Chapter

Vulnerability of Climate Change and Potential of Domestic Adaptation and Mitigation Pathways

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Abstract

Pakistan is in the eye of global climate change and among the top five countries which are severely affected by it. Residents facing unprecedented heat waves temperature hikes and flash floods. The vulnerability of climate change varies from sector to sector relied on the adaptive capability and sensitivity of different regions. According to the researcher's knowledge, it is a pioneer study which will broadly disclose the vulnerabilities of climate change in different economic sectors as well as how to cope with it through domestic adaptation and mitigation strategies. Cereals consider a staple food which is most vulnerable to climate change, even in the presence of effective capital and advancement of mechanisation. The core objective is to capture the vulnerability of climate change on cereal production via the Cobb-Douglus Production Function on annual time series data over 1977-2016 with the help of the Liner ARDL-Bound Test Approach. This study encompasses temperature, precipitation and inputs indices as well as greenhouse gas emanations which make it prominent from prior studies. Temperature index and greenhouse gas emanations have been destructive despite the fact precipitation and input indices, cultivated area and rural population have constructive liaison with cereal production over a long period.

Keywords: vulnerability, climate change, adaptation, mitigation, Pakistan

1. Introduction

Since the 20th century, global warming has hastened ominously, due to a large number of greenhouse gas emanations, a fast increasing population and fossil fuel combustion. At a worldwide scale, the occurrence of climate-induced natural disasters increases the frequency and intensity of extreme weather events, floods, droughts, unpredicted hikes in temperature and unseasonal heavy rainfalls. Global climate changes hastily influence all sectors of the economy specifically the agriculture sector through variations in planting patterns and productivity. The frequent appearance of extreme events, incessant increase in greenhouse gas emanations, hike in temperature patterns and sporadic precipitation will pose a great threat to economies. Climate change has a prominent influence on developing countries, especially in South Asia and Africa. Furthermore, arid and semi-arid areas of South Asia are under the significant threat of climate change. Ullah & Takaaki [1] mention that' *Pakistan is listed among hazard-prone countries which are hardly hit by climate change. For the reason that it does not have adequate resources to tackle and recover from several large-scale disasters because it is quite complex and resource-demanding*'. Pakistan is included in the list of those countries that are vulnerable to climate change, and vulnerability is basically because of its geographical, demographical and adverse climate circumstances [2]. Unexpected variations in temperature and precipitation trends as well as frequent floods and droughts increase the vulnerability of residents of the country. *Climate change has increased global mean temperature* [3, 4] *and melting of glaciers and sea* [5], *changes in precipitation patterns, and the rise in sea level* [6]. Pakistan is included in those countries which will bear huge losses by climate change in the future [7].

Pörtner et al. [8] disclosed vulnerability, adaptation and mitigation through words:

> "*The propensity or predisposition to be adversely affected by climate change and human as well as ecosystems vulnerability are interdependent. Furthermore, it encompasses a variety of concepts and elements, including sensitivity or susceptibility to harm and lack of capacity to cope and adapt*".

"*Adaptation in human systems, the process of adjustment to actual or expected climate and its effects to moderate harm or take advantage of beneficial opportunities. while in natural systems, the process of adjustment to actual climate and its effects; human intervention may facilitate this*".

"*Mitigation is achieved by limiting or preventing greenhouse gas emissions and by enhancing activities that remove these gases from the atmosphere*".

1.1 Greenhouse gas emission

Greenhouse gases are a combination of CH_4, N_2O and F-gases (HFCs, PFCs and SF_6). Pakistan contributed 0.8% to global greenhouse gas emissions while standing on the 135th rank in per capita greenhouse gas emissions, such as 1.9 tonnes per capita, 1/3 of the world average. It is projected to reduce more than 20% of emissions by 2030. The agriculture sector had got the 2nd number of those contributing 24% in greenhouse gas emissions globally. In the future, GHG emissions levels are expected to increase numerous times in different sectors. It relies on the assumption that the anticipated whole GHG emissions are coherent with the economic growth approach which will be more than triple by 2020 and increase about 23 times by 2050 (compared to 1994 emissions). **Figure 1** illustrates the sector-wise GHG emissions projection during 1994, 2008, 2012, 2015 and 2020, whilst **Figure 2** displays future emission scenarios in 2030 and 2050 in which GHG = greenhouse gas and $MtCO_2$ = million tons of carbon dioxide equivalent.

1.2 Frequency and intensity of temperature, precipitation, humidity, clouds, sunshine and solar radiations

From 1901 to 2000, the annual mean temperature abruptly increased by 0.75°C in the South Asian region, whilst 0.57°C in Pakistan [9]. From 1961 to 2007, the temperature increased by 0.47°C; the year 2004 was recorded as the warmest year until 2007,

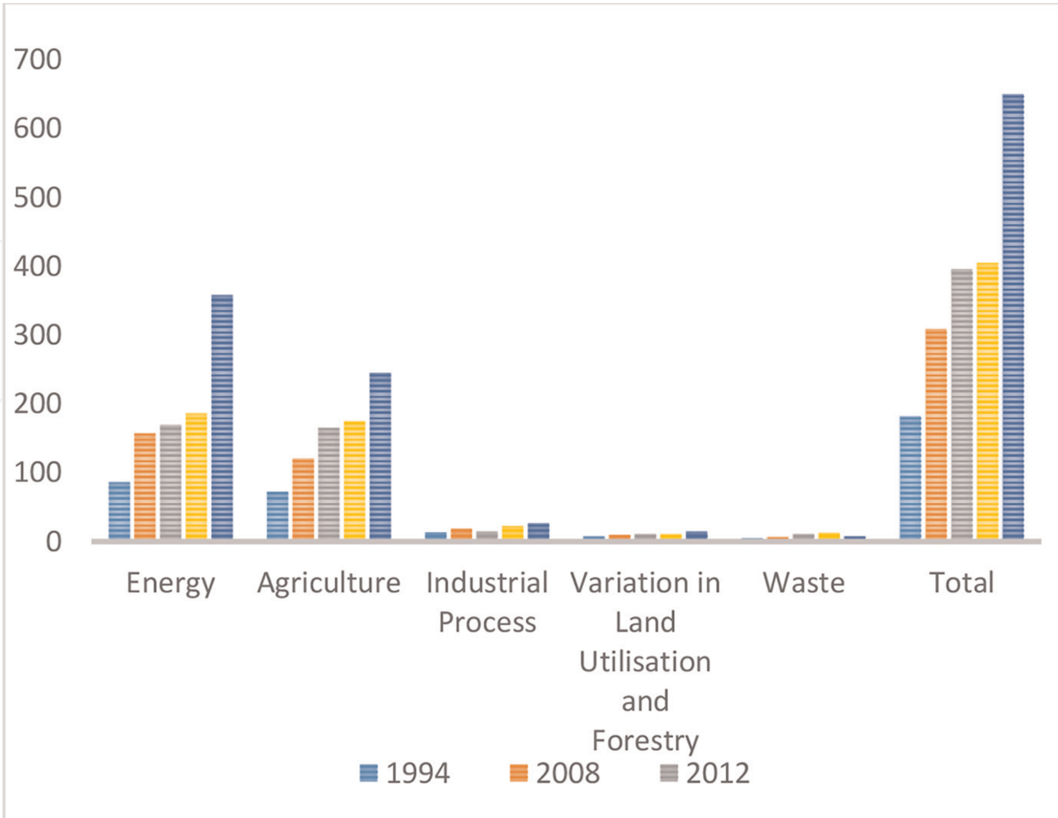

Figure 1.
Sector-wise GHG emissions (Mt CO_2). Source: Author's computations.

