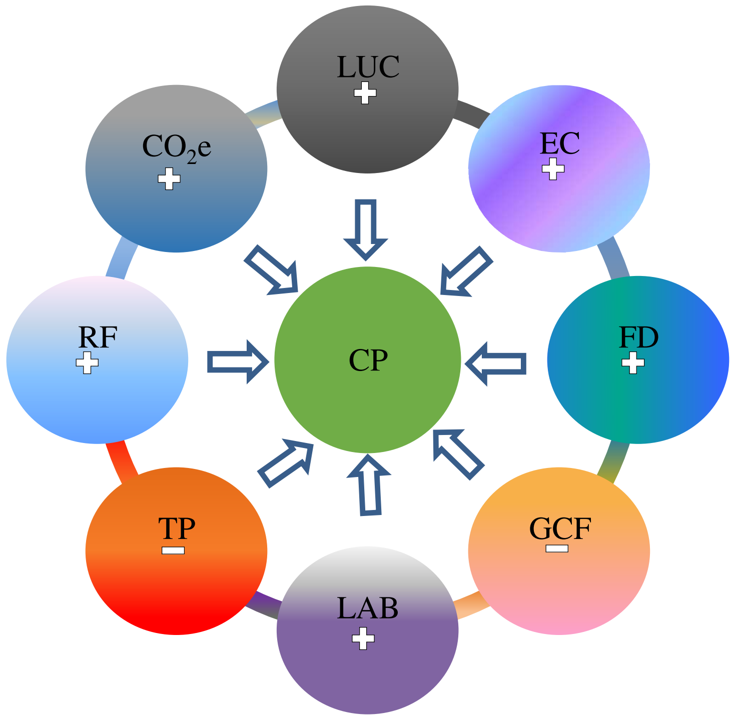

Fig 7. Model (II) – Relationship among variables in the long-run

CO_2 emission positively affects the long-run production of cereal while negatively affects in the short-run. Similarly, the short and long-run estimated coefficients of average temperature showed negative and significant effects on cereal production. The increase in temperature 1℃ will decrease cereal production by 2.308% and 2.331%, respectively. It is supported by the results (Bannayan et al. 2014, Chandio et al. 2020c, Guntukula 2019, Sarker et al. 2014, Zhao et al. 2017), who reported that maximum temperature negatively affects cereal production. In recent decades, climate change severely affects the farming sector of developing countries. Major food crops cannot adapt to the current changes of climate and planting structure. The negative impacts of climate on farming sector mainly contain the following: the performance of agricultural production is declined, the cost of agriculture is increased, and due to limited resources to deal with vulnerability. Moreover, the preventing climate change is more costly, but timely measures can be undertaken to mitigate its adverse effects (Kumar et al. 2017, NSSO 2016). Likewise, the long-and-short-run coefficients of average rainfall indicated positive effects on cereal production. The increase in rainfall of 1 millimeter will enhance the production of the cereals by 0.030% and 0.037%, respectively. These results are similar to the findings of (Attiaoui &Boufateh 2019, Guntukula &Goyari 2020, Sarker et al. 2012). More recent, a study conducted by Warsame et al. (2021) revealed that climatic variables such as temperature and CO_2 emission negatively affected crop production while precipitation positively and significantly contributed to crop production in the case of Somalia.

The estimated long-run and short-run coefficients of non-climate variables such as cereal cropped area, energy consumption, financial development, and labor force revealed positive and significant effects on cereal production. The increase in cereal cropped area, energy use, financial development, and labour force will boost up cereal production by 1.479%, 1.817%, 0.726%, 0.892%, 0.267%, 0.189%, 10.307%, and 6.062%, respectively. These findings are consistent with the findings of previous studies (Chandio et al. 2020b, Rehman et al. 2017, Shahbaz et al. 2013, Zhai et al. 2017). A comprehensive study has documented by Chandio et al. (2021) concluded that financial development plays a greater role to enhance cereal production and ensure food sescurity in the constext of Pakistan. Further they found that improved seeds and fertilizers usage significantly increased cereal production. In this study, we applied various diagnostic and stability tests to verify the estimated ARDL model. Table 6 reports the outcomes of various diagnostic tests. As shown in Table 7, all diagnostic tests confirm that the ARDL is free from diagnostic problems. The CUSUM and

CUSUM square both stability tests show that the ARDL model is stable over the sampled period (see Figures 8 and 9).

Table 7. ARDL model II: The impact of non-climatic and climatic factors on cereal production

Model selection method: Akaike information criteria (AIC)				
Selected model: ARDL(1, 1, 1, 0, 0, 0, 2, 1, 2)				
$CP = f(CO_2, TP, RF, LUC, EC, FD, GCF, LAB)$				
Long-run estimates: CP as a dependent variable				
Variable	Coefficient	SE	t-Statistic	Prob.
CO_2	0.092	0.295	0.313	0.756
TP	-2.308***	0.439	-5.256	0.000
RF	0.030	0.042	0.720	0.476
LUC	1.479***	0.195	7.558	0.000
EC	0.726**	0.304	2.388	0.023
FD	0.267***	0.047	5.589	0.000
GCF	-0.156***	0.054	-2.872	0.007
LAB	10.307***	1.502	6.860	0.000
Constant	-50.468***	7.190	-7.018	0.000
Trend	0.014**	0.006	2.287	0.029
Short-run estimates: ΔCP as a dependent variable				
ΔCP(-1)	-0.228***	0.079	-2.865	0.007
ΔCO_2	-0.488	0.337	-1.447	0.157
$\Delta CO_2(-1)$	0.602***	0.165	3.643	0.001
ΔTP	-2.331***	0.408	-5.710	0.000
ΔTP(-1)	-0.504	0.431	-1.169	0.251
ΔRF	0.037	0.051	0.731	0.469
ΔLUC	1.817***	0.231	7.839	0.000
ΔEC	0.892**	0.393	2.267	0.030
ΔFD	-0.059	0.078	-0.767	0.448
ΔFD(-1)	0.189**	0.095	1.980	0.056
ΔFD(-2)	0.199**	0.077	2.560	0.015
ΔGCF	-0.038	0.063	-0.599	0.553
ΔGCF(-1)	-0.153***	0.051	-2.982	0.005
ΔLAB	-1.642	1.821	-0.138	0.890
ΔLAB(-1)	6.062*	3.947	1.923	0.063
ΔLAB(-2)	-7.755**	3.263	-2.394	0.022
ΔTREND	0.017**	0.007	2.259	0.031
ECM(-1)	-1.228***	0.079	-15.401	0.000
R^2	0.997			
Adj-R^2	0.995			
F-statistic	77.431***			
Diagnostic tests				
Test	F-statistic	Prob.		
Normality	0.401	0.818		
LM Test	0.625	0.542		
ARCH	0.314	0.577		
CUSUM	Stable			
CUSUMSQ	Stable			

***, ** and * indicate statistical significance at 1%, 5%, and 10% level.

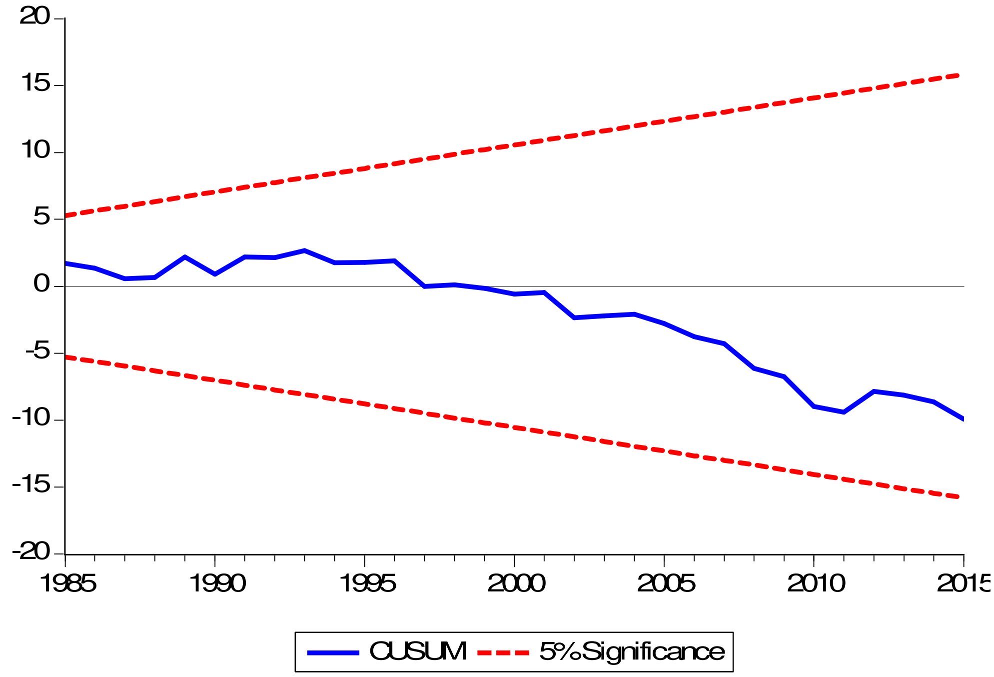

Fig. 8 The plot of the cumulative sum of recursive residual (CUSUM) test for model cereal production

