Pakistan Perspectives
Vol. 28, No.2, July-December 2023

Impact of Coal Rent, Carbon Emissions, Precipitation and Urbanization on Pakistan's Food Export Performance

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Abstract

This study examines the impact of climate change on food exports in Pakistan by employing Johansen cointegration analysis to investigate both long-run and short-run relationships. The study considered urban population, precipitation, coal rent, and carbon emission as four major factors affecting climate change. The findings reveal that coal rents, a measure of the economic benefits of coal mining and use, reduce food exports in the long run. Therefore, the study suggests that as rents affect agriculture, further coal production could harm the environment and affect agriculture that can meet export demand. Similarly, high carbon levels contribute to climate change that can affect agriculture. The results indicate that rapid urbanization increases the pressure on arable land, which can reduce the amount of land available for agriculture and affect the food supply. Further, the study examines that precipitation demonstrates a positive association with food export in the long run, while all other variables display a negative relationship. Overall, this study highlights the crucial need to limit climate change and adopt sustainable agricultural practices to address food export challenges in Pakistan.

Keywords: Coal rent; urbanization; carbon emissions; precipitation; food export, agriculture.

Introduction

Pakistan is ranked eighth among the most adversely affected nations due to climate change.[1] The country is suffering from considerable obstacles to food security; in this situation, climate change would exacerbate already challenging issues for food access and affordability. The effects of climate change, such as altered rainfall patterns, rising average temperatures, and an increase in the frequency of extreme weather events like floods and

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[1] David Eckstein, Vera Künzel, and Laura Schäfer, *Global Climate Risk Index 2021* (Berlin: Germanwatch e.V., 2021), accessed 13 March 2022, https://www.germanwatch.org/en/19777.

droughts, are particularly felt in Pakistan. Pakistan's economy heavily depends on agriculture, a sector that is very susceptible to climate change. Changes in agricultural productivity due to climate change could lead to food insecurity in Pakistan. Wheat production, an important staple crop in Pakistan, is expected to decline due to climate change.[2] Similarly, maize yields are expected to decline due to changing weather conditions, which will have serious consequences for food security.[3] According to the Illegal Foreigners Repatriation Plan (IFRP), Pakistan's agricultural output may drop, exacerbating the country's food insecurity.[4] Climate change is projected to lead to a decline in rice production in Pakistan and affect food security.[5]

Changes in temperature and rainfall patterns can reduce crop yields and reduce water availability for irrigation, which can have a major impact on food production and export. Climate change is thus expected to increase the risk of water scarcity in Pakistan, which could have significant impacts on agricultural productivity and food security.[6] FAO recognizes that Pakistan is highly sensitive to the impacts of land degradation and water scarcity on agriculture.[7] According to a United Nations study, Pakistan is highly vulnerable to the consequences of climate change since

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2 Pervez Zamurrad Janjua, Ghulam Samad, and Nazakatullah Khan, 'Climate Change and Wheat Production in Pakistan: An Autoregressive Distributed Lag Approach', *NJAS - Wageningen Journal of Life Sciences* 68 (7 March 2014), 13-19.

3 Toshichika Iizumi et al., 'Crop Production Losses Associated with Anthropogenic Climate Change for 1981-2010 Compared with Preindustrial Levels,' *International Journal of Climatology*, 38:14 (2018), 5405-5417.

4 International Food Relief Partnership, 'Climate Change Impacts on Health and Livelihood: Pakistan Assessment', 2021, accessed 27 June 2023, https://www.climatecentre.org/wp-content/uploads/RCRC_IFRC-Country-assessments-PAKISTAN-3.pdf.

5 Nasir Abbas Khan et al., ''Rice Farmers' Perceptions about Temperature and Rainfall Variations, Respective Adaptation Measures, and Determinants: Implications for Sustainable Farming Systems', *Frontiers in Environmental Science* 10 (2022), accessed 27 June 2023, https://www.frontiersin.org/articles/10.3389/fenvs.2022.997673.

6 Qamar Uz Zaman Chaudhry, '*Climate Change Profile of Pakistan*' (Asian Development Bank, 2017), accessed 27 June 2023, https://www.adb.org/publications/climate-change-profile-pakistan.

7 Food and Agriculture Organization, *Climate Change and Food Security: Risks and Responses* (United Nations, 2015), accessed 27 June 2023, https://www.fao.org/3/i5188e/I5188E.pdf.

it relies heavily on agriculture for its livelihood.[8] Due to issues including water scarcity, food insecurity, and extreme weather, the Climate & Development Knowledge Network (CDKN) has classified Pakistan as a nation that is particularly vulnerable to climate change.[9]

The consequences of climate change on livestock, a key source of food and income for many people in Pakistan, must also be considered. Climate variability and abrupt changes in weather conditions can affect the livestock sector, which plays a significant role in food supply such as meat, milk, eggs, etc. [10] FAO noted that Pakistan is vulnerable to climate-related impacts on fisheries and aquaculture, which may significantly impact food productivity.[11] Climate-related variables are anticipated to increase the frequency of extreme weather events in the country, which could cause crop failures and food security.[12] For example, disruptions to the food supply chains caused by floods and droughts can cause food prices to rise, making it difficult for people to access affordable and quality food. According to a World Food Programme (WFP) report, climate change is expected to worsen Pakistan's food production as natural disasters such as unprecedented rainfalls and catastrophic floods become more common.[13]

Climate change is the most influential factor and a threat to Pakistan's food security. Investments in methods that can aid in resilience building and climate change adaptation, such as enhancing irrigation infrastructure, promoting sustainable agricultural practices, and diversifying livelihoods to lessen reliance on agriculture, will be crucial to addressing these challenges. The World Bank predicts that climate change

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8 Sharon Burke et al., 'How Floods in Pakistan Threaten Global Security' (14 February 2023), accessed 27 June 2023, https://www.wri.org/insights/pakistan-floods-threaten-global-security.