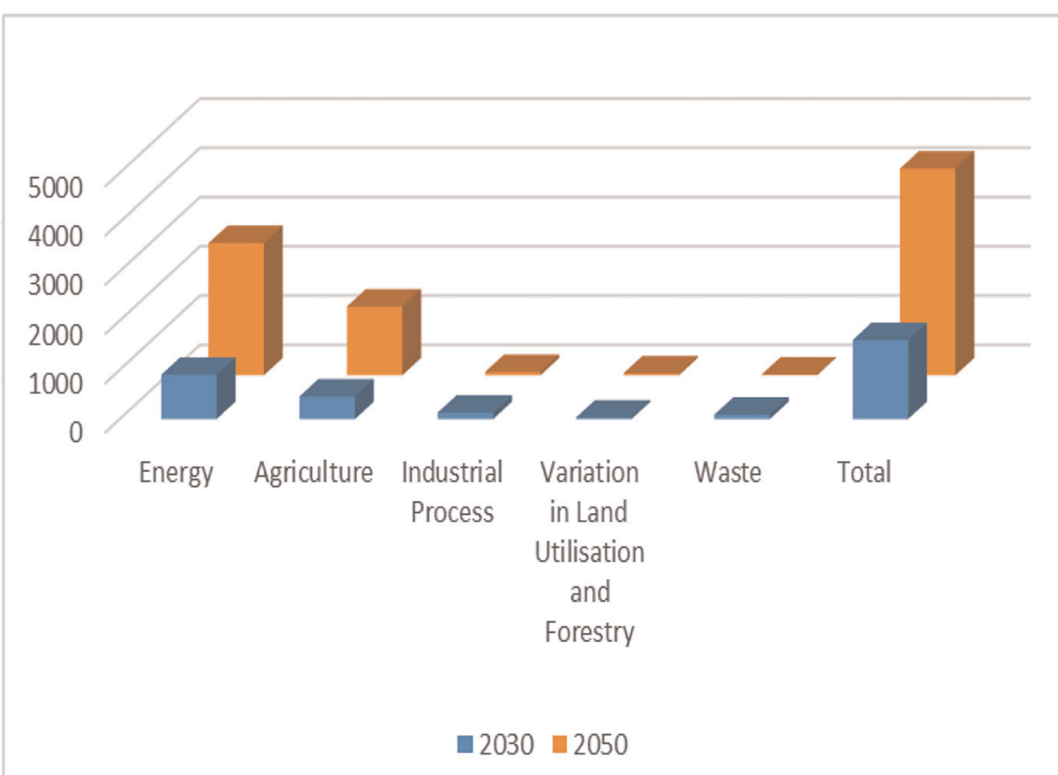

Figure 2.
Future GHG emission scenarios Mt. CO_2. Source: Author's computations.

and the highest temperature rise was recorded during the winter season when it changed from 0.52°C to 1.12°C [10]. During 1951–2000, the mean annual rainfall decreased by 10–15% in arid plains and coastal areas against it increased in the north. During the same time, winter and summer rainfall patterns fell 10–15% in hyper-arid and coastal areas while rose 18–32% in the monsoon zone, particularly in the sub-humid and humid areas. In Baluchistan, relative humidity has recorded a decline of 5%. Furthermore, solar radiation rose by 0.5–0.7% over the southern half, and cloud cover decreased by 3–5% in Pakistan's central region, with an increase in sunshine hours [11].

The various climatic zone-wise annual mean trends of temperature and precipitation are present in **Figure 3**. Zone I (a), Zone III, Zone V (a) and Zone V (b) regions illustrates an increasing trend in the annual mean temperature and precipitation. Zone I (b) and Zone IV regions exposed negative trends in the case of annual mean temperature whilst the adverse trend in the case of annual mean precipitation. Furthermore, only Zone II showed a negative trend in both cases.

1.3 The climate change-induced natural hazards and economic loss

Climate change-induced natural hazards are considered the most devastating reasons for the tremendous loss of human lives, natural resources and infrastructure. According to GCM, climate change-induced hazards (droughts, cyclones, floods, landslides, heat and cold waves) would turn into a greater magnitude, and intensity, more frequently in different regions of Pakistan. The last decade of the 20th century in the Bay of Bengal and the Arabian Sea recorded cyclones, storms and depressions

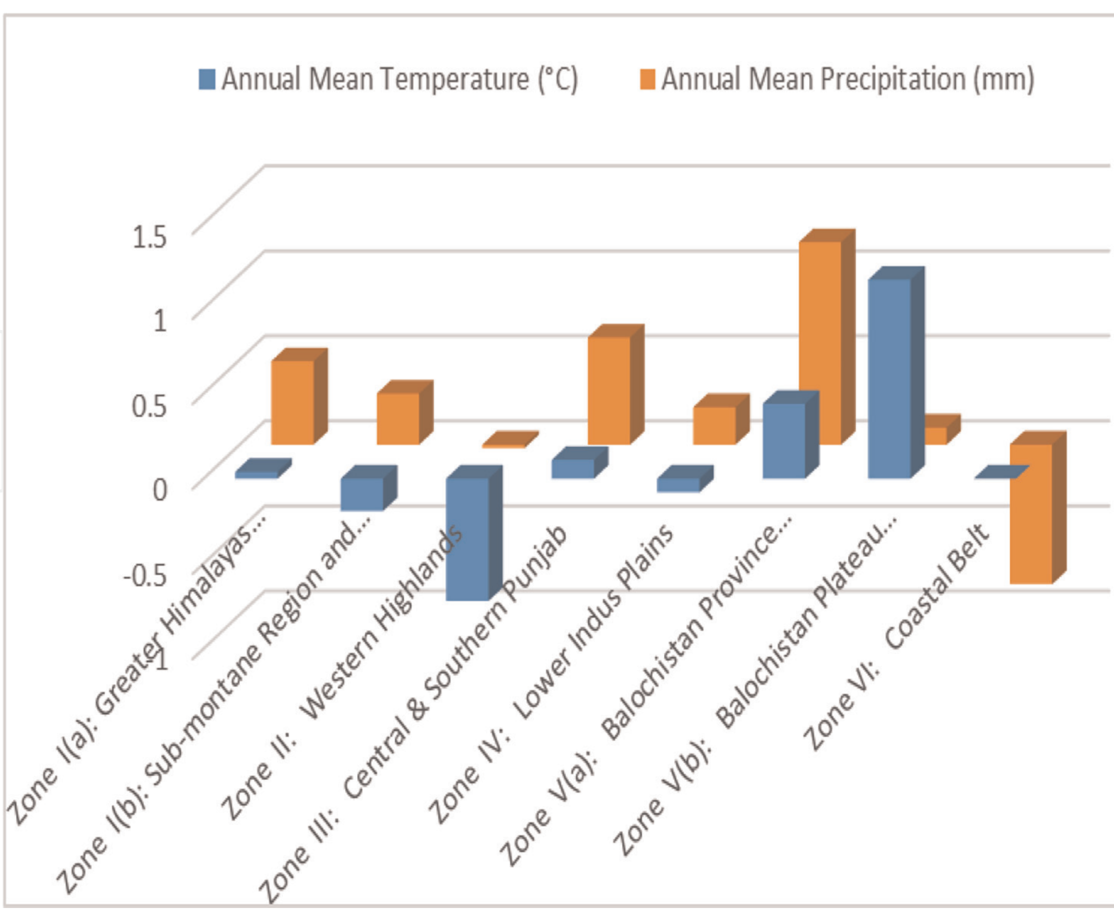

Figure 3.
Zone-wise temperature and precipitation trends (1951–2000). Source: Author's computations.

with high frequency that hit Pakistan and other linked countries of it. Furthermore, this century has also faced seven strong El Niño events. Pakistan's coastal communities of Baluchistan and Sindh provinces are vastly vulnerable to cyclones: Gwadar, Awaran, Lasbella and Ketch and Badin, Karachi, Hyderabad and Thatta, respectively. (GoP[a]) mention that from 1971 through 2001, 14 cyclones were noted. During 1994–2013, extreme climate events did an average annual economic loss of US$ 4 billion. The Yemyin cyclone (2007) hit coastal communities, and about 1000 people lost their lives; above 2 million people were affected by power outages and water shortages, and the cyclone killed more than 2 million livestock. The predicted losses of property from the storm were around 24 billion rupees.