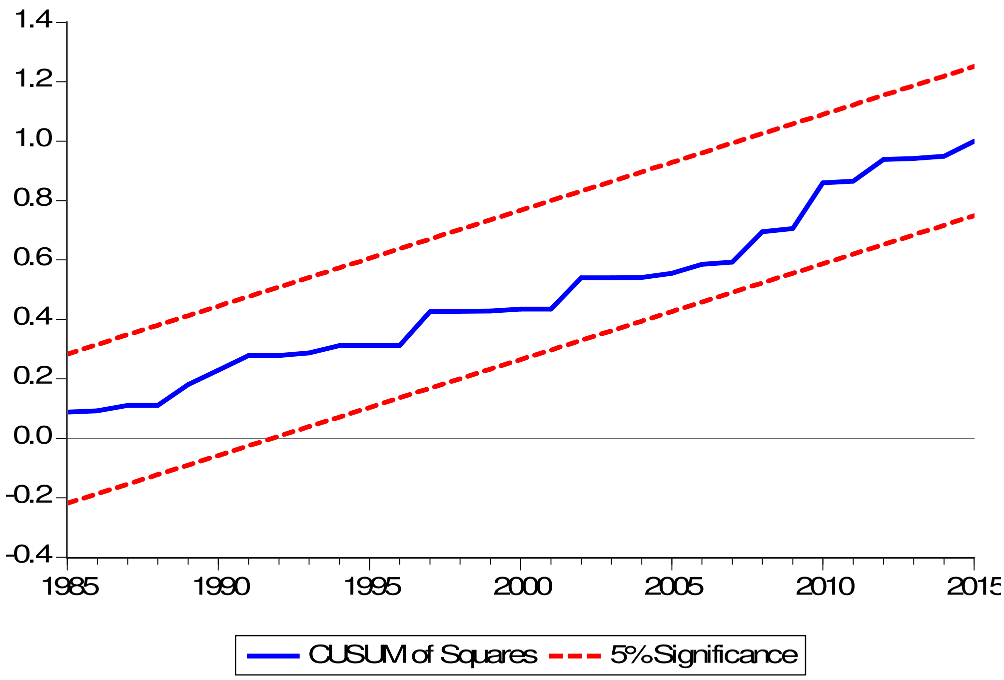

Fig. 9 The plot of cumulative sum of squares of recursive residuals (CUSUMS) test for model cereal production

We undertook the ARDL approach for identifying the non-climatic and climatic factors impacting the yield of cereals. Table 8 presents the empirical long-and-short-run of the ARDL model, and Figure 10 displays the summary of the long-run.

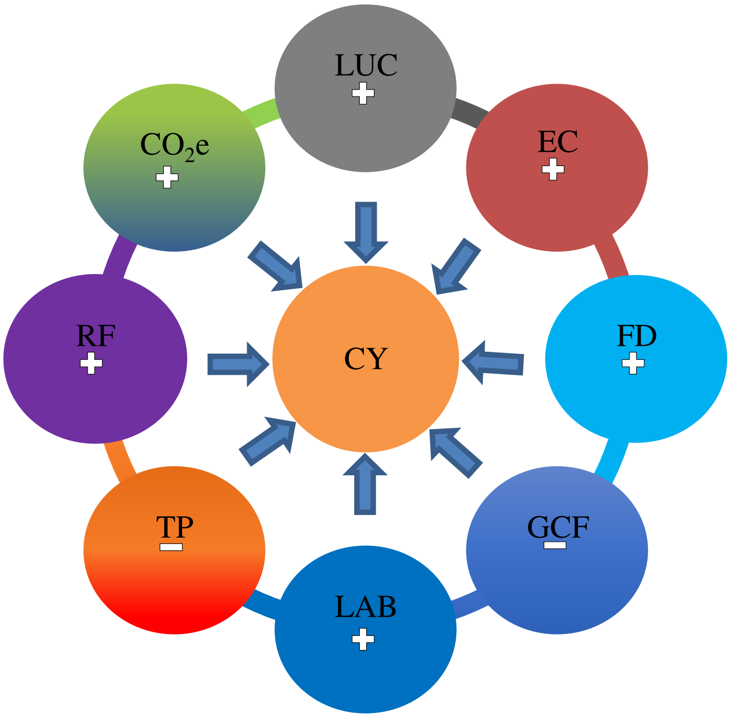

Fig. 10 The long-run association among the variables for the model (III)

Table 8 shows that the coefficient of CO_2 emission is positive in the long-run; however, the coefficient of CO_2 emission is negative in the short run. The coefficients of average temperature in both the long-run and short-run have a significant negative effect on cereal yield; therefore, a 1℃ increase in temperature will decrease the cereal yield by 1.844% and 2.252%, respectively. In coming decades, the crop productivity is more likely to experience largely yield loss due to climate change and extreme weather events such as floods and droughts (Gupta et al. 2014). According to IPCC (2013), reported that 1°C of temperature upsurge, yield of grain crops declined by about 5%. Cereal (i.e., maize and wheat) and other major crops have experienced significantly yields decreases at the global level of 40 megatons per year between 1981 and 2002 due to climate warming. Furthermore, the coefficients of average rainfall in long-and-short-run positively impacts the yield of cereals; therefore, a 1millimeter increase in rainfall in India leads to a 0.042% and 0.051% increase in cereal yield.

Likewise, the coefficients of cereal cropped area, energy consumption, financial development, and labor force in long-and-short-run have a significant positive effect on the cereal yield. These results imply that 1% increase in cereal cropped area, energy consumption, financial development, and labour force leads to increase the cereal yield by 0.617%, 0.753%, 0.600%, 0.733%, 0.250%, 0.193%, 10.004%, and 8.088%, respectively. Besides, the results of several diagnostic tests revealed that the ARDL model had passed all the tests (see below Table 8), and the CUSUM and CUSUMSQ tests confirmed the constancy of the model (see Figure 11 and 12).

Table 8. ARDL model III: The impact of climatic and non-climatic factors on cereal yield

Model selection method: Akaike information criteria (AIC)				
Selected model: ARDL(1, 1, 0, 0, 0, 0, 2, 1, 2)				
$CY = f(CO_2, TP, RF, LUC, EC, FD, GCF, LAB)$				
Long-run estimates: CY as the dependent variable				
Variable	Coefficient	SE	t-Statistic	Prob.
CO_2	0.236	0.290	0.814	0.421
TP	-1.844***	0.318	-5.791	0.000
RF	0.042	0.043	0.975	0.336
LUC	0.617***	0.192	3.207	0.003
EC	0.600**	0.304	1.969	0.057
FD	0.250***	0.048	5.154	0.000
GCF	-0.161***	0.054	-2.959	0.005
LAB	10.004***	1.544	6.476	0.000
Constant	-46.469***	7.112	-6.533	0.000
Trend	0.012**	0.006	2.003	0.053
Short-run estimates: ΔCY as the dependent variable				
ΔCY(-1)	-0.221**	0.090	-2.434	0.020
ΔCO_2	-0.304	0.320	-0.949	0.349
$\Delta CO_2(-1)$	0.594***	0.169	3.512	0.001
ΔTP	-2.252***	0.415	-5.424	0.000
ΔRF	0.051	0.051	0.999	0.324
ΔLUC	0.753***	0.234	3.218	0.003
ΔEC	0.733*	0.385	1.901	0.066
ΔFD	-0.050	0.079	-0.639	0.527
ΔFD(-1)	0.193**	0.096	1.997	0.054
ΔFD(-2)	0.162**	0.073	2.216	0.033
ΔGCF	-0.042	0.0647	-0.660	0.513
ΔGCF(-1)	-0.154***	0.053	-2.887	0.006
ΔLAB	-3.330	12.101	-0.275	0.785
ΔLAB(-1)	8.088*	4.659	1.950	0.060
ΔLAB(-2)	-5.539**	3.650	-2.383	0.023
ΔTREND	0.015**	0.007	2.021	0.051
ECM(-1)	-1.021***	0.090	-13.430	0.000
R^2	0.997			
Adj-R^2	0.995			
F-statistic	710.605***			

Diagnostic tests		
Test	F-statistic	Prob.
Normality	1.081	0.582
LM Test	0.395	0.676
ARCH	0.390	0.679
CUSUM	Stable	
CUSUMSQ	Stable	