9 World Bank Climate Change Knowledge Portal, 'Climate Risk Country Profiles,' last modified 2023, accessed 27 June 2023, https://climateknowledgeportal.worldbank.org/.

10 Ali Asghar Hashmi and Shafiullah, *Agriculture and Food Security* (Pakistan: Planning and Development Department, Northern Area, 2003), accessed 6 July 2023, https://portals.iucn.org/library/sites/library/files/documents/2003-095_1.pdf.

11 Food and Agriculture Organization, *Impact of Climate Change on Fisheries and Aquaculture* (United Nations, 2018), accessed 27 June 2023, https://www.fao.org/3/i9705en/i9705en.pdf.

12 Areeja Syed et al., 'Climate Impacts on the Agricultural Sector of Pakistan: Risks and Solutions,' *Environmental Challenges* 6 (1 January 2022): 100433.

13 World Food Programme, 'Pakistan Country Strategic Plan (2023–2027)' (United Nations Publication, 2022).

will have a severe influence on Pakistan's agriculture sector, which employs more than 40% of the nation's workforce.[14] Similarly, United Nations Development Programme (UNDP) research reveals that climate change poses a serious threat to Pakistan's food security, especially for weaker people in rural regions.[15] Pakistan is largely dependent on fossil fuels, i.e., coal, oil, and natural gas, to fulfil its energy consumption demand. The experts assert that this is the use of fossil fuels that results in the emissions of GHGs, which in turn lead to detrimental environmental repercussions. In addition, the rapid increase in population and modernization due to economic development has increased the energy requirement and the mining and consumption of coal in Pakistan over the last few decades. Since 2012, coal-fired power plants in the country have risen from 61 gigawatt hours in 2012 to 15,774 gigawatt hours in 2018.[16] Prioritizing coal fire power plants would pose serious threats to accelerating climate change in the country.[17] In this scenario, an increase in coal rent from coal production, like any other resource rent, necessitates understanding the relationship between coal rent and sustainable food supply. Therefore, investigating the environmental and ecological effects of coal extraction and combustion on agricultural systems is essential because coal has become an important source of energy in Pakistan nowadays. To the best of our knowledge, this is the first study to examine empirically the link between coal rent and food export. However, work has been done on the specific influence of urbanization, carbon emissions, and precipitation on food export performance in Pakistan. Therefore, completing an in-depth study by taking into consideration all these driving forces is essential for comprehending the dynamics and developing

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14 World Bank and Asian Development Bank, *Climate Risk Country Profile: Pakistan* (World Bank, 2021), accessed 22 June 2023, http://elibrary.worldbank.org/doi/book/10.1596/36372.

15 United Nations Development Programme, 'Scaling Up of Glacial Lake Outburst Flood Risk Reduction in Northern Pakistan | UNDP Climate Change Adaptation,' last modified 2022, accessed 27 June 2023, https://www.adaptation-undp.org/projects/scaling-glacial-lake-outburst-flood-risk-reduction-northern-pakistan.

16 Rishikesh Ram Bhandary and Kelly Sims Gallagher, 'What Drives Pakistan's Coal-Fired Power Plant Construction Boom? Understanding the China-Pakistan Economic Corridor's Energy Portfolio', *World Development Perspectives* 25 (1 March 2022): 100396.

17 Murad Ali, 'Pakistan's Quest for Coal-Based Energy under the China-Pakistan Economic Corridor (CPEC): Implications for the Environment', Environmental Science and Pollution Research, 25:32 (1 November 2018): 31935-31937.

suitable strategies to improve Pakistan's food export performance. To address this research gap, this study examines how urbanization, carbon emissions, precipitation, and coal rent affect food exports in Pakistan.

Research Objectives

1. To estimate the short-run and long-run impact of energy production and consumption features like coal rents on food exports in Pakistan from 1990 to 2020.
2. To analyze the short-run and long-run effects of precipitation, carbon emissions, and urbanization on Pakistan's food exports from 1990 to 2020.

Significance of the Study

Analyzing the impacts of coal rent, urbanization, carbon emissions, and precipitation on Pakistan's food export performance is crucial because it may provide useful information and lead policy decisions to boost the country's agricultural industry and economic growth. Pakistan's agrarian sector employs a large number of people and contributes significantly to the country's GDP. Policymakers can gain a better understanding of how factors like coal rent, urbanization, carbon emissions, and precipitation affect food production and exports. This information may be utilized to develop targeted activities and legislation to enhance agricultural processes, reduce negative environmental consequences, and improve the country's food export capability.