In Sindh and Baluchistan, regions frequently faced droughts because of the decrease in rainfall patterns and other socio-economic situations. The worst drought of history (1998–2001) in South Asia special in Pakistan allied with the La Nina phenomena [12]. Larsen et al. [13] point out that droughts in the period of 2000 and 2002 disturbed more than 3 million people and loss millions of livestock nearly US$ 2.5 billion. According to Government of Pakistan [14] in 2015, hundreds of people lost their lives due to the drought in Thar.

During 1950, 1973, 1976, 1992, 2010 and 2022, major floods were recorded with massive losses of human beings, and the agriculture sector, infrastructure and economy bore losses of near about US$ 400 billion. The floods of 2010–2014 affected 38.12 million people, damaging 3.45 million houses, destroying nearly about 10.63 million acres of crops destroyed and causing more than US $18 billion in monetary losses [15]. The flash flood of 2022 has had devasting effects on human and livestock casualties in addition to extensive home and infrastructure destruction, such as 1600 people killed and 12,900 injured, 805 thousand houses destroyed and 1.2 million houses damaged, 1.1 million livestock lost as well as 13.1 thousand kilometres of roads damaged [16]. Furthermore, the economic cost of the recent severe flood is US$30 billion [17].

A heatwave is defined as a constant increase in maximum temperature intended for a particular time frame, whilst in the case of a cold wave, it will be the opposite. Zahid & Rasul [18] disclosed that '*during 1961–the 1990s, the heatwave events were not as much of common, but throughout 1990-2018s, a rise in frequency is observed*'. Khan et al. [19] exposed that Pakistan faced intense heatwave events in the southwest and the southeast regions due to the high population rate. The month of March 2022 was recorded as the warmest month in the last 60 years; in addition, March to June experienced brutal heatwaves and the hottest temperatures especially in the Nawab Shah city of Sindh, which recorded 51°C and is situated in the southern part of Pakistan. Across Pakistan especially in Sindh, thousands of people were killed due to unprecedented heatwaves in 1952, 1978, 1984, 1988, 2002, 2006, 2009, 2010, 2012, 2013, 2015, 2016, 2017, 2018 and 2022. North-western areas of Pakistan have experienced cold waves, which rise for 30–60 days; on the other hand, in the case of Punjab and the southern areas of Sindh, their trend declined. The average number of cold wave days did not show any significant trend across the country.

Smog is an amalgamation of smoke and fog, and it is described as a combination of several gases with dust and water vapour. It occurs mostly in dry and cold winter months. Three to 4 years ago, smog hit Pakistan, particularly Punjab; it caused lung diseases and breathing problems. Pakistan's northern areas, particularly Azad Jammu Kashmir (AJK), were affected by frequent landslides. Larsen et al. [13] explored that Azad Kashmir, the northern Areas and Khyber Pakhtunkhwa (KPK) were vulnerable to landslides. Since 1926, 13 landslide events have occurred and 413 lives lost, and avalanches have also occurred in the Gilgit Baltistan region, northern parts of KPK and Azad Kashmir.

1.4 Sea level and coastal areas

Climate change threats to coastal areas including Karachi may increase cyclonic activity and sea-level rise due to a higher sea surface temperature. Chaudhry [10] mentioned that '*from 1856 to 2000 coast sea level rose at 1.1 mm per year (mm/year)*', whilst Pakistan was the least affected by it. Khan & Rabbani [20] point out that '*Pakistan has 1,046 km-long coastlines with the Arabian Sea in the South falling within Sindh and Balochistan. The coastal zone of Sindh vulnerability is greater than the Balochistan despite its flat tidal topography and higher speed population growth due to coastal areas and industrial activities for instance Karachi A 2-m SLR area of 7500 Km^2 probably goes under the Indus Delta and Pasni, can also be affected by SLR since 1.4 mm mean sea level in the coastal areas. On the other hand, through the Indian Ocean plate, the Balochistan coast is tectonically active in addition to uplift at the rate of 1–2 mm per year*'. The sea level has remained all but level since 1960, which is a 60-year period where nothing has happened to the sea level despite the purported steady increase in global temperature over the same period. In the future, if the sea level increases, it will raise the erosion rate beside the coastal belt, decline the quality of drinking water, degrade mangrove forests and cause a decline in fish and shrimp production. Coastal erosion and monsoon waves are also a threat to agriculture farms, which are the source of food and fuel for the population located along the west Makran coast. Pakistan's mangroves are assessed to be declining by 4900 hectares per year, which is alarming [21]. These are being cut to construct shrimp farms and other coastal developments. Near about 80% of fish caught from the coastal water are used for the food web [22].

1.5 Water resources

Water resources are considered as the utmost sensitive sectors of climate change; it also negatively influences water availability and quality. '*Pakistan's Indus Basin Irrigation System is known as the world's largest contiguous system that is mainly reliant on precipitation, snowmelt glaciers, and groundwater abstraction*' [10]. The temperature rise worst affects glaciers and snowfall, which lead to increased stream flows beside glacial lake outburst floods in the coming decades. Snow cover has decreased by about 10%, whilst per capita water availability is down from 5000 of water to 1000 m^3/capita and is projected to decrease from 1000 m^3 to 800 m^3 by way of 2025, transitioning it from a water-stressed to a water-scarce country. Chaudhry [10] highlighted '*the use of water in different sectors such as agriculture (92%), industries (3%), as well as domestic and infrastructure (5%)*'. In the future, sectoral demand for water will rise because of the high rate of population and socio-economic development.

1.6 Agriculture sector

The agriculture sector is considered the most sensitive to climate change. It can influence food quality, accessibility and availability. Agricultural cultivation through irrigation and spate farming systems is vastly sensitive to temperature and precipitation trend variability, and a decline in water availability may lead to a reduction in productivity. It plays an essential role in the economy as it adds 19.2% to the gross domestic product (GDP) and engages 38.5% of the labour force. Almost 65–70% population are directly and indirectly joined with it [23]. GCISC has highlighted that during Rabi and Kharif seasons, the increase in average maximum temperature is projected such as 1–2.0°C for RCP 4.5 and 5–6°C for RCP 8.5, which have serious implications for the agriculture sector [23]. Dehlavi et al. [24] evaluated that increase in temperature (+0.5–2°C) would lead to a decline in agricultural productivity by 8–10% by 2040. Athar [25] found out that major crops yield to fall, specifically wheat and rice and the growing season's length in four agro-climatic zones.

Chaudhry [10] mentioned that the findings of the World Bank Knowledge Portal in these words all major crops and cereals yield will decline, while the yield of wheat will reduce very sharply at the end of 2080 as well as the yield variations, specifically in case of wheat production is panic intended for Pakistan, furthermore significant adaptation and mitigation strategies requires to tackle it. Chaudhry [10] highlighted that the temperature trend increased at night time greater than in the daytime. It showed negative effects on agricultural productivity in heat stress, increased water requirements, and higher respiration rates. Besides the temperature rise, extreme events contribute to losses of crops and land productivity, pest attack, and soil erosion. The warmer climate may bring minor yield improvements in the north by extending the growing period, while staple crop yields (wheat, rice and maize) mostly grown in the south are predicted to decrease.