***, ** and * indicate statistical significance at 1%, 5%, and 10% level.

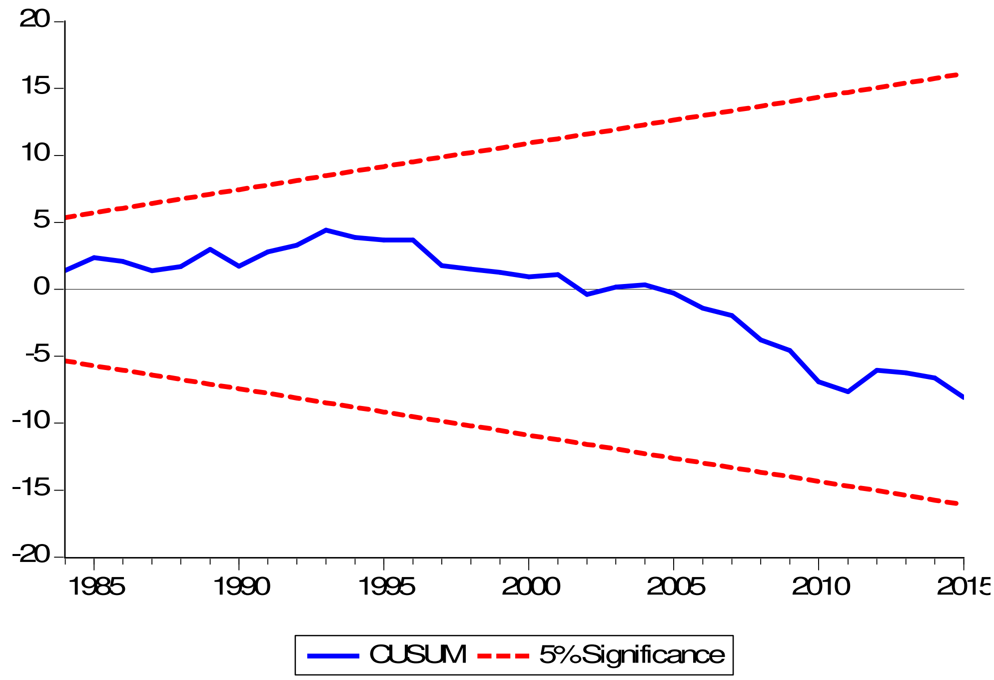

Fig. 11 Plot of CUSUM test for model cereal yield

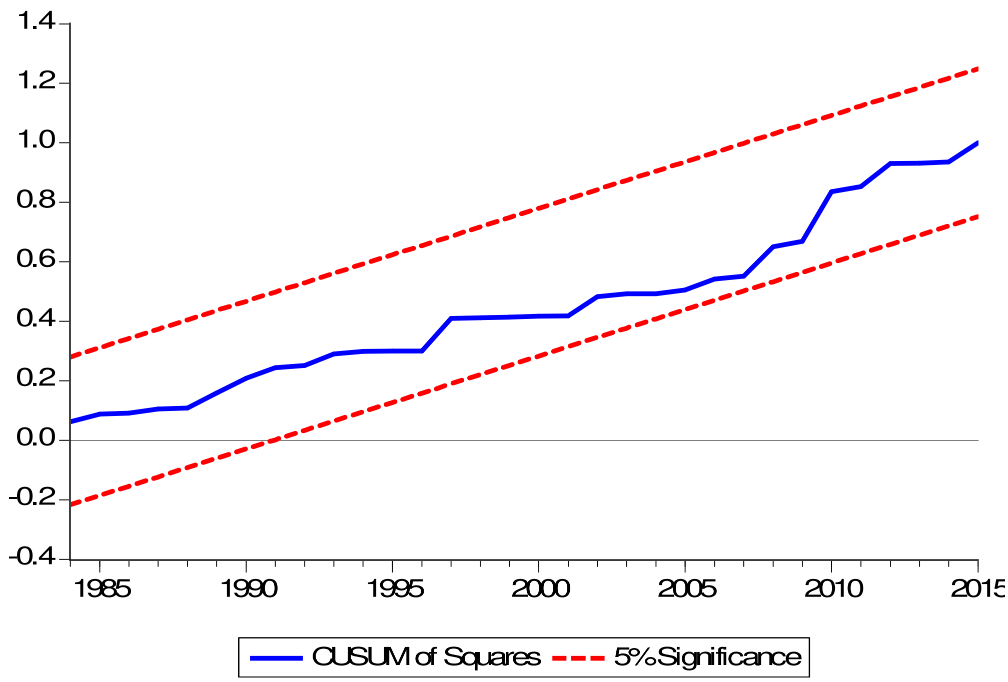

Fig. 12 The plot of the cumulative sum of recursive residual (CUSUM) test for model cereal yield

Granger causality test results for model I (Agricultural value-added)

The pairwise Granger causality test is applied to explore the causal associations between the study variables. The estimated results are summarized in Table 9, indicating the existence of one-way causality between CO_2 and agricultural value-added. Furthermore, two-way causal link is existed between temperature and agricultural value-added. This reveals that climatic factors have a signifcant effect on agricultural value-added. In addition, the unidirectional causality from energy usage to agricultural value-added and two-way causality from financial development and gross capital formation to agricultural value-added are indicating that non-climatic factors also significantly improved agricultural value-added in the context of India.

Table 9. Results of the Granger causality test for Model I (AVA)

Null Hypothesis:	F-Statistic	Prob.
CO_2 does not Granger Cause AVA	6.817***	0.000
AVA does not Granger Cause CO_2	0.974	0.432
TP does not Granger Cause AVA	2.966**	0.031
AVA does not Granger Cause TP	4.491***	0.004
RF does not Granger Cause AVA	1.373	0.261
AVA does not Granger Cause RF	0.589	0.672
LUC does not Granger Cause AVA	1.707	0.168
AVA does not Granger Cause LUC	1.912	0.128
EC does not Granger Cause AVA	6.199***	0.000
AVA does not Granger Cause EC	0.936	0.453
FD does not Granger Cause AVA	2.142*	0.094
AVA does not Granger Cause FD	3.420**	0.017
GCF does not Granger Cause AVA	2.443*	0.063
AVA does not Granger Cause GCF	2.102*	0.099
LAB does not Granger Cause AVA	1.868	0.136
AVA does not Granger Cause LAB	3.650**	0.013

***, ** and * indicate statistical significance at 1%, 5%, and 10% level.

Granger causality test results for model II (Cereal production)

In order to verify the existence of causal links between variables, the results obtained in the estimation of model II are reported in Table 10, showing the unidirectional causality from CO_2 and rainfall to cereal production while two-way causality explored from temperature to cereal production. This means climatic factors significantly influencing cereal production. Besides, the unidirectional causality from cereal cropped area, energy consumption, and financial development to cereal production whereas two-way causality discovered from gross capital formation and rural labour to cereal production is varified. These results imply that non-climatc factors play an important role to enhance cereal production and ensure food security in India.

Table 10. Results of the Granger causality test for Model II (CP)

Null Hypothesis:	F-Statistic	Prob.
CO_2 does not Granger Cause CP	14.948***	0.000
CP does not Granger Cause CO_2	2.5620	0.116
TP does not Granger Cause CP	13.609***	0.000
CP does not Granger Cause TP	13.090***	0.000
RF does not Granger Cause CP	5.466**	0.023
CP does not Granger Cause RF	0.458	0.501
LUC does not Granger Cause CP	8.724***	0.004
CP does not Granger Cause LUC	1.648	0.205
EC does not Granger Cause CP	14.659***	0.000
CP does not Granger Cause EC	1.100	0.299
FD does not Granger Cause CP	4.512**	0.038
CP does not Granger Cause FD	0.837	0.364
GCF does not Granger Cause CP	4.195**	0.046
CP does not Granger Cause GCF	5.977**	0.018
LAB does not Granger Cause CP	11.640***	0.001
CP does not Granger Cause LAB	9.288***	0.003

***, ** and * indicate statistical significance at 1%, 5%, and 10% level.

Granger causality test results for model III (Cereal yield)

Specifically, the results of Table 11, the Granger-type causality test, display that CO_2, RF have an unidirectional causality towards cereal yield while TP has two-way causality to cereal yield. The causal results also indicate LUC, EC, GCF, and LAB significantly causes cereal yield. In other words, These variables have significalty asscoations with cereal yield in the case of India.

Table 11. Results of the Granger causality test for Model III (CY)

Null Hypothesis:	F-Statistic	Prob.
CO_2 does not Granger Cause CY	14.418***	0.0004
CY does not Granger Cause CO_2	2.115	0.1524
TP does not Granger Cause CY	12.837***	0.0008
CY does not Granger Cause TP	14.294***	0.0004
RF does not Granger Cause CY	4.527**	0.0386
CY does not Granger Cause RF	0.437	0.5114
LUC does not Granger Cause CY	5.648**	0.0216
CY does not Granger Cause LUC	1.648	0.2055
EC does not Granger Cause CY	13.659***	0.0006
CY does not Granger Cause EC	1.264	0.2666
FD does not Granger Cause CY	2.530	0.1184
CY does not Granger Cause FD	0.654	0.4227
GCF does not Granger Cause CY	3.013*	0.0891
CY does not Granger Cause GCF	6.349**	0.0152

LAB does not Granger Cause CY	7.751***	0.0077
CY does not Granger Cause LAB	15.398***	0.0003

***, ** and * indicate statistical significance at 1%, 5%, and 10% level.

Conclusions

The current study explores the effects of non-climatic and climatic variables such as Carbon dioxide, mean temperature, mean rainfall, cropped area of cereals, energy use, financial development, and labor force on agricultural output as well as on cereal production and yield in India. However, in the past, none of the researchers have examined the effects of non-climatic and climatic factors on agriculture and cereal production and yield in India by using the autoregressive distributed lag (ARDL) modeling technique. Therefore, the present empirical study fills this gap in climate change literature. For empirical estimation, we utilized the time series data covering the period from1965 to 2015 and applied several econometric techniques to achieve study's objectives. The estimated results of both the ARDL bounds test and the Johansen and Juselius (JJ) cointegration testing show the presence of the long-term equilibrium relationship between climate, non-climate variables, agricultural output, cereal production, and cereal yield.

Furthermore, the results on long-run elasticities suggested that climate variables such as CO_2 emissions and temperature adversely affects agricultural output, while rainfall positively impacts agricultural production. Similarly, the elasticities of the non-climatic variables, including energy used, financial development, and labor force, are found to be affecting positively. Results also show that the long-run elasticities of Carbon dioxide emissions and rain can positively impact both cereal production and yield, while temperature adversely affects. The long-run elasticities also exhibited that the cereal cropped area, energy used, financial development, and labor significantly affected both cereal production and yield. Finally, pairwise granger causality test confirmed that both climatic and non-climatc factors play an important role to enhance agriculture and cereal production as well as ensure food security in India Based on these results, policymakers and governmental institutions can form a policy related to cereal production in the country to meet the present and current and future needs of the food for countering the adverse climatic impacts. In addition, the rapid increase in CO_2 emissions causes sudden and drastic environmental changes in India resulting in the low production of crops. Therefore, strict action should be taken to reduce CO_2

emissions from crop waste burning, deforestation and organic farming should be promoted in the long run.