Literature Review

Pakistan's economy is based on agriculture. Over 80% of the water used in production is provided by an irrigated system, which consumes 90% of the river water that is available for output from agriculture. The base of food production is land and water, both of which are limited, if not diminishing productive resources. Climate change is one such factor that is directly and indirectly (through enhanced soil processes like denitrification leading to greenhouse gas emissions, unavailability of plant nutrients, increased crop water needs, etc.) placing pressure on these resources. In addition, extreme climate events such as floods, droughts, cyclones, etc., are occurring more frequently and with greater intensity, which has serious effects on the standing crops. The country's food security in the context of two main food crops, wheat and rice, is anticipated to be significantly impacted by these changes. Analysis of the effects of climate predicts changes in agriculture in the form of decreasing agricultural yields, shorter growing seasons, higher crop water needs, and lower irrigation water supplies.[18]

Another study discusses how climate change could impact the food supply in Pakistan. Based on secondary data sources, the study found evidence of climate change and its catastrophic effects on the country's already limited and destroyed natural resources.[19] The primary impacts of climate change include temperature increase, changes in precipitation patterns, an increase in glacier melt, an increase in evaporation, and a rise in irrigation water needs. The research also focused on the structure and capability of Pakistan's irrigation system, the issue of irrigation water availability, disputes over internal and external transboundary water resources, food shortages, and a high rate of inflation in the price of food components. According to the study, the fundamental cause of the current food deficit is the low crop production brought on by the irrigation water shortage. Despite having the greatest integrated irrigation system in the world, the country's water shortage has caused people to think differently. Although Pakistan provides the largest irrigation system in the world, farmers are now planting various crops instead of water-intensive ones like rice, cotton, wheat, and sugarcane, which is adding pressure to the food market. It is because of a lack of water.

Moreover, poor agricultural communities are expected to experience additional disruptions due to climate change. With the help of detailed information from 950 farmers across Pakistan's major provinces, the study examined the variables impacting farmers' decisions about adaptation to climate change strategies and the effects on household food security and poverty. The use of climate change adaptation strategies was studied using a probit model. The number of strategies used was examined using the Censored Least Absolute Deviation (CLAD), and the effects of strategies on food security and poverty levels were assessed using the Propensity Score Matching (PSM) method. The three main responses were changing the sowing date (22% of families), using drought-tolerant cultivars (15%), and switching to new crops (25%) were reported.[20]

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[18] Muhammad Iqbal, M. Goheer, and A.M. Khan, 'Climate-Change Aspersion on Food Security of Pakistan', *Science Vision*, 15 (1 January 2009), 15-23.

[19] Muhammad Asif, '*Climatic Change, Irrigation Water Crisis and Food Security in Pakistan*', 2013, accessed 20 June 2023, https://urn.kb.se/resolve?urn=urn:nbn:se:uu:diva-211663.

[20] Akhter Ali and Olaf Erenstein, 'Assessing Farmer Use of Climate Change Adaptation Practices and Impacts on Food Security and Poverty in Pakistan', *Climate Risk Management*, 16 (1 January 2017), 183-194.

Extreme weather has placed Pakistan's food security in danger due to climate change.[21] Sajjad Ali et al. analyzed the effects of climatic change, including maximum and minimum temperature, rainfall, relative humidity, and sunshine, on the major crops of Pakistan, including wheat, rice, maize, and sugarcane. The approaches of Feasible General Least Squares (FGLS) were used to time series data from 1989 to 2015. The results of the study demonstrate that while the effect of minimum temperature is advantageous and significant for all crops, the effect of maximum temperature has a detrimental effect on wheat output. Except for wheat, rainfall reduces the yield of a crop.

Similarly, Pakistan is a country where animal production plays an important role in meeting the country's demand for protein.[22] Livestock accounts for over 60% of agricultural inputs and 11.22% of the country's GDP. According to estimates, over 35 million individuals participate in activities related to cattle. Over the past few decades, meat production has increased, particularly that of chicken. In countries with limited resources, such as Pakistan, climate change has a significant impact on animal productivity, both directly through heat stress and indirectly through changes to ecosystems. Global warming, unpredictable weather patterns, melting glaciers, droughts, and other effects of climate change pose a severe threat to life on Earth. Examples include shortage of food and safe drinking water.[23] The WHO and other international organizations have been very active in holding international conferences, seminars, and workshops to encourage member nations to take decisive action to slow down environmental degradation and protect future generations from the catastrophic effects of climate change. This issue has been in the forefront for more than 40 years.

A Significant study for Pakistan used the ARDL cointegration approach to investigate the asymmetrical impact of agriculture, energy

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[21] Sajjad Ali et al., ‘Climate Change and Its Impact on the Yield of Major Food Crops: Evidence from Pakistan', *Foods*, 6:6 (24 May 2017), 39.

[22] Hammad Ahmed Hashmi et al., ‘Impacts of Climate Change on Livestock and Related Food Security Implications—Overview of the Situation in Pakistan and Policy Recommendations', in *Emerging Challenges to Food Production and Security in Asia Middle East, and Africa: Climate Risks and Resource Scarcity*, ed. Mohamed Behnassi et al. (Cham: Springer International Publishing, 2021), 197-239, accessed 18 October 2023, https://doi.org/10.1007/978-3-030-72987-5_8.

[23] Mohammad Perwaiz Iqbal, ‘Effect of Climate Change on Health in Pakistan: Climate Change and Health in Pakistan’, *Proceedings of the Pakistan Academy of Sciences: B. Life and Environmental Sciences*, 57:3 (5 September 2020), 1-12.

use, and food security on Pakistan's carbon emissions from 1970 to 2019.[24] According to the study, environmental degradation is accelerated by rapid population growth and energy consumption. Along with this, the findings also support the presence of an unequal short-term and long-term impact of agriculture on CO_2. Similarly, Pakistan's metropolitan areas' microclimate has changed as a result of its growing urbanization.[25] The study highlights the different factors through which urbanization influences the microclimate, i.e., precipitation and wind patterns, temperature, and humidity. The research has identified land use change and growing urban heat islands as potential drivers of climate change. Parallel to this, population growth, economic growth, growth rate of energy consumption, and energy mix give rise to the country's CO_2 emissions.[26] The study unveils the role of these factors in determining the carbon emissions trajectories as well as the need for effective policies to reduce carbon emissions to ensure sustainable economic development.

