https://doi.org/10.52131/joe.2022.0402.0081

*i*RASD Journal of Economics

Volume 4, Number 2, 2022, Pages 310 – 328

Journal Home Page:
https://journals.internationalrasd.org/index.php/joe

Climate Change and Food Security: Steps towards Sustainable Development Goals

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ARTICLE INFO

Article History:
Received: June 03, 2022
Revised: June 11, 2022
Accepted: June 27, 2022
Available Online: June 29, 2022

Keywords:
Agriculture
Agricultural Policy
Asia
Global warming
Panel data models

JEL Classification Codes:
C33, O13, O53, Q18, Q54

Funding:
This research received no specific grant from any funding agency in the public, commercial, or not-for-profit sectors.

ABSTRACT

With the commendation of Sustainable Development Goals (SDGs) by the United Nations in 2015, the whole world is trying to accomplish these goals. All countries of the world are making efforts to achieve these goals. As compared to developed countries, developing countries are still far behind on the track of the sustainable development agenda. Realizing the goal of Zero Hunger (SDG 2) under climate change proves to be "challenging". Climate change can potentially be associated with eradicating hunger (SDG 2) worldwide, specifically in South Asia. Food security is considered a prerequisite to eradicating hunger and remains a challenge for developing countries. The study reconnoiters the potential footprints of climate change along with socio-economic variables on food security in climate-vulnerable food-insecure economies of Asia from 1980 to 2020. This study examines the impacts of variations in temperature on the supply of cereals for human consumption. The method of ARDL/PMG has been employed. There are two widely used techniques, i.e. FMOLS and DOLS, have also been employed to check the strength of the results. Outcomes of panel ARDL/PMG show that average yearly change in temperature has substantial and positive impacts on food security in the long run, but the square of the annual average change in temperature adversely and significantly impacts food security. Climate change has substantial and adverse effects on the food security of Bangladesh, Myanmar and Nepal but positive effects on Pakistan in the short run. From empirical outcomes, generalized and widespread policy guidelines have been endorsed to achieve food security (SDG 2) in the climate-vulnerable food-insecure economies of Asia. The study recommends evidence-based policy implications for the stakeholders of Asian economies.

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Citation: Fahmida, Chaudhary, A. R., & Hanif, U. (2022). Climate Change and Food Security: Steps towards Sustainable Development Goals. IRASD Journal of Economics, 4(2), 310–328. https://doi.org/10.52131/joe.2022.0402.0081

1. Introduction

Tackling "zero hunger" is a challenging goal in the Sustainable Development Goal agenda. In 2020, about 720 million people faced hunger, which affected 21 per cent of Africans, 9 per cent of Asians, and 9.1 per cent of Latin Americans. It is projected that about 60 million individuals will face hunger by 2025. While the prevalence of undernourished people has increased by 1.5 per cent during 2020, more than half of the world's malnourished individuals live in Asia, while more than one-third are in Africa. Moreover, it is projected that the number of undernourished people may rise in upcoming decades due to the internal (disorganized chains of food supply and low productivity) and external (climate variability, extreme weather events, and conflicts) drivers by raising the cost of healthy food production and availability.

In 2015, the United Nations Organization (UNO) set Zero Hunger, attaining food security, escalating nutritious food, and viable agricultural production as a second goal among seventeen (17) Sustainable Development Goals. Food insecurity is spreading due to the rise in undernourished people, and it seems perplexing to achieve the Zero Hunger (SDG) goal by 2030. Food insecurity is a multifaceted issue which has roots in socio-economic, global warming and climate change issues (Affoh, Zheng, Dangui, & Dissani, 2022).

The impacts of temperature rise are already noticeable in various parts of the globe, and now it has become a global issue. Considering these changes in the overall climate with its related latent impacts on agricultural production has become a dynamic field of research. Since the agriculture sector is immensely vulnerable to vagaries of nature and climate change (Hanif, Syed, Ahmad, Malik, & Nasir, 2010), it is considered a vital input in the agricultural sector. There are numerous primary and secondary impacts of climate change on food security globally. Various studies (von Braun, 1995) reported direct adverse effects of climate change on crop yield through different stages of crop growth (Z. Liu et al., 2015) and indirect impacts on pests, diseases and the nutritional value of food (Gitz, Meybeck, Lipper, Young, & Braatz, 2016). However, accumulative carbon dioxide and temperature rise benefit temperate crops like rice, wheat, and potatoes. Hence, climate hazards and climate change damage crops in the short run and, consequently, food security in the long run.