Limitations and future research

There is no any study without limitations, and consequently, there is always room for adequately improvement. The present study used financial development as non-climate factor which may positively contribute towards agricultural value added. As Shahbaz et al. (2013); Anh et al. (2020); and Zakaria et al. (2019) suggested that domestic credit to the private sector is a suitable proxy for financial development, and it plays a fundamental role to enhance agricultural value added. However, future studies may consider agricultural credit as indirect input of agricultural value added. Furthermore, in future studies the impact of rainfall on agricultural value added/cereal production should be examined at the states level/agro-environmental regions with panel dataset, as the present study examined the impact of rainfall on agricultural value added/cereal production by using countrywide time series data.

Authors' contributions

Abbas Ali Chandio performed the conception and design of the study, data collection and analysis, drafting the work, and validation of the results.

Yuansheng Jiang has contributed to proofreading and final approval.

Asad Amin has contributed to writing the literature part.

Waqar Akram, **Ilhan Ozturk,** and **Avik Sinha** contributed to article writing, reviewed and edited the manuscript.

Fayyaz Ahmad has contributed to data analysis and results interpretation.

Data availability

The data will be available on request.

Conflict of interest

The authors declare that they have no conflict of interest.

Funding

No funding was received from conducting this study.

Ethical Approval

Not applicable

Consent to Participate

Not applicable

Consent to Publish

Not applicable

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Figures

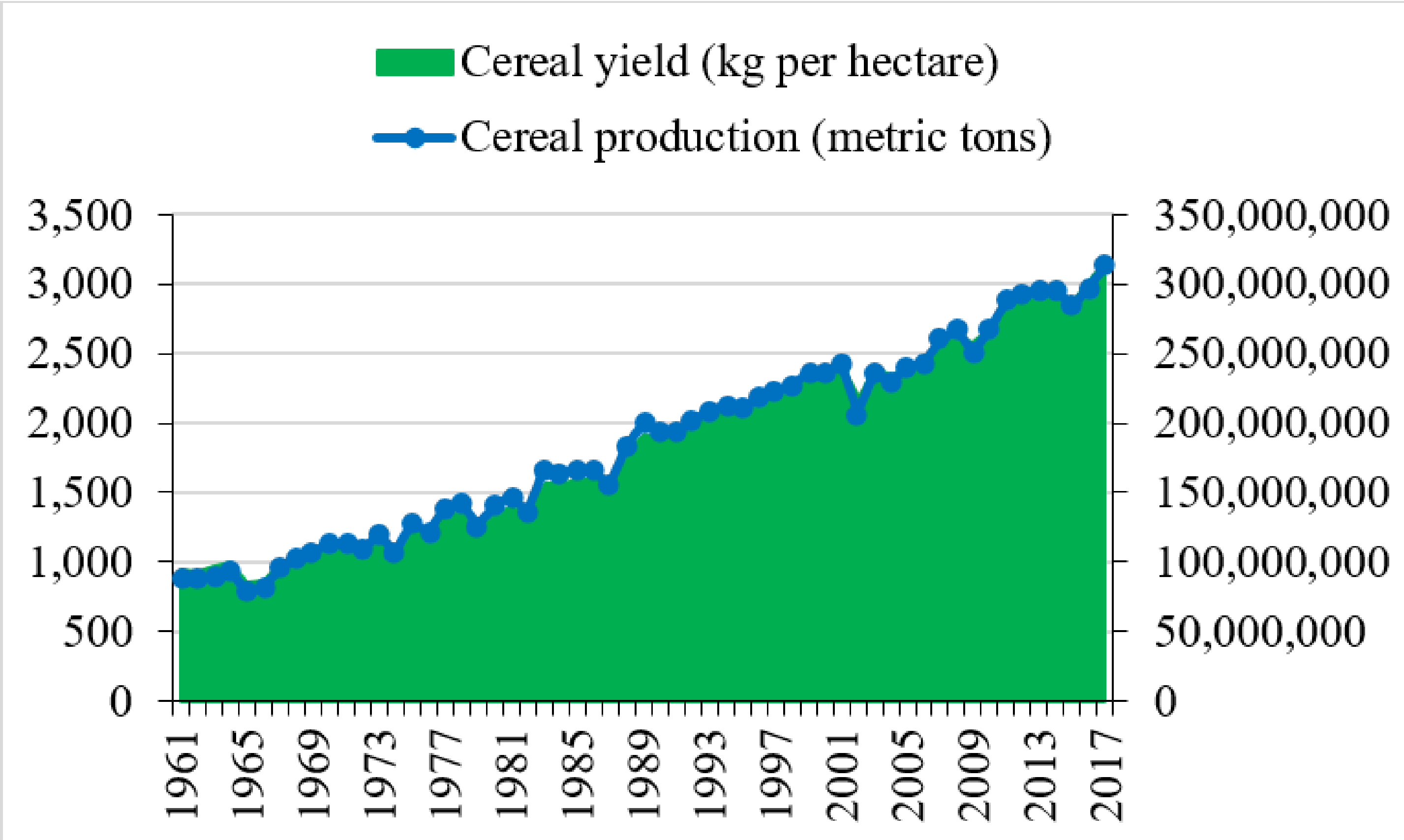

Figure 1

The trend of cereal production and yield in India. Source: World Development Indicators (2017)