The issues of climatic variability and their effects on the rural sector of Pakistan are also investigated.[27] The authors analyzed that the rural inhabitants are more vulnerable to climate change. Climate change can reduce their livelihoods, agriculture output, and groundwater. Likewise, addressing the relationship between population growth, climate variability, forestry, livestock production, and crop production is crucial for creating effective strategies for environmental sustainability.[28] The findings revealed that the rapidly increasing population put pressure on resources and raised emissions. The study also discussed that forestry

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24 Snovia Naseem, Tong Guang Ji, and Umair Kashif, ‘Exploring the Impact of Energy Consumption, Food Security on CO2 Emissions: A Piece of New Evidence from Pakistan', *International Energy Journal*, 20:2 (25 May 2020), accessed 20 June 2023, http://www.rericjournal.ait.ac.th/index.php/reric/article/view/2224.

25 Adnan Ahmad Tahir et al., ‘Impact of Rapid Urbanization on Microclimate of Urban Areas of Pakistan’, *Air Quality, Atmosphere & Health*, 8:3 (1 June 2015), 299-306.

26 Boqiang Lin and Muhammad Yousaf Raza, ‘Analysis of Energy Related CO2 Emissions in Pakistan’, *Journal of Cleaner Production*, 219 (10 May 2019), 981-993.

27 Shah Fahad and Jianling Wang, ‘Climate Change, Vulnerability, and Its Impacts in Rural Pakistan: A Review', *Environmental Science and Pollution Research International*, 27:2 (January 2020), 1334-1338.

28 Abdul Rehman et al., ‘Towards Environmental Sustainability: Devolving the Influence of Carbon Dioxide Emission to Population Growth, Climate Change, Forestry, Livestock and Crops Production in Pakistan’, *Ecological Indicators* 125 (1 June 2021), 107460.

contributes to carbon sequestration and highlights the significance of measures for afforestation and reforestation. The results explored that methane emissions, in particular, are significantly influenced by the production of animals, and methods for lowering these emissions through better livestock management techniques are required.

Pakistan has a population of 220 million, making it the sixth most populous country in the world.[29] By 2050, it is expected that Pakistan's urban regions and the entire subcontinent will face a danger of socioeconomic losses as a result of climate change. The capacity for human endurance and survival will likely be pushed to its maximum by long and extremely hot waves. Climatologists believe that human activities are the main cause of climate variation, and unfortunately, these changes are largely irreversible. They have put a lot of effort into determining what factors led to climate change and how it would impact people's lives today and in the future. This knowledge is crucial for those in positions of authority to act timely and wisely to reduce the effects of climate change and prevent irreversible adverse effects. As the problem is complicated, thus, there are still certain issues that need to be resolved. Decision-makers must be on guard because climate change is increasingly being accepted as a fact, and Pakistan is no different.[30]

Worldwide, climate change is a major factor in food insecurity, particularly in terms of food production.[31] The findings of the study reveal that the main climatic factors, affecting Pakistan's food security by lowering wheat production, are the rising minimum and maximum temperatures and unpredictable rainfall patterns brought on by global warming. However, this study's findings also indicated that increasing the land area used for wheat farming might help Pakistan achieve greater food security by boosting the country's regional production.

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29 Syed Ghazanfar Abbas, Mirza Barjees Baig, and Gary S. Straquadine, 'Impacts of Climate Change on Agricultural Labour Force and Food Security in Pakistan: The Importance of Climate-Smart Agriculture', in *Food Security and Climate-Smart Food Systems: Building Resilience for the Global South*, ed. Mohamed Behnassi et al. (Cham: Springer International Publishing, 2022), 51–66, accessed 19 January 2024, https://doi.org/10.1007/978-3-030-92738-7_4.

30 Naeem Shahzad and Muhammad Amjad, *Climate Change and Food Security in Pakistan* (Springer International Publishing, 2022), 579-94.

31 Tehmina Batool, '*Impact of Climate Change on Food Security in Pakistan'*, 2022, accessed 20 June 2023, https://urn.kb.se/resolve?urn=urn:nbn:se:umu:diva-196398.

A consistent weather pattern is necessary for rain-fed agriculture, which supports 60% of Pakistan's population.[32] Climate change influences agriculture, and those consequences seem to be becoming worse every day. Wheat, rice, cotton, sugarcane, and maize are among the crops that are impacted by climate change in Pakistan. The timing of the monsoon season in Pakistan is changing as a result of ongoing global warming, which is changing precipitation patterns. This leads to malnutrition and a shortage of food in farming communities by influencing farm livelihoods, agricultural production, and agribusiness infrastructure.

Climate change, which has an impact on all parts of the globe and causes significant agitation to the natural ecosystem, is now the most complicated issue.[33] It has an impact on a variety of aspects of life, including social, political, economic, and scientific. Natural ecosystem disruptions ultimately block economic development by posing serious hazards to agricultural output and food security. The study examined how Pakistan's agricultural productivity and food security is impacted by climate change. By 2050, nine billion people are expected to experience food insecurity worldwide, primarily due to declining agricultural output.