1.7 Livestock

Livestock is an imperative part of agriculture and plays a vital character in the rural economy, especially in socio-economic development. It contributed 11.53% of GDP and 60.07% in value-added in agriculture, and 8 million rural families are associated with it [23]. Near about 8 million folks are involved and receive more than 35–40% income from it. Ahmad et al. [26] described that a wide range of pastures and rangelands are livestock sources. It is projected that 60% of the land be utilised as rangeland in arid, semiarid areas of Punjab and Sindh, northern areas and Balochistan. Mansoor et al. [27] mention that just in Balochistan, rangelands provide feed to near about 93 million livestock which is nearly 87% of the whole population originating their means of support from it.

Mir and Ijaz [28] mention that GHG emissions from livestock are considered a large part of the agriculture sector's total emissions. For instance, approximately 40% of total GHG emissions while 90% of the agricultural sector emits from fermentation and manure management. It predicted that the impacts of climate change on livestock would be in the form of heat stress and drought leading to a reduction in animal productivity, degradation of grazing systems, a decline in quality and quantity fodder production in addition to developed stress on rangelands and water resources as well as epidemics of diseases.

1.8 Fisheries

Climate change also hazards marine and aquaculture fisheries. It is the core resource of diet employment and income generation in coastal communities. According to Government of Pakistan, [23, 29] GDP share is 0.4%, while overall marine and inland fish production remained at 690.600 thousand m. tons in addition to the exported value of US$ 303.606 million. The Indus Delta's rise in temperature may lead to a drop in river flows and superior water habitat and species loss. Furthermore, the surface water of mountainous regions and the Arabian Sea felt an increase in temperature which adversely affects the growth, existence, reproduction and migration of cold water species.

1.9 Energy sector

This sector has causes and effects of climate change such as rising population, economic growth, varying consumption patterns and the summer month's rising demand for air conditioning which will likely increase energy demand and consequently increase GHG emissions from the energy sector in Pakistan. During 1990–2016, electricity accessibility rose from 59.6 to 99.15%. Unfortunately, continuing power outages in the summer season because of the demand for cooling on top has crippled the economy with an annual loss of 2.6% of $5.8 billion. A comparison of the fiscal year 2012–2013 and 2022 contribution of energy sources was: thermal energy contribution declined from (64%) to (60.9%), followed by nuclear and renewable energy demonstrating an increasing rate from 5 to 12.4% and 0 to 3%, respectively, while hydel energy showed decreasing rate from 31 to 23.7 energy. During 2021–2022, the electricity consumption pattern indicated that the household sector is the largest consuming sector (47%), followed by industries (28%), the agriculture sector (9%) and commercial consumers (7%) in addition to other sectors (8%). Successive governments have affianced National Electricity Plans which are related to future power generation projects, pricing issues and setting high standards for power consumers.

Climate change showed a solid impact on power generation through asymmetrical river flows, concentrated and numerous floods in addition to droughts. Hydel power contributed 23.7% to the energy supply. However, the rise in temperature and fall in rainfall patterns will decline water supplies, leading to a shortfall in energy production and creating an alarming situation for a future scenario. Hydel power production is determined in the north, where the temperature rise is predicted to be at the highest level. In the future, climate change-persuaded natural threats might negatively influence oil besides gas infrastructure because immense precipitation leads to a flood. Most gas fields are in the neighbourhood of the Indus River and are near about 1/3 of primary commercial energy requirements satisfy through imported oil transported by sea mode. Any impairment in infrastructure might break the supply intended for a long period and create a large burden on the national economy. Higher temperatures will increase the evapotranspiration rate, leading to rising electricity requirements for pumping water used for agricultural irrigation [10].

1.10 Human health

Climate change can influence health and environmental factors such as clean air, safe drinking water, sufficient food and secure shelter. It may be over and done with extreme heat events, variable rainfall patterns and natural disasters. The fluctuations in temperature and rainfall patterns are associated with the spread of different infectious diseases and food security [30]. Furthermore, extreme events are also linked with the inhabitant's mental health, such as depression, aggression and distress. Rise in temperature increases the risk of water-borne and vector-borne diseases. Khalid and Ghaffar [31] disclosed that climate change is projected to increase malaria and dengue by 12–27% and 31–47%.

1.11 Deforestation and biodiversity

Forests play a decisive role in ensuring soil and water preservation and decreasing climate change's destructive effects. One of the major reasons for vulnerability to climate impacts is a very low forest cover area. *"Pakistan is included in the list of low forest cover countries with only 5% of land area under forest and tree cover; however, the international requirement is 25%*" [2]. The average deforestation rate is 27,000 hectares per year of which 84% of cut wood is utilised for domestic purposes [2]. Forests are known as a crucial natural resource for the livelihood of rural areas. It makes available timber, food, fuelwood, habitat designed for wildlife and numerous significant ecosystem facilities, for instance reducing or controlling cyclones and storms in coastal areas and mitigating carbon dioxide. *"It is projected that the impacts of climate change, for instance, variation in temperature and precipitation pattern, increasing intensity and frequency of extreme events will sharply affect the forest in addition to threatening the biodiversity status, and soil quality"* [10]. Trios et al. [32] explored that "At the end of the century climate change is turning into one noteworthy driver of biodiversity loss". Climate change would also worsen the hazard of biodiversity due to variations in land utilisation besides population pressure.

1.12 Population growth and infrastructure

Pakistan consists of 5th most populated country and top 10th largest labour force in the world. Its estimated population is 215.25 million folks, while at the time of independence in 1947, they were only 32.5 million [23]. According to 1951, 1961, 1972, 81 and 1998 censuses, Pakistan had a population of 33.7 million, 42.8 million, 65.3 million, 83.783 million and 132.35 million, while on the 2017 census, the population of Pakistan was 207.77 million [33]. The average annual population growth rate is 1.80% which shows that rapid population increases refer to a rise in demand for water and agricultural products. The population of 10 major cities increased by 74.8%; major reason for urbanisation is the accessibility of better socio-economic facilities for mass. Chaudhry [10] revealed that climate change influences urban agglomeration is well-thought-out due to variations in weather or climate change in either duration or magnitude. From past experiences, it is explored that in Pakistan, most infrastructure is situated in hazardous areas from variations in climate. Generally, the urban infrastructure facilities are mutually dependent; a let-down of any single infrastructure leads to distractions into further associated urban facilities. In the next coming decades, climate variation might escalate the frequency of disturbances.

A review of empirical studies was conducted to access the influence of climate change on the agriculture sector. Verge and De Kimpe [34] studied the liaison between greenhouse gases emission and crop production and pointed out that Asia will be a gigantic food consumer and greenhouse gas producer. Gowdy [35] rendered a new method to analyse climate change and economic development through a pragmatic approach. South Asia released a massive quantity of carbon dioxide. Ahmed and Schmitz [36] investigated the economic impact of climate change on the agriculture sector in Pakistan and accessed that climate change adversely affects it. Siddiqui et al. [37] evaluated that increase in temperature in the long and short run was beneficial and harmful, respectively, for wheat production, while the increase in precipitation was beneficial. Variation in temperature besides precipitation is favourable for rice production but the opposite for cotton crops. Furthermore, the temperature rise is harmful to sugarcane production. Janjua and Samad [38] explored that climate change will not destruct Pakistan's wheat production over in long and short periods. Zhai et al. [39] found out technological progress induced while climate variables had detrimental impact on wheat yield in China. Simionescu et al. [40] explored the greenhouse gases effect in the EU and found out a positive relationship among them. Chandio et al. [41] examined that carbon dioxide has a positive influence in the long and short-run, while temperature and rainfall negatively influence just in long run in the case of China. Ahsan et al. [42] quantified a positive relationship among temperature, rainfall, carbon dioxide and cereal crop production in the case of Pakistan. Chandio et al. [43] investigated that temperature and carbon dioxide have a negative association with cereal yield while contrasting in rainfall.