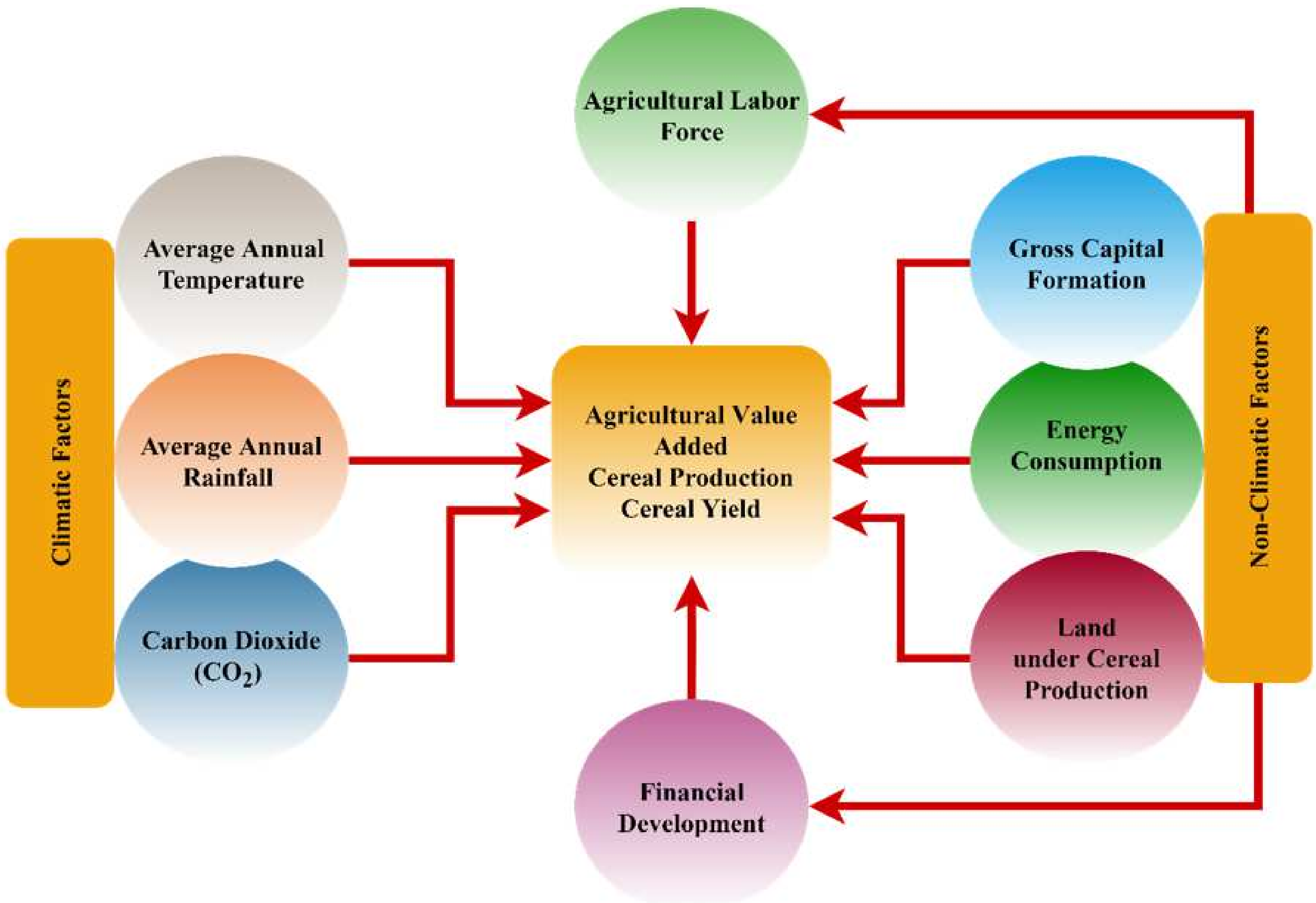

Figure 2

Conceptual framework of the study

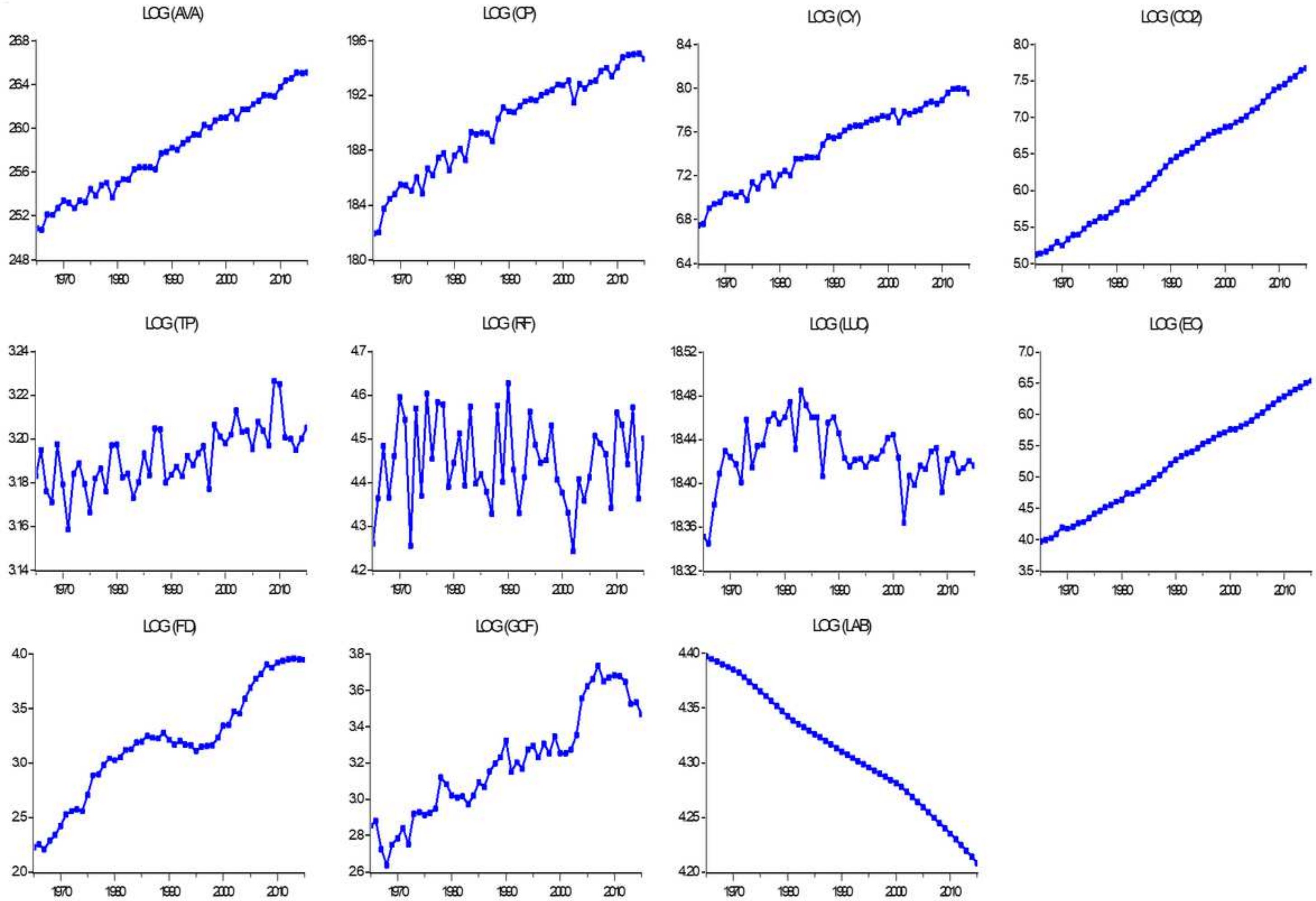

Figure 3

Trend of all the study variables in their natural log form.

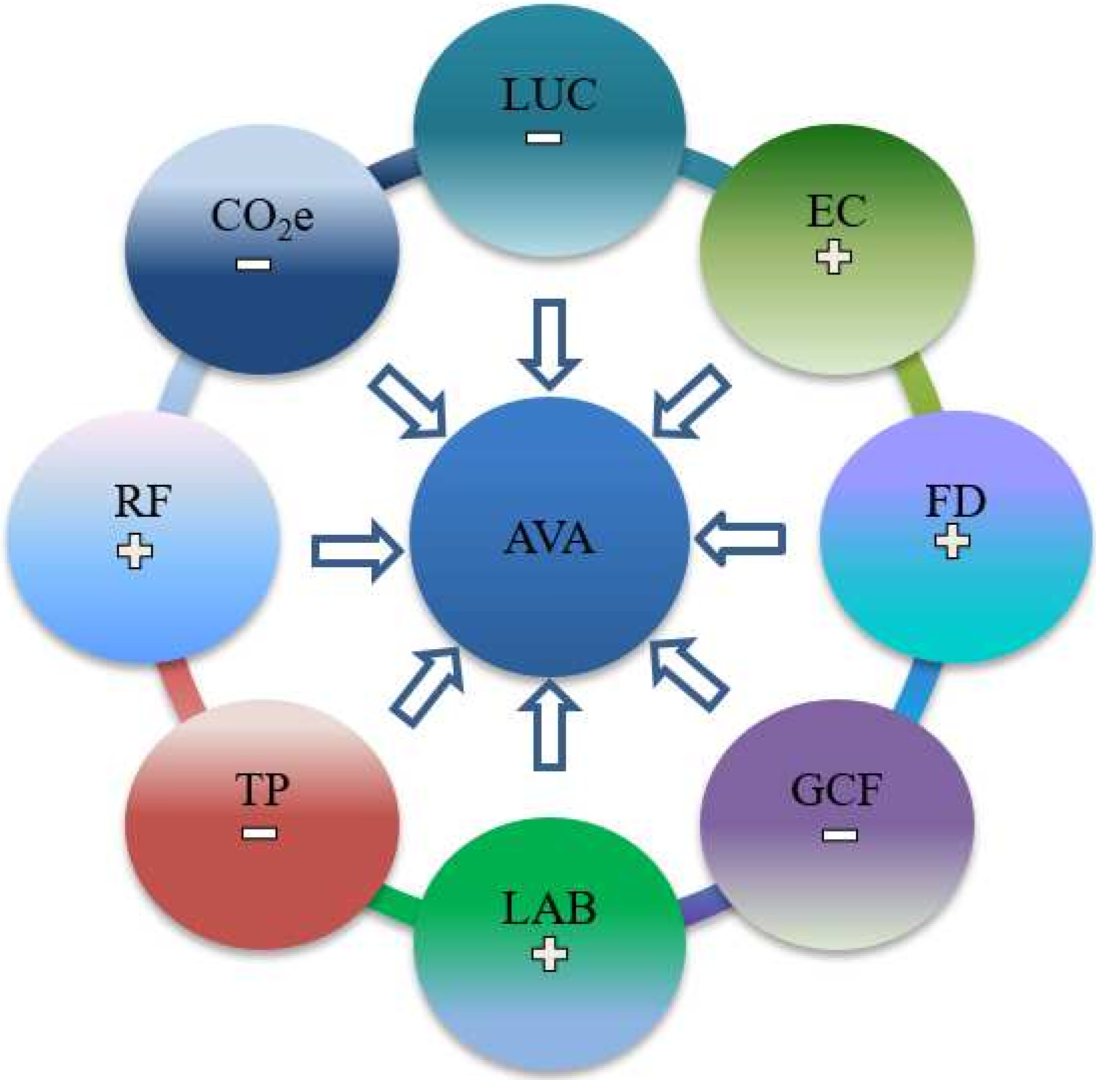

Figure 4

Association among variables in the long-run – model (I)