Data and Variables

The description of the variables used in the study is given below.

1. Precipitation (mm/day)

Precipitation refers to the amount of water that falls on the surface of the earth as rain, snow, sleet, or hail. It is usually measured in millimeters per day (mm/day) and is an essential component of the water cycle. Precipitation is vital to crops' growth and overall agricultural productivity. Data on precipitation is collected from World Development Indicators.

2. Food Export (% of Merchandise Exports)

Food export refers to the trade of food items, including agricultural commodities and processed food products. It represents the country's comparative advantage in agricultural production and its ability to generate earnings from the sale of food products. Data on food export is collected from World Development Indicators.

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32 Areeja Syed et al., ‘Climate Impacts on the Agricultural Sector of Pakistan: Risks and Solutions', *Environmental Challenges*, 6 (1 January 2022), 100433.

33 Dr Nazia Tabasam, Shagufta Rasheed, and Dr Almazea Fatima, ‘Food Security in Context of Climate Change in Pakistan: A Review’, *Research Journal of Social Sciences and Economics Review*, 3:4 (2022), 141-148.

3. Coal Rents (% of GDP)

Coal rents represent the revenue generated from extracting and selling coal resources. The variable 'Coal Rents (%age of GDP)' means a country's GDP percentage comes from coal-related activities. A higher value suggests that coal substantially generates economic output and income for the country. It also represents that the country depends upon coal extraction, highlighting the need for economic diversification and environmental conservation. Data on Coal rents is collected from World Development Indicators.

4. Carbon Emissions (kg per 2015 US$ of GDP)

Carbon emissions are the total quantity of CO_2 emitted due to human activities. The indicator 'Carbon Emissions (kg per 2015 US$ of GDP)' measures the kg of carbon emissions for every $ of GDP in a country. It indicates the country's carbon intensity, which reflects the effect of economic activity on the environment. A higher number represents greater carbon emissions with economic output. It draws attention to the carbon-efficient economic activities of the country and provides insights into its environmental performance. Data for carbon emissions (kg per 2015US$ of GDP) is collected from World Development Indicators.

5. Urban Population Growth (Annual Percentage)

Urban population growth refers to the annual percentage change in the population residing in urban regions within a country. It gauges the rate at which the urban population is growing over time. Urbanization is the process of population moving from rural to urban regions. Urban population growth is influenced by factors such as rural-urban migration and natural population increase. A higher percentage depicts a rapid rise in the urban population, which can have significant implications for urban infrastructure development, resource management, social services provision, and environmental sustainability. Data on urban population growth is collected from World Development Indicators.

Methodology

A statistical technique that allows for multiple combinations of cointegrated variables is the Johansen cointegration test, which is used to determine whether there is cointegration between variables. The equation for the Johansen cointegration test can be expressed as follows:

$$Y_t = \sigma_1 Y_{t-1} + \cdots + \sigma_k \Delta K_{t-k+1} + U_t \quad (1)$$

Where t represents time (t = 1, 2, 3, ..., T), Y_t is a vector of integrated variables of order 1, Δk_{t-k+1} means the differenced variable, and U_t is the residual white noise vector.

When Eq. (1) is rewritten, it takes the following form:

$$Y_t = \sigma_1 \Delta Y_{t-1} + \sigma_2 \Delta Y_{t-2} + \cdots + \sigma_k \Delta K_{t-k+1} + U_t \quad (2)$$

The coefficients in Eq. (2) can be represented by the matrix Θ, defined as:

$$\Theta = [-1, \Theta_1, \Theta_2, \Theta_3 \ldots\ldots \Theta_k] \quad (3)$$

Here $\sigma_1 = -1 + \sum \Theta_{ik} \sigma_i \sigma_j$, where i and j range from 1 to k.

The primary goal of the Johansen cointegration test is to find a long-term link between the variables. The matrix's rank (r) contains the essential details about cointegration. There are no cointegration correlations between the I(1) variables if the rank of the matrix σ_1 is zero. There may be cointegrating vectors linking non-stationary variables according to a reduced rank matrix σ_1 (r < n). All variables are considered stationary when the rank of the matrix σ_1 equals the number of variables (r = n). When a single cointegrating vector is found in this situation, the estimated vector should satisfy the requirement [1, -1].

Two widely used likelihood ratio tests are employed to estimate the crucial values for the rank of the matrix σ_1. The trace test statistic (βtrace) is defined as:

$$\beta\text{trace} = -T * \sum \log(1 - \beta_i) \quad (4)$$

where i ranges from r+1 to k, and T represents the sample size.

The maximum eigenvalue test statistic (βmax) is given by:

$$\beta\max = -T * \log(1 - \beta_{r+1}) \quad (5)$$

where r represents the rank of the matrix σ_1.