Climate change is a worldwide phenomenon, but its impacts are prominent in underdeveloped countries (UDCs) as developing countries have a low capacity for climate change resilience (Rauf, Zhang, Li, & Amin, 2018) and become climate vulnerable. Climate change is unevenly affecting the world and will become a significant threat to food security in climate-vulnerable developing countries in the upcoming decades. Therefore, in the face of climate change, the goal of zero hunger (SDG 2) and food security becomes difficult in underdeveloping and low-income countries. Since food security is a prerequisite for achieving SDG two (zero hunger), globally, 2.37 billion people faced food insecurity in 2020. Of which 267 million people live in Latin America and the Caribbean, 1.2 billion are from Asia, while there in Africa, there are 799 million. However, 928 million masses have faced severe food insecurity globally.

Asia is one of the utmost climate-sensitive continents around the globe, and the global mean temperature of South Asia is higher than in other parts of Asia, and by the end of the 21st century, it will rise by 3-4^{o}C (Spijkers, 2010). Consequently, arid areas of western China, Pakistan, and India are expected to be more scorching. Many research studies have measured latent and possible impacts of climate change on different sectors, specifically agriculture. These studies documented that climate change is distressing food security with the help of agriculture production in Asian countries. A study (Z. Liu et al., 2015) reported an upsurge in rice cultivation areas from 1980 to 2000 (Wang et al., 2014). Gupta, Somanathan, and Dey (2017) estimated that wheat production has declined by 5.2% from 1981to 2009 in India due to climate change. Daytime and night-time temperatures have risen (Jha & Tripathi, 2017). Similar research studies have also been conducted in Pakistan that climate change is dominantly distressing agriculture production and food in Pakistan.

Regions related to the Hindu-Kush Himalayan (China, India. Nepal and Pakistan) are experiencing frequent climate change events. Many studies have been directed in these regions to find mountainous people's food security status. It was found that hazard exposure, frequent floods, prolonged droughts, low productivity, poor infrastructure, physical isolation, and limited access to international markets contribute to food insecurity (Din, Tariq, Mahmood, & Rasul, 2014; Hussain, Rasul, Mahapatra, & Tuladhar, 2016; Rasul et al., 2019). It is also projected that the possible impacts of climate change on Asia will have less freshwater availability by the year 2050. While in coastal areas of East Asia, South-East Asia, and South Asia number of floods from sea and river will increase. However, it is also projected that diarrhoeal disease will increase due to the rapid changes in the hydrological cycle in various parts of Asia. Hence, climate change is a deliberate menace to the food security status of 4.7 billion people in Asia.

With high economic growth and reduction in global temperature in Asian countries to attain the goal of zero hunger, there is a dire need to take the right climate actions to intensify agriculture productivity (Di Falco & Chavas, 2009). The contribution of this study is twofold since various studies investigated the impacts of temperature and precipitation on food security (Praveen Kumar, Tokas, Kumar, Lal, & Singal, 2018), but it is hard to find such type of study which considers the significance of the annual average change in temperature on food security across in Asian countries of Myanmar, Pakistan, Bangladesh, and Nepal. Climate change and food security are complex and have various uncertainties and risks associated with them. It is also a challenge for ecologists, sociologists and economists alike; these uncertainties and risks can fluctuate in magnitude and significance across space and time. Therefore, to achieve SDG two, natural scientists and economic policymakers must consider the food supply and demand in the context of SDG 12 (Production and Consumption) and SDG 13 (Climate Change). There is a dire need for SDG-oriented and food security-focused climate action policy in selected countries. Four Asian countries, i.e., Myanmar, Pakistan, Bangladesh, and Nepal, have been chosen to accomplish this aim and the study period from 1980 to 2020. The choice of countries is twofold, firstly, these countries are at high risk of climate change, and secondly, these are food insecure at the same time. The selection of these Asian countries will help to draw an evidence-based policy framework to set a benchmark for other food-insecure climate-vulnerable countries. Whereas the previous research works have been dedicated to the association concerning climate change and food security, there is a necessity for the convergence of policy frameworks to realize the targets of SDG 2 and SDG 13. Therefore, the present study proposes the SDG-oriented agricultural policy framework. Extreme weather events and long-run climate change have caused economic losses, fatalities, and damage to agricultural and industrial infrastructure in selected countries. In the following table 1, climate-induced losses can be seen. Myanmar ranked among the four most climate-vulnerable Asian countries, followed by Pakistan, Bangladesh, and Nepal, from 1999 to 2018 (Eckstein, Künzel, Schäfer, & Winges, 2019). Myanmar has been experiencing overwhelming floods, droughts, deforestation, and land sliding in the last twenty years. Myanmar faced Cyclone Nargis hit Myanmar badly in 2008. More than 95 % of deaths and damages accounted for, and it lost 20% of GDP from 1999 to 2018.