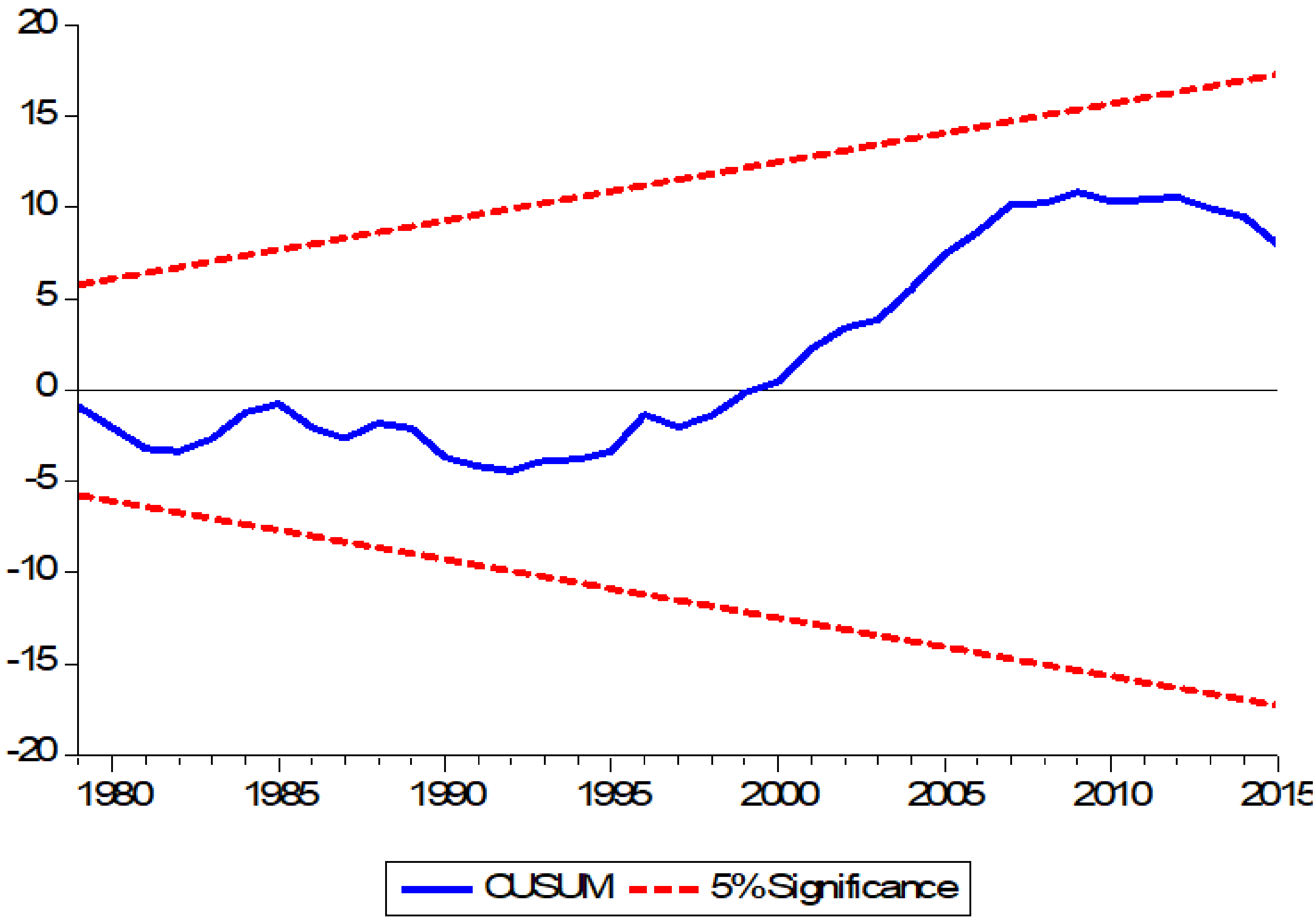

Figure 5

The plot of the cumulative sum of recursive residual (CUSUM) test for model agricultural value-added

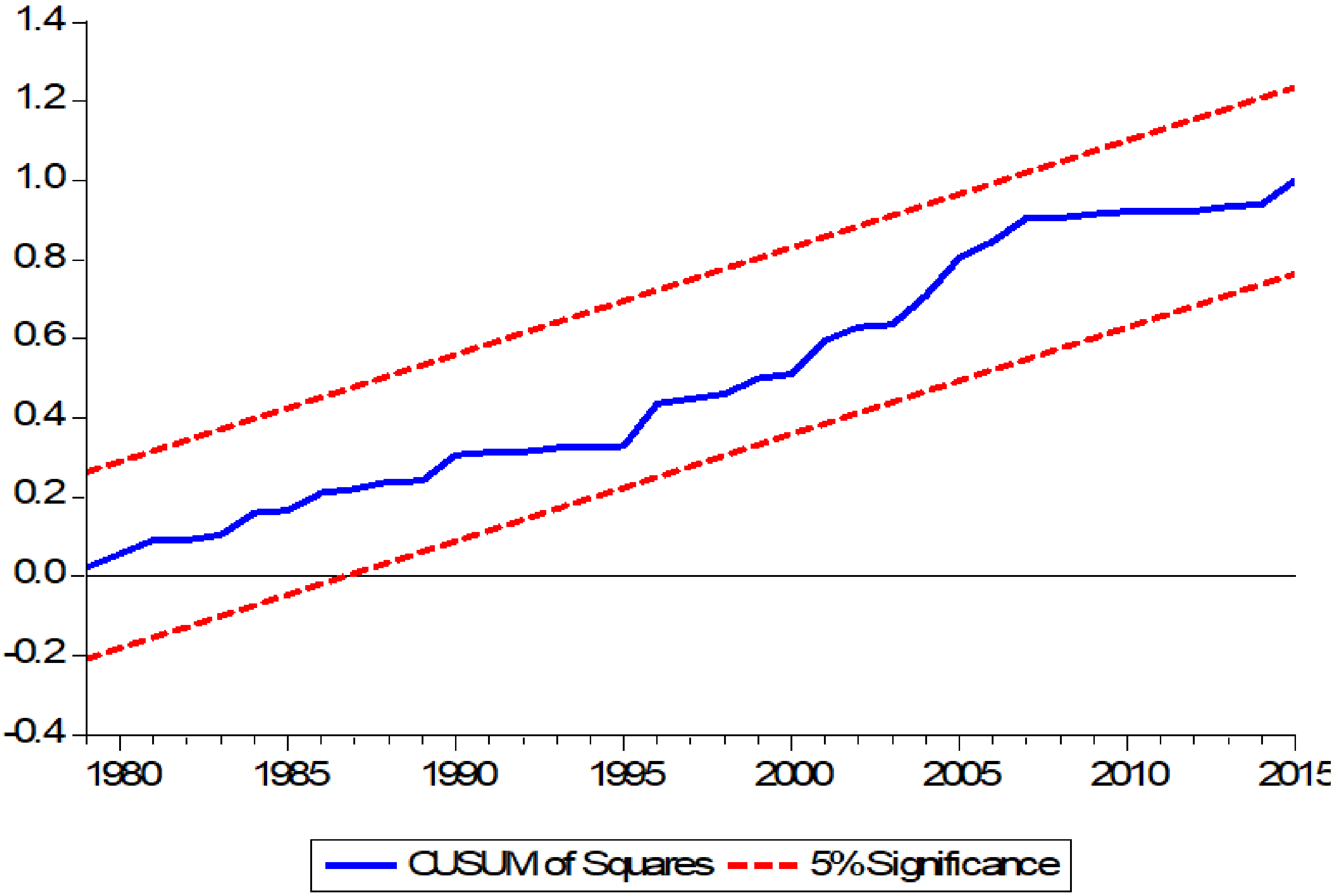

Figure 6

The plot of cumulative sum of squares of recursive residuals (CUSUMS) test for model agricultural value-added