Furthermore, short-run dynamics can be examined through the Error Correction Model (ECM). Cointegration implies a long-term equilibrium relationship between two variables, Y_t and X_t. However, in the short run, these variables may deviate from equilibrium due to the presence of the error term. The ECM connects the long-term and short-term behaviour of variables and can be represented as follows:

$$\Delta Y_t = \sigma_0 + \sum \beta_t \Delta Y_{t-i} \ldots\ldots + \sum y_t \Delta X_{t-i} + \delta u_{t-1} + \epsilon_t \quad (6)$$

Where i varies from 1 to k for $\sum \beta_t \Delta Y_{t-i}$ and from 1 to p for $\sum y_t \Delta X_{t-i}$, in Eq. (6), ΔY_t and ΔX_t represent the differenced variables, σ_0 represents the intercept, β_t, and y_t denote the coefficient matrices for the lagged differenced variables, δ is the adjustment coefficient, u_{t-1} defines the error term, and ϵ_t is white noise. The value of δ represents how quickly the equilibrium value of Y_t is restored after an external shock, whereas the term δu_{t-1} is known as the error correction term. The number of changes, which ranges from 0 to 1, shows that only a portion of the Y_t behaviour imbalance error will be stationary in the following period.

Findings

The study has employed time series regression to examine the inter-relationship between precipitation (mm/day), food export (% of merchandise exports), coal rents (percentage of GDP), carbon emissions (kg per 2015 US$ of GDP), and urban population growth (annual percentage). The period of the data ranges from 1990 to 2020. Precp represents precipitation (mm/day), Fexp represents food export (% of merchandise exports), Clr represents coal rents (percentage of GDP), Crbem represents carbon emissions (kg per 2015 US$ of GDP), and Urpg represents urban population growth (annual percentage).

Unit Root Test

To avoid the risk of erroneous conclusions, a stationarity test is performed on the data set.

H_0: Time series contains a unit root and is non-stationary.

H_1: Time series contains no unit root and is stationary.

The results of the Augmented Dickey-Fuller (ADF) unit root test have been presented in Table 1.

Table 1: Results of the ADF Test

Variables	Level	1st Difference	Stationarity
Clr	-0.422649	-6.649272*	I(I)
Crbem	-0.144212	-6.282042*	I(I)
Urpg	-1.123273	-3.617699*	I(I)
Fexp	0.583680	-7.313101*	I(I)
Perc	-1.309561	-11.73268*	I(I)

*Note: * represents significance at a 10% level.*

According to Table 1, we could not reject the null hypothesis, which shows the existence of non-stationarity in the variables at the level. The results show that the variables possess unit root at levels. However, the null hypothesis is disproved when the variables are first differenced. As a result, it is concluded that all of the variables are integrated of order one, or I (1). As a result, cointegration tests can be performed to assess whether there is a long-run equilibrium relationship between the variables.

Lag Order Selection Criteria

The results of the lag length criteria are presented in Table 2.

Table 2: Lag Order Selection Criteria

Lag	LogL	LR	FPE	AIC	SC	HQ
0	-14.3369	NA	2.61e-06	1.333581	1.56932	1.40741
1	61.8179	120.7974*	7.90e-08*	-2.194342	-0.77989*	-1.75135*
2	88.3382	32.92168	8.43e-08	-2.29918*	0.29396	-1.48704

*Note: * indicates lag order selected by the LR, FPE, SC, and HQ information criterion at 5% level.*

Table 2 shows the results of lag order selection criteria based on the given endogenous variables Precp, Fexp, Clr, Crbem, and Urpg and exogenous variable (C) for the specified date and sample range. The lag order selection criteria are commonly used to determine the appropriate number of lagged terms to include in the model. Different criteria are employed to assess the goodness of fit and avoid overfitting. Here's how to interpret the values:

Lag: The number of lagged terms included in the model.

LR: The likelihood ratio statistic, which compares the fit of the current model with the fit of a model with one fewer lag term. In this case, the asterisk (*) next to the value 120.7974 indicates that the model with one lag term (lag 1) is significantly better than the model without any lag terms (lag 0).

FPE: The Final Prediction Error, which measures the mean squared forecast error of the model. A smaller value of 7.90e-08 indicates better predictive performance.

SC: The Schwarz Criterion is another measure that penalizes model complexity. Lower SC values indicate better models. As shown in Table 2, the value of SC is -0.7798.

HQ: The Hannan-Quinn Criterion, which is a modification of the Schwarz Criterion. Lower HQ values indicate better models. The value HQ obtained is -1.7513.

Based on the criteria, the asterisk (*) indicates the selected lag order. In this case, the lag 1 model is favored as it provides a significantly better fit compared to the lag 0 model. Therefore, based on these criteria, the lag 1 VAR model appears to be the most appropriate for the given data. One lag is selected using the lag order selection criteria. The structural lags are chosen based on LR, FPE, SC, and HQ criteria.

Johansen Cointegration Test Results

The results of Johnson's cointegration test provide information about the presence of cointegration relationships among the variables. Based on the unrestricted cointegration rank test (Trace) and the unrestricted cointegration rank test (Maximum eigenvalue) results, the conclusion is as follows:

Trace test results:

- The null hypothesis of ‘None’ (no cointegrating equations) is rejected at 5% significance level.
- The null hypothesis of ‘At most 1, ‘At most 2, ‘At most 3’, and ‘At most 4’ cointegrating equations is not rejected at 5% significance level, as p-value > 0.05.

The trace test indicates that there is at least one cointegrating equation among the variables Precp, Fexp, Clr, Crbem, and Urpg. This suggests the presence of a long-term relationship among these variables.

Max-eigenvalue test results:

- The null hypothesis of ‘None’ (no cointegrating equations) is not accepted at the 0.05 significance level.
- The null hypothesis of ‘At most 1, ‘At most 2, ‘At most 3’, and ‘At most 4’ cointegrating equations is accepted at the 0.05 significance level.