Table 1
Climate-related Losses

Country	Fatalities per 100000 inhabitants 1999-2018	Fatalities 1999-2018	Losses per unit GDP in % 1999-2018	Losses in million US$ (PPP) 1999-2018 (Rank)	Climate Risk Index
Myanmar	1	1	20	19	10.33
Pakistan	46	11	31	8	28.83
Bangladesh	37	9	40	17	30.00
Nepal	17	17	41	56	31.50

Source: Eckstein et al. (2019)

Pakistan is an agricultural climate change-sensitive country due to its unique geographical, demographic and socio-economic factors. A rise in temperature and change in precipitation patterns will directly impact water-dependent sectors like energy and agriculture. Pakistan has confronted economic losses of 31% of GDP; mortalities per 100000 are 46 residents due to extreme weather and climate change during this period. Bangladesh has a warm and humid climate, and tropical Cyclones and heavy rainfall have damaged its infrastructure and economic resources. Bangladesh's historical temperature has been observed at 26°C, and the annual average precipitation was almost 2200 mm from 1901 to 2020. According to Eckstein et al. (2019) estimates, Bangladesh has lost 40% of its GDP, and mortalities per 100000 are 37 residents due to climate change and climate hazards. It is also expected that tropical cyclones will increase Bangladesh's storm surges, high-speed winds, and heavy rainfalls.

Nepal is Asia's fourth climate-vulnerable landlocked country (Eckstein et al., 2019). About 80% population of Nepal lives in rural areas, and 69% of people are indirectly and directly related to the agriculture sector. However, the agriculture sector contributed to Nepal's GDP by 23.12% in 2020. Nepal lost 41% of its GDP due to climate-related hazards from 1999 to 2018. Nepal's forestry, agriculture, water resources, health, sector and biodiversity are at risk because of climate change. Climatic exposure impacts reduced the purchasing power of people through economic losses and deteriorated food security status (M. M. Islam & Al Mamun, 2020).

Asian developing economies are highly susceptible to the challenge of food security in the face of climate change; at the same time, food security is imperative for achieving zero hunger (SDG 2) by 2030 under the emergence of climate change (SDG 13). This understanding is crucial for local, national, and international policymakers to implement an SDG agriculture-oriented climate policy to tackle zero hunger. The study investigates long- and short-run climate change's latent influences on food security in selected Asian countries.

The rest of this study is structured as follows: section 2 highlights existing literature to reinforce the significance of the related issues and pinpoint the research gap. Section 3 is associated with the empirical framework, theoretical framework, and suitable econometrics techniques. Section 4 covers the estimated quantitative results and discussion. Lastly, section 5 is based on conclusions and policy recommendations from the perspective of SDGs.

2. Literature Review

2.1 Climate Change and Food Security

Ample literature concerns climate change's impacts on agricultural production and food security. Various studies from the natural sciences, environmental sciences, and economics identified the adverse effects of climate change on agriculture productivity, crop production, food security, and hunger in various countries, specifically UDCs.

Ahmad, Iqbal, and Farooq (2016) cited that food security is a condition "when all people, at all times, have physical and economic access to sufficient safe and nutritious food to meet their dietary needs and food preferences for a healthy and active life". Food security has four dimensions: availability, accessibility, utilization, and stability. The first pillar of food security is called the availability of food, and this dimension encompasses the aggregate of domestic food production, food exports, food imports, and domestic stock variations. Climate change is appearing as a difficult task for worldwide agricultural production.

Daily and Ehrlich (1990)investigated the simulated negative and positive impacts of changing climate on global food security. They applied Stochastic Perturbations (computer model). The main parameters used in the study are population size, no. of deaths related to hunger, consumption, production and grain storage under different climatic scenarios. The number of deaths from hunger is expected to increase due to climatic changes and unfavourable trends. Absolute global shortages of grains, serious social breakdown and widespread epidemics could also outpace the casualty toll. Moreover, the upshots of the model indicate that a slight increase in population growth rate (0.3%) and a decrease in agriculture production will considerably impact hunger and global food security.