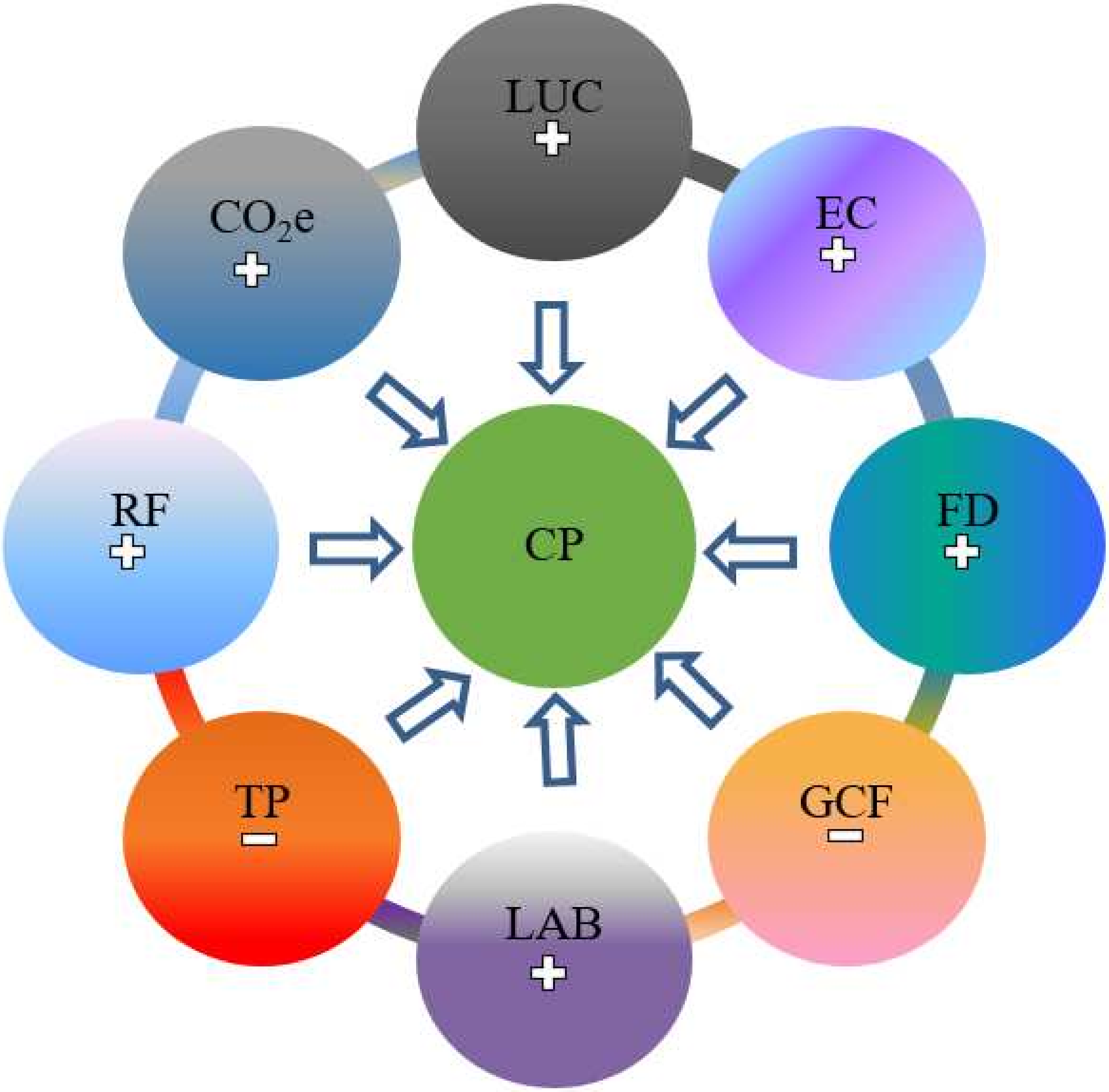

Figure 7

Model (II) – Relationship among variables in the long-run

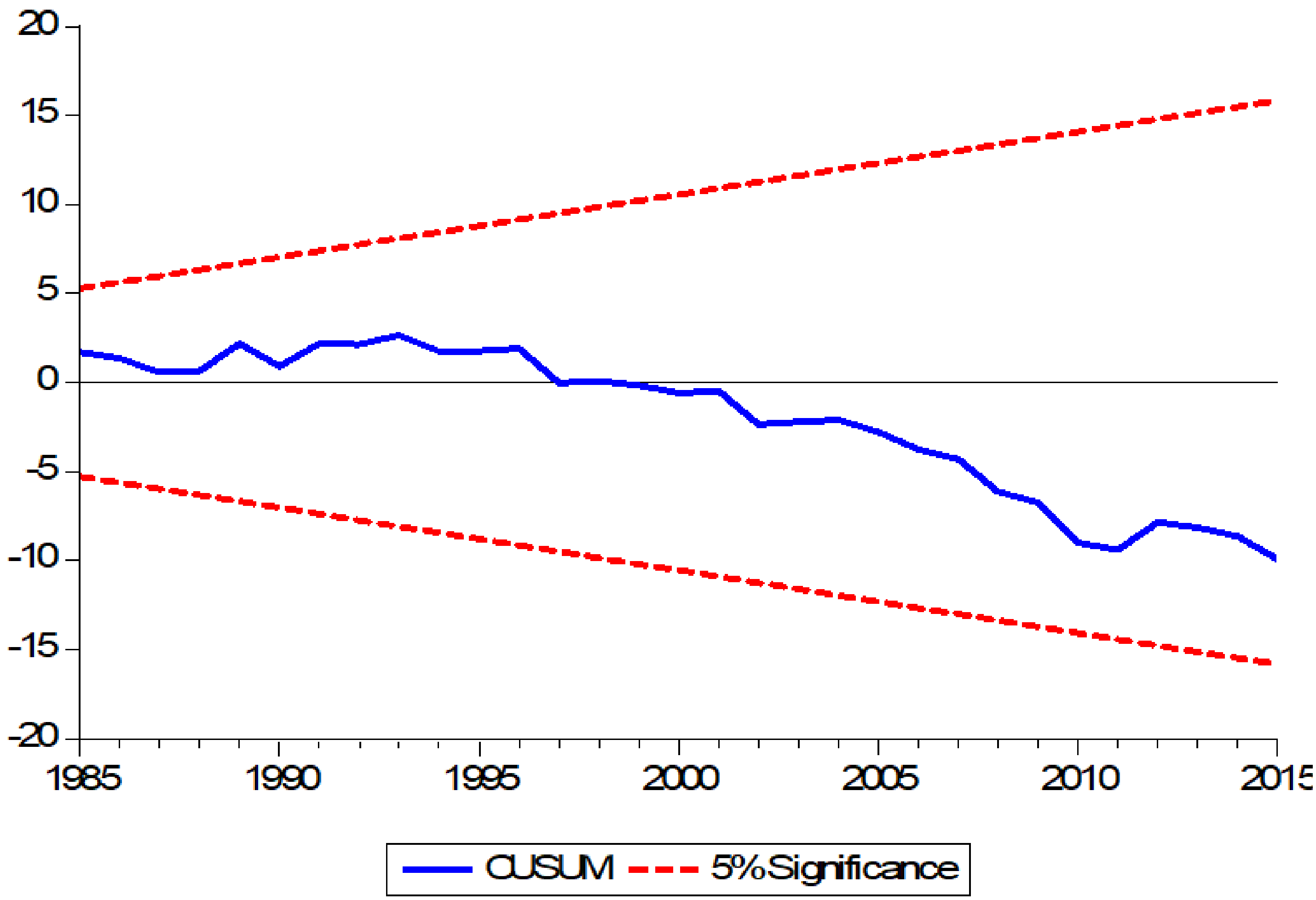

Figure 8

The plot of the cumulative sum of recursive residual (CUSUM) test for model cereal production

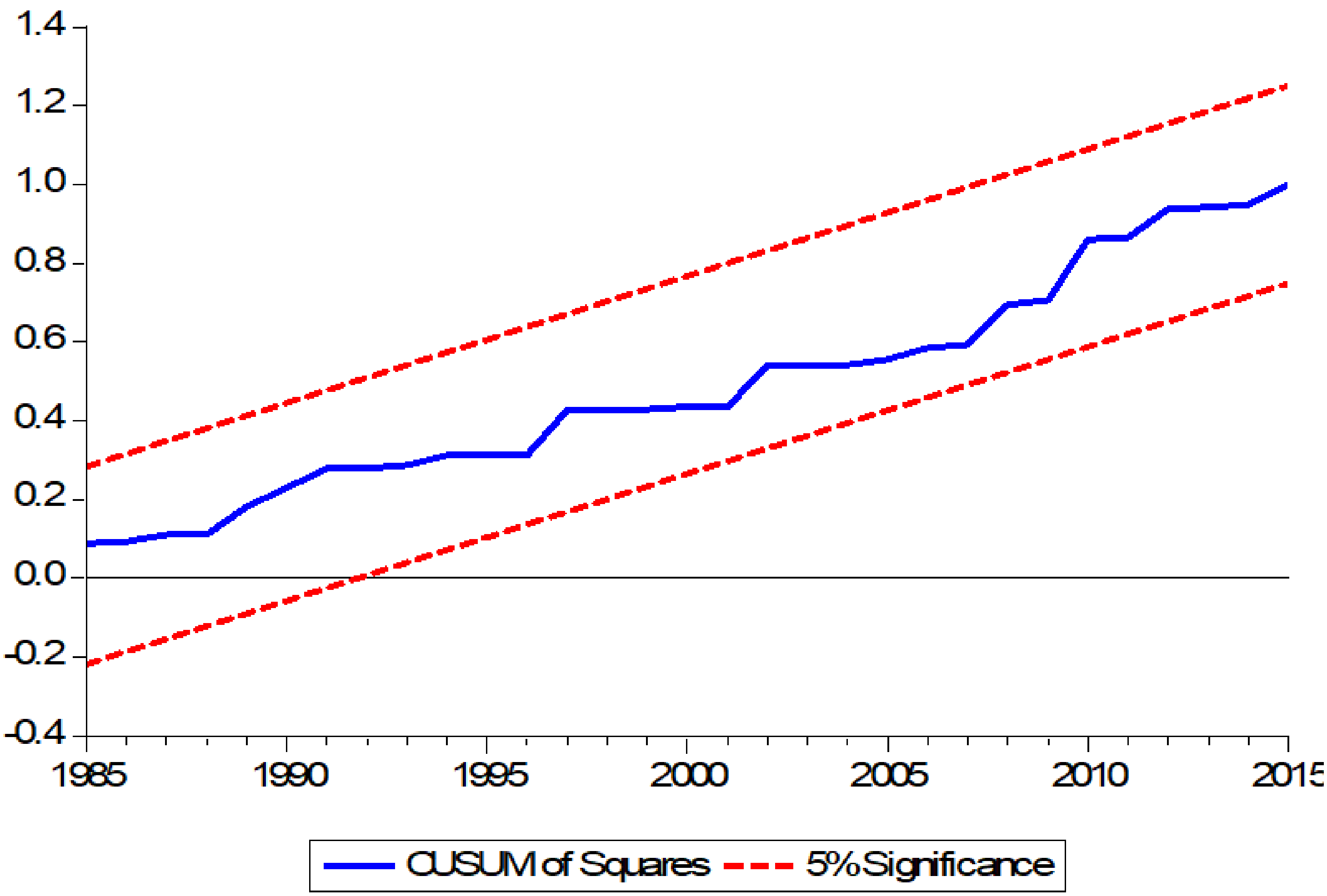

Figure 9

The plot of cumulative sum of squares of recursive residuals (CUSUMS) test for model cereal production