The max-eigenvalue test also indicates the presence of at least one cointegrating equation among the variables Precp, Fexp, Clr, Crbem, and Urpg at the 0.05 significance level. This implies that these variables move together in the long run and are not independent of each other.

Table 3: Johansen Cointegration Test Results

Unrestricted Cointegration Rank Test (Trace)				
Hypothesizes No. of CE(s)	**Eigenvalue**	**Trace Statistics**	**0.05 Critical Value**	**Prob.****
None*	0.765422	82.60975	69.81889	0.0034
At most 1	0.441572	40.56074	47.85613	0.2031
At most 2	0.413409	23.66449	29.79707	0.2150
At most 3	0.208069	8.195074	15.49471	0.4448
At most 4	0.048112	1.429926	3.841465	0.2318

Table 3A: Johansen Cointegration Test Results

Unrestricted Cointegration Rank Test (Maximum Eigenvalue)				
Hypothesizes No. of CE(s)	**Eigenvalue**	**Max-Eigen Statistics**	**0.05 Critical Value**	**Prob.****
None*	0.765422	42.04901	33.87687	0.0043
At most 1	0.441572	16.89625	27.58434	0.5889
At most 2	0.413409	15.46941	21.13162	0.2574
At most 3	0.208069	6.765148	14.26460	0.5173
At most 4	0.048112	1.429926	3.841465	0.2318

Vector Error Correction Model (VECM)

Vector Error Correction Model short-run and long-run results are presented in Tables 4 and 5 respectively. The estimates for the coefficients of lagged variables in the VECM are provided. The standard errors and t-statistics are also presented in Tables. The variables included in the model are Precp, Fexp, Clr, Crbem, and Urpg.

The value of the error correction term is –0.26912. The negative and statistically significant value of (ECT) confirms the adjustment mechanism in the short run when the variables deviate from their long-term equilibrium.

Table 4: Vector Error Correction Model Short Run Results

Regressions	Coefficients	Standard Errors	t-statistics
CointEq1	-0.26912	0.08609	-3.1259
Crbem(-1)	-19.2171	10.5787	-1.8165
Precp(-1)	-0.768891	0.40984	-1.8760
Clr(-1)	27.59411	13.1659	2.09587
Urpg(-1)	0.03845	1.61679	0.02379

The variables Crbem(-1), Urpg (-1), and Precp(-1) are statistically insignificant because the t-statistic is less than the critical value, indicating no short-run impact of Crbem(-1), Urpg (-1), and Precp(-1) on Fexp(-1). The variable Clr(-1) is statistically significant. The t-statistic of 2.095 is higher than the critical value, suggesting a significant relationship with Fexp(-1). The results of VECM reveal that Clr(-1) improves the food export in the short run with coefficient values of 27.594. The values of efficiency reveal that a 1% increase in coal rent increases food export by 27.59 % in the short run. The ECT term is statistically significant and negative. This means that the variables may have a substantial impact on carbon emissions in the long run. Therefore, it is of great importance to analyze their long-term relationships.

Table 5: Vector Error Correction Model Long Run Results

Regressions	Coefficients	Standard Errors	t-statistics
Fexp(-1)	1.000000		
Crbem(-1)	42.35939	9.95943	4.25320
Precp(-1)	-6.888772	0.98367	-7.00312
Clr(-1)	114.4104	22.5023	5.08439
Urpg(-1)	5.464382	0.68032	8.03209

The variable Precp(-1) is statistically significant because the t-statistic of -7.003 is higher than the critical value, indicating a strong relationship between Fexp(-1) and Precp(-1). The variable Crbem(-1) is statistically significant for the same reasons as mentioned above. The t-statistic of 4.253 exceeds the critical value, indicating a significant relationship with Fexp(-1). The variable Clr(-1) is also statistically significant. The t-statistic of 5.084 is higher than the critical value, suggesting a significant relationship with Fexp(-1). The variable Urpg(-1) represents the lagged value of the variable 'Urpg.' The t-statistic of 8.032 indicates that the coefficient is statistically significant.

The values of normalized coefficients for the model taking Fexp(-1) as a dependent variable are as follows:

$$Fexp = -42.35939Crbem + 6.88772Precp - 114.4104Clr - 5.464382Urpg$$

The long-run dynamics results revealed that Precp(-1) has a positive impact on food exports. At the same time, Crbem(-1), Clr(-1), and Urpg(-1) have a negative impact on food exports in the long run. The variable Precp(-1) is positively related to food export. With a 1% in precipitation, food exports increased by 6.88%. The variable Crbem(-1) is statistically significant and has a negative impact on food exports in the long run. The value of the coefficient reveals that 1% in carbon emissions decreases food exports by 42.35% in the long run. The variable Clr(-1) is also statistically significant and has a negative relationship with food exports in the long run. As reported by the normalized coefficient, if coal rent increased by 1% in the long run, then food exports decreased by 114.4%. Similarly, the variable Urpg(-1) is statistically significant and has a negative impact on food exports in the long run. The value of the coefficient indicates that a 1% increase in urban population growth causes food exports to decline by 5.46% in the long run. In conclusion, the results of the long-run dynamic revealed that Precp(-1) has a positive impact on food exports. At the same time, Crbem(-1), Clr(-1), and Urpg(-1) have a negative impact on food exports in the long run.

Diagnostic Tests

Diagnostic tests have been performed to find out normality, serial correlation autocorrelation, and heteroscedasticity. Table 6 presents the results of the LM test to check out consecutive relationships. The result of the LM test reveals that the p-value > 0.05 up to lag three. This shows that the null hypothesis could not be rejected. Thus, there is no serial correlation between variables.