Warsame et al. [44] revealed that rainfall and temperature have positive and negative while carbon dioxide has no significant effect on crop production. Abbas [45] evaluated the impact of climate change on wheat and maize crop production in Pakistan with the help of a panel-pooled mean group. Temperature revealed significant negative results on crop production during the long run while insignificant in the short run. Arable land and fertilisers gave positive and significant effects in the long and short run while improve quality seeds showed the insignificant result. Baig et al. [46] accessed the asymmetrical effects of climate change on rice production in India. This research finds out that rice production has a negative relationship with mean temperatures in the long run while positive in the short run. Positive shocks in rainfall and CO_2 emission have a significantly negative effect in the long and short run. Furthermore, cultivated area, agriculture credit and fertiliser consumption positively affect rice production. Chandio et al. [47] probed the impacts of climate change on cereal production in Bangladesh. CO_2 and rainfall have a negative and positive impact on cereal production in the long and short run, respectively, while temperature has an adverse impact just in the short run. Furthermore, arable land, energy consumption and financial development have positive impacts on cereal production under both runs.

Furthermore, a considerable number of researchers had provided literature on the vulnerability of climate change and its impacts on the rest of the world at different levels and sectors for instance [48–62]. Specific vulnerability-related literature gave attention to systems, places and activities [63, 64], whereas others focus on ecosystems, livelihoods, individuals and landscapes [65].

Pakistan has high-altitude mountains from north to west, arid deserts in the south, the hot and dry Indus River Valley in the centre to the south and a humid 990 km coastline. In this passing century, climate change has become a massive challenge because of its geographical location and its reliance on natural resources; further pressure on water resources, the agriculture sector, human health, and the energy sector, so it has a long-term catastrophic effect on Pakistan's economy. According to the researcher's knowledge and literature review, no sole prior study employs temperature, precipitation and input indices in addition to greenhouse gas emission against these drawbacks; this research will overcome the gap and give a new direction to researchers, policymakers, and national and international organisations. Moreover, the core objective is to evaluate the vulnerability of climate change on cereal production in Pakistan and based on the outcome provide adaptation and mitigation strategies to tackle climate change. On these accounts, it will increase the scope of the study and the nature of the analysis. The research is planned in the following channel; this first section introduction consists of 12 subsections which comprehensively discuss all related aspects and literature review of prior studies; the second section deals with conceptual framework; the succeeding third and fourth sections deal with data collection, model and methodology as well as analysis result with discussion. The last fifth section contains the conclusion, policy implications and a brief history of legislation and plans in Pakistan.

2. Conceptual framework

The liaison between climate change and cereal production reconnoitre through three approaches: Production Function approach (agronomic models)[1], Ricardian approach (hedonic models)[2]and Simulation models. Firstly, the inkling of climate change and agriculture acquaint [66–68] by exhausting "agronomic models" to evaluate the environmental variable's impact on agriculture crop yield. Charles Cobb and Paul Douglas developed and tested the Cobb–Douglas in contrast to statistical evidence during 1927–1947. Afzal et al. [69] mentioned the pros of Cobb Douglas Production Function; it is more appropriate when observations are not large, and it is easy to estimate and interpret. Production theory assumes that the liaison among multiple outputs and multiple inputs is replicated through the concept of transformation function [70] further assumptions (e.g., free disposal of inputs and exclusion of technical inefficiency) in addition to aggregation of all outputs, the input-output liaison is often reduced to a production function) [71] in which one output depends on multiple inputs: Y = f(x). In the traditional specification of the production function, all inputs are treated symmetrically; that is, they are assumed to contribute to the output in the same way [70].

3. Method (data collection and analysis)

This study encompasses annual time series data of Pakistan over 1977–2016 in details temperature, greenhouse gas emanations, precipitation, cereal production, cultivated area and rural population data acquired from World Development Indicators, while seeds availability, water accessibility, fertilisers, mechanisation and agriculture credit comes from Economic Surveys of Pakistan. Prior studies employed temperature and precipitation data (maximum or minimum or average) which are not favourable for cereal production; these models may have either under- or overestimated; in addition to wind speed, sunshine and humidity also play a core role in cereal production but due to unavailability of data going to skip them. Furthermore, this current research developed temperature and precipitation indices which are the summation of maximum, minimum and average data, while the input index is a combination of water accessibility, seeds availability, fertilisers, agriculture credit and mechanisation; in addition, all indices are constructed by principal component analysis. The rural population engages as a proxy of the rural labour force due to the inability of data. Furthermore, variable codes with descriptions and measuring units are listed in the **Table 1**.

The prior studies related to the impact of climate change on cereal [72] in the case of Burkina Faso, [73, 74] empirical evidence from China also adapted Cobb–Douglas production function for estimation purpose. Now, it is also extended according to the present study in which α_0 is intercept, and $\alpha_1 \ldots ..\alpha_5$ are parameters of variables:

$$\mathrm{CP_t} = \alpha_0 + TI_t^{\alpha_1} + PI_t^{\alpha_2} + GG_t^{\alpha_3} + CA_t^{\alpha_4} + II_t^{\alpha_5} + RP_t^{\alpha_6} + \varepsilon_t \tag{1}$$

[1] *The production function approach is based on the agronomic models that consist of mostly controlled experimental studies.*

[2] *These models are often based on cross-sectional data and based on the Ricardian approach.*

Variables	Description	Measuring Units
CP (Predictand)	Cereal Crops Production	Kg per Hectare
TI	Temperature Index	Celsius
PI	Precipitation Index	Millimetres
GG	Greenhouse Gases Emanation	kt of CO_2 equivalent
CA	Cultivated Area	Hectares
II	Input Index	
RP	Rural Population	Million

Source: Author's Computations.

Table 1.
Data description.

This algebraic form of the Cobb–Douglas production function changed into log form:

$$\ln\ \mathrm{CP_t} = \alpha_0 + \alpha_1 \ln TI_t + \alpha_2 \ln PI_t + \alpha_3 \ln GG_t + \alpha_4 \ln CA_t + \alpha_5 \ln II_t + \alpha_6 \ln RP_t + \varepsilon_t \tag{2}$$