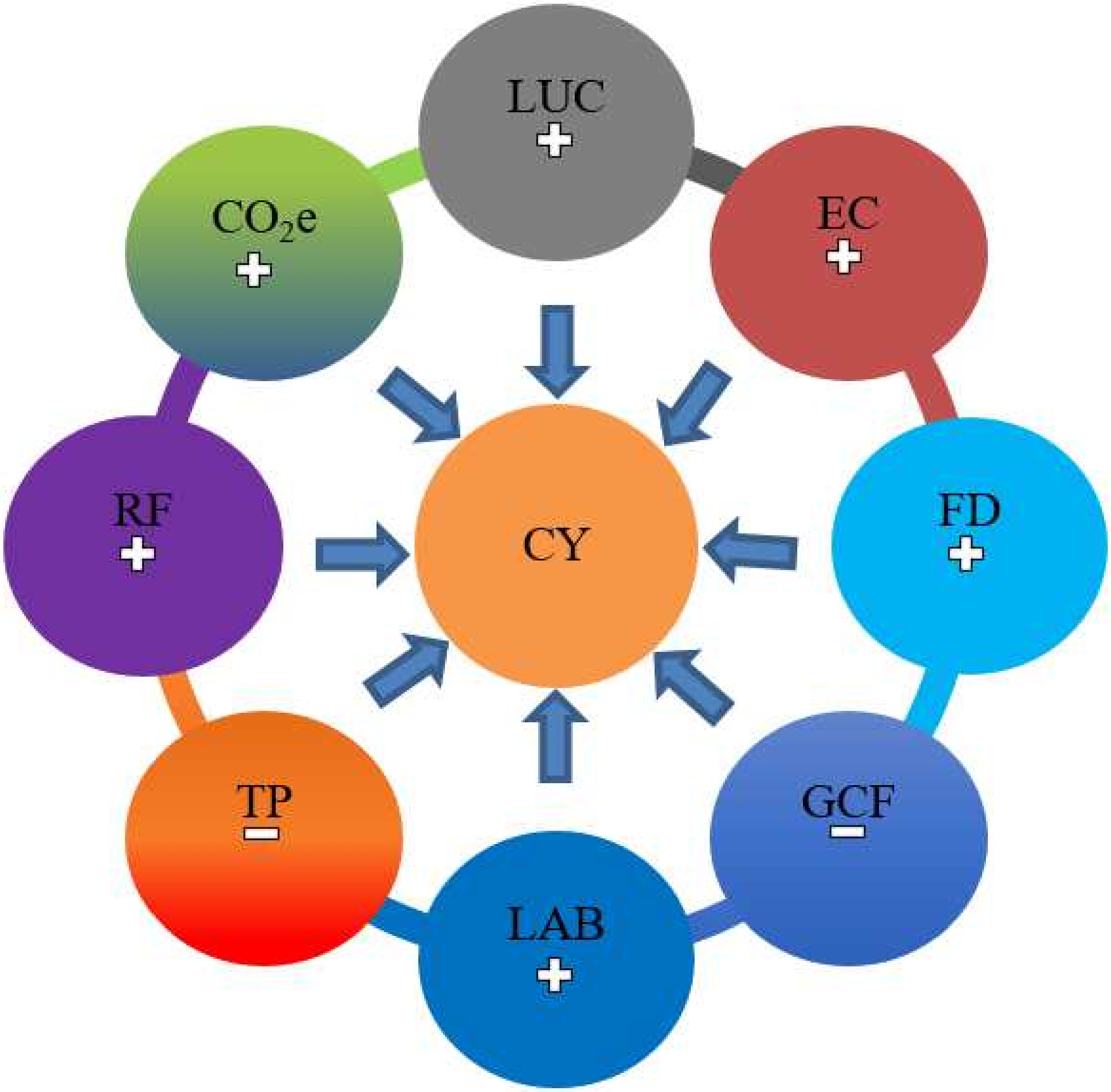

Figure 10

The long-run association among the variables for the model (III)

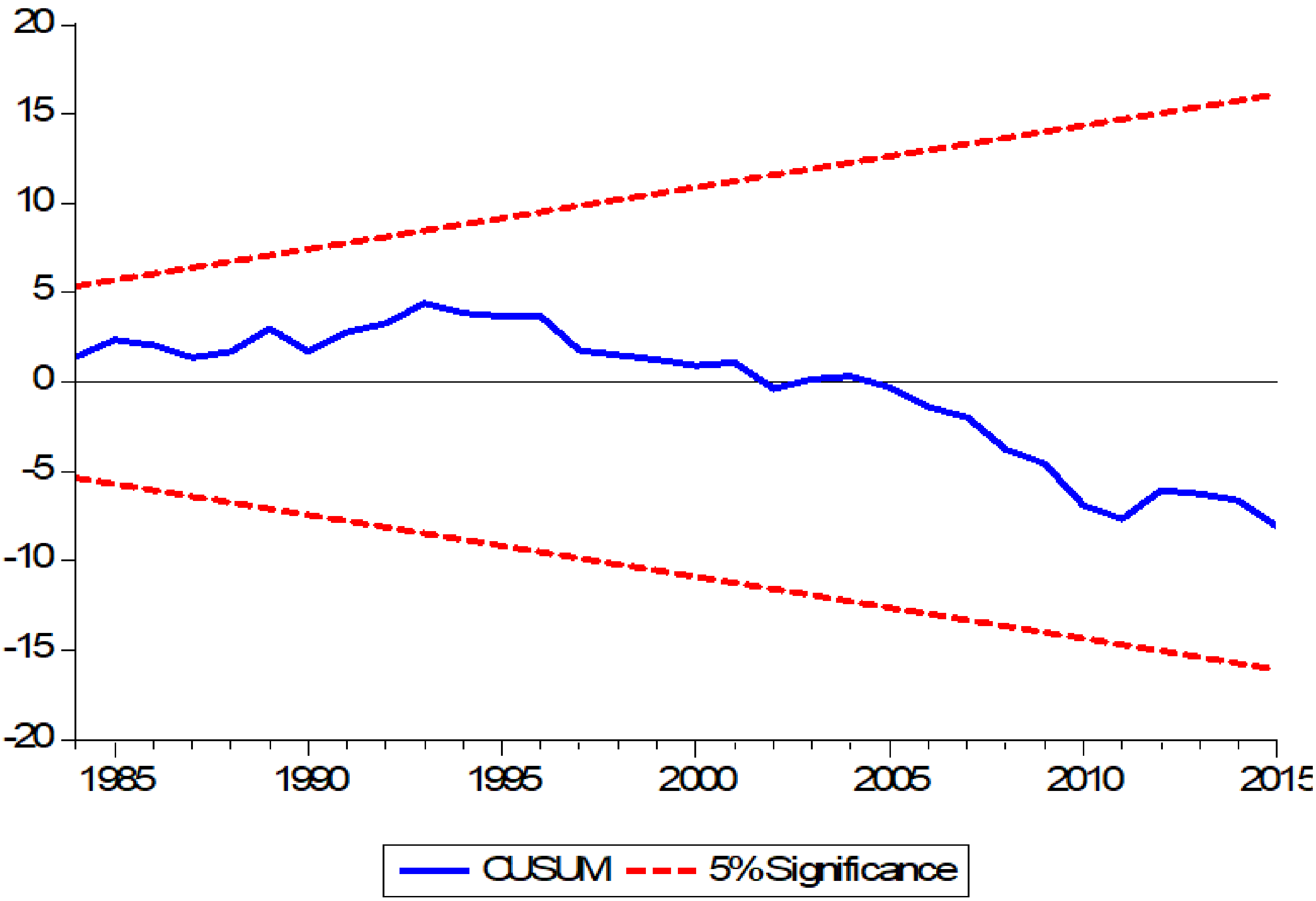

Figure 11

Plot of CUSUM test for model cereal yield

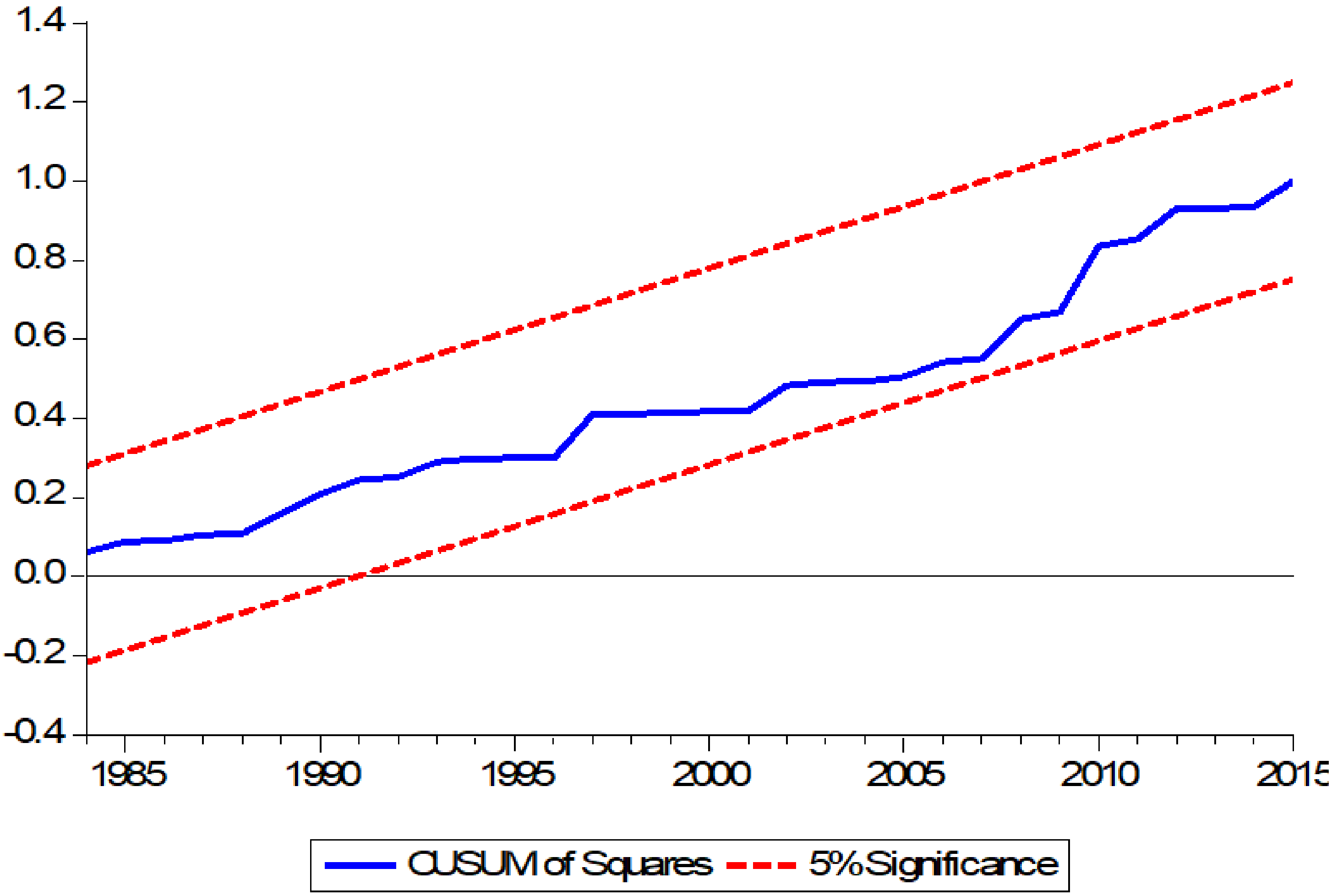

Figure 12

The plot of the cumulative sum of recursive residual (CUSUM) test for model cereal yield