H_0: There is no serial correlation of orders up to 3

H_A: There is a serial correlation of orders up to 3

Table 6: Residual Serial Correlation LM Test

Lag	LM Stat	df	Prob.
1	44.10703	36	0.1929
2	25.76746	36	0.9082
3	44.41054	36	0.1846

Table 7 represents the results of the normality test. The normality examination indicates that the value of the Jarque–Bera test is 7.4989, which is nonnegative and much greater than zero, which indicates that the dataset is not normally distributed. Even in cases when data is not normally distributed, the Johansen approach can be used as it is not sensitive to non-normal residuals.

H_0: The sample data is normally distributed.

H_A: The sample data is not normally distributed.

Table 7: Residuals Normality Test

Statistics	Chi-square	df	Prob.
Skewness	2.5661	6	0.4885
Kurtosis	2.057382	6	0.9143
Jarque- Bera	7.498967	12	0.8230

Similarly, Table 8 provides the results of the heteroscedasticity test.

H_0: Homoscedasticity is present (the residuals are distributed with equal variance)

H_A: Heteroscedasticity is present (the residuals are not distributed with equal variance)

Table 8: Residuals Heteroscedasticity Test

White Heteroscedasticity	Chi-square	d.f	Prob
Statistics	261.3096	252	0.3302

Based on the White Heteroscedasticity test, the findings suggest that there is no significant evidence of heteroscedasticity in the residuals. The p-value is 0.3302 that is greater than 0.05 level of significance, indicating that the assumption of constant variance is reasonable for the model.

Discussion

This study aims to fill the research gap in the existing literature by exploring the causal relationship between food exports, precipitation, coal rent, urban population, and carbon emissions in Pakistan. The study considered urban population, precipitation, coal rent, and carbon emission independent variables, while food export was the dependent variable. All the data for interpreted variables was taken from 1990 to 2020. The Augmented Dicky Fuller (ADF) unit root test had been applied to check the stationarity of the variables. By analyzing the results of the ADF test at the first difference, the null hypothesis cannot be accepted and the results indicate that all variables are stationary at the first difference. Cointegration analysis was conducted by using the Johansen cointegration approach. The finding reveals that precipitation positively affects food export in the long run, while the other variables display a negative relationship. This suggests that as climate change intensifies, food insecurity in Pakistan may be exacerbated due to decreased precipitation. The erratic and insufficient rains harm crop growth and agricultural productivity.

Furthermore, an increase in urban population growth, coal rent, and carbon emissions increase food insecurity. The study investigated the effect of rents on food exports. The coal rent has been highlighted as a key factor influencing food insecurity. Coal rents, a measure of the economic benefits of coal mining and use, can harm food exports, as further coal production could halt the environment and affect agriculture that can meet export demand. The results suggest the existence of a long-run cointegration relationship between urbanization and food exports. Urbanization is associated with the increasing non-food producers and growing demand for agricultural products. Rapid urbanization increases the pressure on arable land for non-agricultural uses, reducing the amount of land available for agriculture and thus reducing the capacity of food producers. The already overburdened food systems of the country come under more strain due to the expansion of urban areas. Urban population growth increases per capita food consumption, which puts more pressure on the exports of food items. With regard to climate change, the study also highlighted the vital contribution of carbon emissions to declining food exports.

Conclusion

The primary goal of this study was to expand knowledge by bringing together and analyzing the impact of urban population, precipitation, coal rent, and carbon emission on food exports in Pakistan from 1990 to 2020. The results show that coal rent has a positive effect on food exports in the short run. Similarly, the outcomes of the long run reveal that low precipitation, high rate of urbanization growth, increase in coal rent, and carbon emissions all have an adversative impact on food exports during the period of analysis. According to the results observed through the Johansen cointegration analysis, the above-mentioned variables affect the country's ability to export food items.

It is evident that coal rent deteriorates Pakistan's performance in terms of food exports in the long run. Coal rents from the production of coal incentivize the business to extract and consume coal as an energy source, which results in soil pollution and environmental degradation. Consequently, the country's capacity to produce a sufficient quantity of food for export is harmed. Secondly, the findings of the study have shown that growing urbanization results in land demand for non-agricultural activities and hence loss of agrarian land, consequently leading to the possibility of a decrease in export food.

Moreover, the results support a negative relationship between carbon emissions and food export. The carbon emissions increase pollution, destroy the yielding, and thus worsen food export results. Finally, precipitation plays a positive role in determining food production. Higher rainfalls are beneficial for the country and cause increased harvests. Pakistan's reliance on rain-fed agriculture makes it particularly vulnerable to climate change-related challenges. The study's results suggest some important policy implications.

Policy Recommendation

1. Excessive coal extraction and consumption have the potential to exacerbate environmental concerns such as soil deterioration and consequently make the previously cultivable land unusable for food production to reduce this, the economy should invest in innovative and environmentally friendly businesses in order to secure sustainable agricultural production.

2. The use of land for urban development instead of productive land usage increases food insecurity. Therefore the government should avoid horizontal urban development and instead may promote vertical construction.
3. Planning and designing home gardening and urban rooftop farming could be initiated to increase food production in cities and towns, thus relieving pressure on rural areas.
4. The carbon emissions can be reduced by imposing more stringent environmental policies and regulations that limit industrial emissions and promote renewable energy and hence boost agricultural productivity.