This study takes one ARDL approach introduced by Pesaran and Shin [75] and Pesaran et al. [76] to search out the cointegration liaison among variables when their integration order is I(0), I(1) or assortment. It is statistically significant for small data span, restraint to employ in same order integration and provide unbiased outcomes in the amalgamation of I(0) and I(1). There is no necessary and sufficient condition to find out the stationarity order of integration, but to keep a safe path and avoid I(2), search out variables stationarity through ADF[3]test; on the bases of its outcomes, move towards L-ARDL[4] technique with the Bound test. For instance, some previous empirical studies [42, 44, 47, 74, 77] also had employed the same techniques to determine the impact of climate change on cereal production. The following model of ARDL is employed for cointegration testing among predictand and regressors:

$$\begin{aligned}\Delta \ln CP_t = \Omega_0 &+ \sum_{a=1}^{s} \Omega_{1a} \Delta \ln CP_{t-a} + \sum_{a=1}^{r_1} \Omega_{2a} \Delta TI_{t-a} + \sum_{a=1}^{r_2} \Omega_{3a} \Delta PI_{t-a} \\ &+ \sum_{a=1}^{r_3} \Omega_{4a} \Delta GG_{t-a} + \sum_{a=1}^{r_4} \Omega_{5a} \Delta \ln CA_{t-a} + \sum_{a=1}^{r_5} \Omega_{6a} \Delta \ln II_{t-a} \\ &+ \sum_{a=1}^{r_6} \Omega_{7a} \Delta \ln RP_{t-a} + \Psi_{1a} \ln CP_{t-a} + \Psi_{2a} TI_{t-a} + \Psi_{3a} PI_{t-a} \\ &+ \Psi_{4a} GG_{t-a} + \Psi_{5a} \ln CA_{t-a} + \Psi_{6a} \ln II_{t-a} + \Psi_{7a} \ln RP_{t-a} + \phi_t\end{aligned} \tag{3}$$

[3] *Augmented Dicky Fuller*

[4] *Linear Autoregressive Distributed Lag*

Here, Δ is a sign of the first difference and ϕ error term. The null hypothesis (no cointegration) is articulated as:

$$H_0 : \Psi_1 = \Psi_2 = \Psi_3 = \Psi_4 = \Psi_5 = \Psi_6 = \Psi_7 = 0.$$
$$H_1 : \Psi_1 = \Psi_2 = \Psi_3 = \Psi_4 = \Psi_5 = \Psi_6 = \Psi_7 \neq 0.$$

OLS[5] is the methodology proposed for testing long-run liaison among point-out variables in addition to F-statistics employed for the testing hypothesis that indicates cointegration prevails or not among prediction and regressors. The decision is made on lower and upper bounds values: if the statistical value is higher than the value of the upper bound, then reject H_0 (no-cointegration) otherwise case will be the opposite case if values rely on among both bounds then the result will appear as inclusive. In the case of cointegration, move on to the second step which highlights the long-run relationship among variables. The long interval of time for cereals production model (s, r_i) undertakes the succeeding form:

$$\begin{aligned}\Delta \ln CP_t = \Omega_0 &+ \sum_{a=1}^{r} \Psi_{1a} \ln CP_{t-a} + \sum_{a=1}^{r_1} \Psi_{2a} TI_{t-a} + \sum_{a=1}^{r_2} \Psi_{3a} PI_{t-a} \\ &+ \sum_{a=1}^{r_3} \Psi_{4a} GG_{t-a} + \sum_{a=1}^{r_4} \Psi_{5a} \ln CA_{t-a} + \sum_{a=1}^{r_5} \Psi_{6a} \ln II_{t-a} \\ &+ \sum_{a=1}^{r_6} \Psi_{7a} \ln RP_{t-a} + \phi_t\end{aligned} \tag{4}$$

Here, Ψ and ϕ_t are the long intervals of time parameter and error term, correspondingly. The last step is to insist on an error correction model for evaluating the dynamic in cereals production in a short interval of time specified as:

$$\begin{aligned}\Delta \ln CP_t = \Omega_0 &+ \sum_{a=1}^{r} \Omega_{1a} \Delta \ln CP_{t-a} + \sum_{a=1}^{r_1} \Omega_{2a} \Delta TI_{t-a} + \sum_{a=1}^{r_2} \Omega_{3a} \Delta PI_{t-a} \\ &+ \sum_{a=1}^{r_3} \Omega_{4a} \Delta GG_{t-a} + \sum_{a=1}^{r_4} \Omega_{5a} \Delta \ln CA_{t-a} + \sum_{a=1}^{r_5} \Omega_{6a} \Delta \ln NCI_{t-a} \\ &+ \sum_{a=1}^{r_6} \Omega_{7a} \Delta \ln IPC_{t-a} + \omega ECM_{t-1} + \phi_t\end{aligned} \tag{5}$$

Here, Ω and ϕ_t are the short intervals of the time parameter and error term, respectively.

4. Analysis results

In the case of L-ARDL, there is no necessary and sufficient condition to check the stationarity of the variables although this research did this in the first step to keep the safe side and confirm that no single variable is stationary at 2nd degree. Results in the **Table 2** indicate that all the variables are stationary at the level except cereal

5 *Ordinary Least Squares*

Variables	Intercept	Intercept and Trend	None	Outcomes
CP	8.786	8.678	6.704	I(I)
TI	8.203	8.087	8.282	I(0)
PI	13.361	13.182	13.540	I(0)
GG	4.750	4.670	1.349	I(I)
CA	5.370	5.527	2.866	I(I)
II	4.846	4.840	3.230	I(0)
RP	6.550	6.460	2.082	I(0)

Source: Author's Computations.

Table 2.
Outcome of ADF test on level.

production, greenhouse gases emanation and land under cereal production on the level at 5%, so now, it is confirmed that the L-ARDL is the best option and Akaike information criterion chose for optimum lag order. Bound test outcomes and long- as well as short-run outcomes are mentioned in **Tables 3** and **4**, respectively.

The estimated F $lnCP_t$ ($lnCP_t/TI_t$; PI_t; GG_t; $lnCA_t$; $lnII_t$; lnRPt) came out 5.840 and superior from upper and lower analytical outcomes of the bound test at 5 and 10% outcomes presented in **Table 2**. Furthermore, Eq. (6) and **Figure 4** disclose the cointegration among predictand and regressors during 1977–2016.

$$\text{Cointeq} = \text{CPG} - \Big(-1.000^{*}\,\text{TI} + 0.175^{*}\,\text{PI} - 0.617^{*}\,\text{GG} + 2.384^{*}\,\text{CA} + 0.303^{*}\,\text{II} + 0.095^{*}\,\text{RP}\Big) \tag{6}$$

The empirical outcomes of the long and short run are presented in **Table 3** panel A. Temperature index has a coefficient value of −1.000 and a significant probability value of 0.029, indicating that cereal production will drop when the temperature upsurges. The previous studies outcomes are sustained by Pickson et al. [74], Chandio et al. [41], Chandio et al. [43], Warsame et al. [44], Chandio et al. [78] and Baig et al. [46] in case of India by using N-ARDL on data from 1991 to 2018 found that temperature has an adverse influence on rice production. In a short interval of time, the coefficient of temperature index is 1.049 and significant which means that a 1°C increase in temperature will increase the 1.049 tonnes of cereal production which is reinforced by Chandio et al. [79] and Baig et al. [46]. While contradicts [79] attained on the rice crop of Pakistan coving 1968–2014 through ARDL and [47] relied on ARDL achieved in cereal production in Bangladesh during 1988–2014.

The precipitation index has a coefficient value of 0.175 and a significant probability value of 0.022 which illustrates that cereal production will trigger as precipitation increases. This outcome is congruent with previous results [43, 44, 47, 72, 74, 78, 80, 81] achieved on cereal production in Bangladesh. The short-run coefficient of the precipitation index is significant, and 0.092 reveals that a 1 mm upsurge in precipitation will lead to a 0.092 tonnes escalation in cereal production [43, 47, 72, 74, 80, 81] also sustained the same results.

$lnCP_t = f (lnCP_t/ TI_t;PI_t;GG_t; lnCA_t; lnII_t; lnRP_t)$			
F-Statistics 5.840			
Critical Values			
5%		10%	
I(0) Bound	I(1) Bound	I(0) Bound	I(1) Bound
2.04	3.24	1.75	2.87
Source: Author's Computations.			

Table 3.
Outcomes of bound test.

Predictand: ln CP; Selected Model: ARDL (1,1,0,1,1,0,0)				
Predictors	**Coefficient**	**Std.Error**	**TStat.**	**Prob.**
Panel A: long and short-run outcomes				
TI	−1.000	0.437	−2.285	0.029
DTI	1.049	0.420	2.498	0.018
PI	0.175	0.072	2.416	0.022
DPI	0.092	0.043	2.150	0.040
GG	−0.617	0.187	−3.284	0.002
DGG	−0.153	0.220	−0.696	0.492
LnCA	2.384	0.944	2.524	0.017
D(lnCA)	1.365	0.566	2.410	0.022
LnII	0.303	0.118	2.558	0.016
D(lnII)	0.318	0.115	2.765	0.009
LnRP	0.095	0.311	0.306	0.761
D(lnRP)	0.100	0.326	0.306	0.761
C	−6.648	11.195	−0.524	0.421
Coint. Eq (−1)	−1.049	0.145	−7.190	0.000
Panel B: Model Criteria				
R-Squared	0.599	Adjusted R Square	0.474	
Durbin-Waston	1.811	Jarque-Bera	2.105 (0.349)	
Breusch-Godfrey	1.545(0.229)	Ramsey Reset	0.86 (0.80)	
Breusch-Pagan-Godfrey	0.972 (0.459)			
CUSUM	Stable	CUSUM Square	Stable	
Source: Author's Computations.				

Table 4.
Outcomes of long and short intervals of time.

Greenhouse Gas Emanations has a coefficient value of −0.617 and a highly significant probability value of 0.002 which indicated that cereal production will decline when greenhouse gas concentration starts increasing in the atmosphere. Findings are

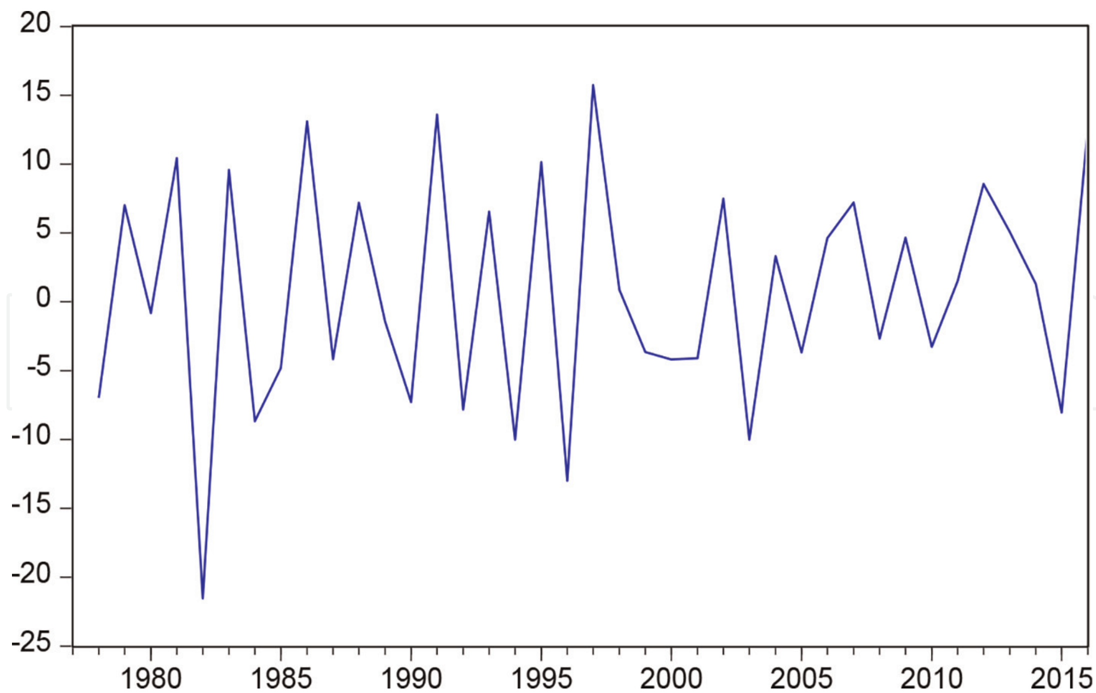

Figure 4.
Cointegration graph. Source: Author's computations.

in line with just CO_2 emission. Pickson et al. [74] employed ARDL on time series data (1990–2013) from cereal production in the case of China. Chandio et al. [79] also achieved the same result on the rice crop of Pakistan through ARDL from 1968 to 2014. Findings are contradicting [41, 42, 72, 79, 82]. While in the short run, it also has an adverse but insignificant liaison with cereal production such that 1kt will reduce 0.153 tonnes of cereal production this outcome is similar to [43, 46, 47, 74, 78].

Cultivated Area is known as a prime influencer for cereal production which has a coefficient value of 2.384 and a significant probability value of 0.017 and showed cereal production will increase in case of a rise in land under cereal production. Chandio et al. [41, 42, 44–47, 74, 78, 79, 83, 84] also provided similar result. The land under cereal production coefficient is 1.365 and significant which makes it possible that 1 per cent rise in the area will promote 1.365 per cent cereal production past studies; Chandio et al. [41, 42, 45, 47, 74, 79] supported it.

The input Index plays a pivotal character to boost and cope with the negative influence of climate change on cereal production over a long interval of time. The cereal input index coefficient is 0.303 with a probability value of 0.016 which exhibits that a 1 per cent increase in it will upsurge 0.303 cent cereal output. Proper practice of inputs helps to enhance soil fertility and nutrition and in addition is a major source of boosting production [41, 45, 46, 78, 79, 83]. In a short interval of time, cereal input index coefficient is 0.318 which means that a 1 per cent increase in it will increase 0.303 per cent cereal output and is similar to [41, 45, 83].

Rural Population is employed as a proxy of the rural labour force, indicating positive but insignificant linkages with a cereal production coefficient value is 0.095 which suggests that in the long interval of time, 1 per cent rise in it will increase 0.095 per cent cereal production. Results are matched by [42, 74, 77, 78] on labour force and [43] on rural population contradict by Warsame et al. [44]; and Sossou et al. [72]. Also, in a short interval of time, it has positive and insignificant such as a 1 per cent rise in it will ease −0.100 per cent cereal production [43].

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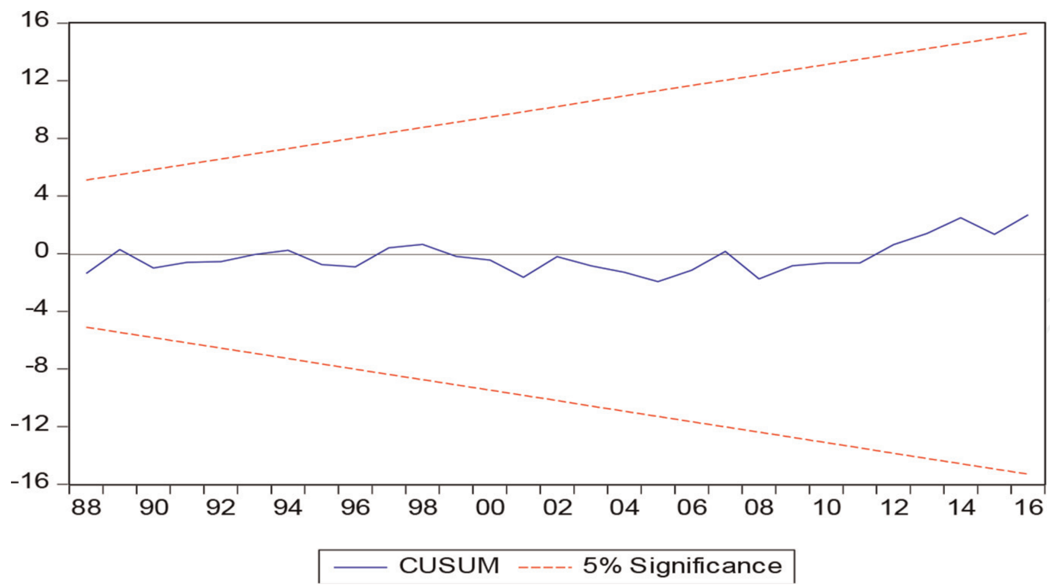

Figure 5.
Cumulative sum.

The Error Correction Coefficient is −1.049 and significant which infers a higher converging speed in the direction of equilibrium. This infers that the change in cereal production from short to long intervals of time is adjusted by almost 1% per year. The adjustment is highly significant because of the probability value. The input index plays a pivotal role to absorb any adverse shock in a short interval of time.

Furthermore, diagnostic inspection tests attempted to enhance the validity of analysis **Table 3**, and panel b displayed the outcome of it, which accessed that the cereal production model is normally specified, functional form and free from serial correlation, as well as heteroscedasticity. Mutually cooperated stability tests CUSUM[6] and CUSUMQ[7] plots specified that the cereal production model is stable and cannot be rejected, which are displayed in **Figures 5** and **6**. Furthermore, The pore over model is the goodness of fit for the reason that R^2:0.599 and Adj- R^2:0.474 suggest that very nearly 59% variations in cereal production are expounded by temperature index, precipitation index, greenhouse gases emanations, cultivated area, input index and rural population as well as a remaining error term.

5. Conclusion and policy relevance

Pakistan is known as a climate change persuaded hazard-prone country. Due to its geographical position, climate change manifests in the form of temperature rise, deplete glaciers, storms, heavy rainfall, an upsurge in sea level, typhoons, flash floods, glacial lake outbursts, unusual smog, droughts and landslides. The agriculture sector has got a crucial position in Pakistan's economy, and climate change has greatly influenced its production as compared to rest of the sectors. This article has drawn attention towards the vulnerability of climate change and the significance of adaptation and mitigation-based policies. Numerous models of climate change scenarios

[6] *cumulative sum*

[7] *cumulative sum of square*

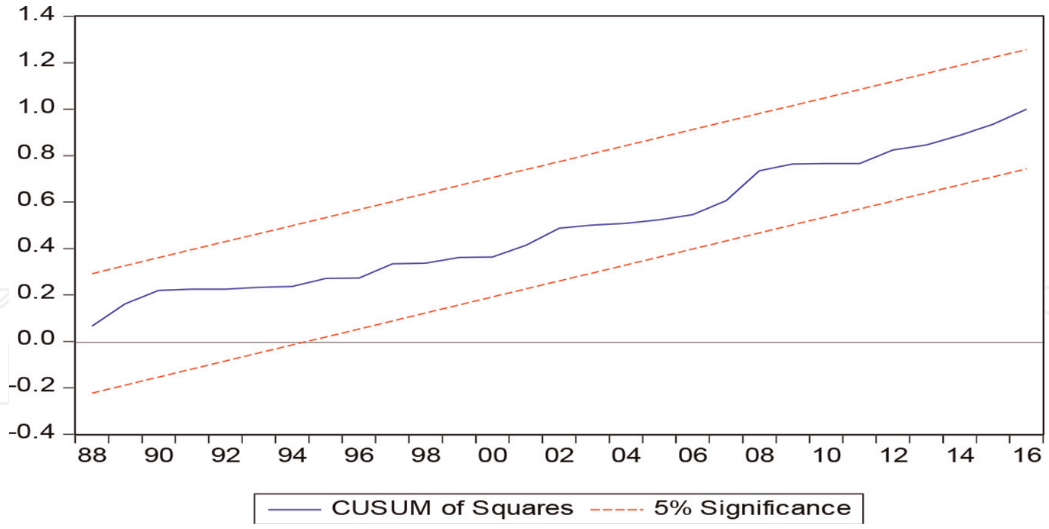

Figure 6.
Cumulative sum of square.

draw attention to the decline in cereals production during the current situation. The L-ARDL analysis hindered that temperature and greenhouse gas emanation have negative bonds with cereals production in the long run although greenhouse gas emanation is just in short intervals. Pakistan is standing in the row of low greenhouse gas emissions countries and, on the other hand, is drastically disturbed by it. This research suggests some adaptation and mitigation strategies through which we can tackle climate change:

- The government needs to introduce a national climate fund and insurance schemes for poor farmers. Rice crops should be cultivated through the latest cultivation way with lower methane emission and nitrous oxide from agricultural soil.

- World Trade Organisation plays a pivotal role to reduce barriers to transferring low-carbon and environment-friendly technologies.

- Decline dependency on fossil fuels for energy purposes and transfer from fossil fuels to renewable energy resources (solar energy and hydropower) and the need to construct large hydropower projects according to present and future requirements.

- To mitigate greenhouse gas emissions, the government should introduce sustainable development policies. It is time for the administrative system to take strong steps to promote the Clean Development Mechanism to reduce the carbon footprint of different sectors and employ a carbon pollution tax on those who emit more than a limited amount of carbon dioxide.

Conflict of interest

"The authors declare no conflict of interest."

Annexure 1

A.1 Brief History of Legislation and Plans of Climate Change in Pakistan

On 25th September 2015, United Nations introduced sustainable development goals with the 13th Sustainable Development Goal being "Climate Action". The past and present governments are acquainted with this issue and adopt strategic measures at national and international levels to abate climate change effects. Furthermore, climate change concerns are overcome with the help of endorsing legislation and generating strategies and policies instead of a healthy environment. The leading legislations and strategies to combat the climate change challenge are as under:

i. In 1983, Pakistan Environment Protection Ordinance was endorsed.

ii. During 1991–1993, National Environmental Quality Standards were prepared by the National Conservation Strategy adopted in 1993.

iii. In 1997, Pakistan's Environmental Policy derived from the Pakistan Environment Protection Act.

iv. During 2004–2005, Prime Minister Committee on Climate Change convenes National Environment Policy.

v. For the duration of 2008, the Planning Commission recognised the task force and Inter-Ministerial Committee introduced on climate change.

vi. Ministry of Disaster Management was renamed and converted into the Ministry of Climate Change

vii. In 2012, National Climate Change Policy introduced a plan to talk about climate change. And the National Disaster Risk Reduction Policy was also introduced

viii. Climate Change Policy Implemented framework for the duration of 2014 Framework.

ix. In 2015, the Division of Climate Change upgraded to the Ministry of Climate Change, Ministry Of Climate Change designed Forest Policy.

x. Green Pakistan Programme was designed for the plantation of 100 million plants all over the country.

xi. In the course of 2016, the government of Pakistan endorsed the Paris Climate Change Agreement in addition to the announced Climate Change Bill.

xii. Pakistan Climate Council was developed for the implementation of the Kyoto Protocol and the Paris Agreement.

xiii. During 2014–2018, the government took some positive steps to reduce carbon emissions, especially the adoption of Euro-II standard fuel, switching to RON

92 petrol from RON 87, banning the import of furnace oil for power generation and plans to CAP coal-fired power generation plants.

xiv. For the year 2019–2023, the Ten Billion Tree Tsunami Programme was launched which will plant 3.296 billion 1586.18 million planted in the whole of Pakistan.

Classification

Jel code: Q1, Q22, Q23, Q25, Q54.

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