Downing (1993) explained that the increasing amount of carbon dioxide in the atmosphere would likely threaten agricultural production. The study predicts that a rise in mean annual average temperature by 1^0C will increase the thermal limits by 150-200 km in mid-latitude countries and increase altitudinal limits by 150-200m, subsequently a falloff in winter seasons and speeding up the grain filling process of crops. However, high carbon dioxide is found to be beneficial for rice growth but harmful to wheat productivity.

Ayoub (1999) argued that rainfall variability (climate change) affects the food security status in the world's rainfed areas. This study has important implications related to agricultural productivity and land resources, and land and rainfall variability are significant determinants of crop yields. The low crop yield (sorghum, millet, groundnuts and sesame), land degradation due to climate change and ethnic conflicts in different areas of Sudan are responsible for chronic food insecurity.

Nguyen (2002) explained that global food security is highly dependent on the production of rice and its supply. Because of the high demand and consumption of rice. However, climate change affects land and water supply and leads to low rice yields in various parts of the world. It is imperative to ensure food security to increase rice production by adapting climate change strategies. In addition, Droogers (2004) explored the linkages between environmental quality and food security in the context of climate change. The study was conducted in the Walawe-Basin of Sri Lanka and carried out by the successful and widely used Hadley Climate Center (HadCM 3) coupled global circulation model (GCM). One reference period (1961-1990) and two (2010-2039 and 2070-2090) future periods have been used in the SWAP (Soil–Water–Atmosphere–Plant) model and WSBM (Water and Salinity Basin Model). The prompted results of the Walawe Basin study suggested that the overall production of rice is expected to expand with the increase in rainfall and higher levels of carbon dioxide. However, in the long run, these climatic changes will be more profound, and food security will decrease with the irrigation depth and higher temperature.

The Risk of Hunger (ROH) is probable to upsurge in African and South Asian countries as an outcome of climate change, as pointed out by Parry, Rosenzweig, Iglesias, Livermore, and Fischer (2004). Therefore, low income and high food prices are responsible for increasing the vulnerability of poor people in climate-vulnerable countries. Combined results of crop yield models with different climate change scenarios exhibited beneficial impacts for developed countries; however, declining trends were projected for developing countries. Results of the study also illustrate that significant polarization and risk of hunger are expected to rise based on crop production patterns amongst developed and undeveloped countries.

Kar and Kar (2008) examined the relationship between the negative sway of climate variability on food security for Orissa, India. They applied Cobb-Douglas Production Function to empirically explore the affiliation between climate variability and food security. Farm-level households' food security was found to be more affected by low productivity, marketing and distribution limitations and low income. The model results revealed that agricultural production is contingent on input expenses and the use of chemical manures. A significant interconnection has been observed between rainfall and the income of farmers.

Ramasamy (2010) claimed that food security and climate change are becoming the world's biggest challenges. Floods, droughts, extreme temperatures and climate hazards damage crops, agricultural production, woodland fires, livestock mortality and sea life. Consequently, the food security of most of the world's population is highly vulnerable due to these economic losses. Hence, climate change is responsible for regional and global food insecurity. Moreover, climate variability and climate change are immense perils to food security, and per person availability of wheat will be declined from 198 kilograms per year to 84 kilograms per year with the rise in temperature 3°C by 2050 in Pakistan (Tariq, Tabasam, Bakhsh, Ashfaq, & Hassan, 2014).

Ozcan and Strauss (2016) discussed that land positively affects cereal yields in the short run, but climate change will badly affect land and food production in the long run. They estimated that 10% of the cultivated land has decreased since 2010 due to climate change in Turkey. Therefore, a temperature rise is also expected to increase the demand for irrigation water to grow crops.

While food security in Central Asia is at high risk due to climate change, heavy and erratic rainfall, pests and crop diseases, water scarcity and population growth (Reyer et al., 2017). It has been found that the urban population is more food insecure compared to rural areas. The people of Central Asia are highly dependent on food imports; consequently, disruptions in food imports will exacerbate the food security in this region. Chandio, Ozturk, Akram, Ahmad, and Mirani (2020) studied several climatic factors on cereal yield in Turkey. They applied the Auto Regressive Distributive Lag model to analyze the dynamic association among the variables for the period 1968 to 2014. The study results revealed that rainfall positively impacts cereal yields. Moreover, land for cereal production has adverse effects on cereal yields. Another study (Pushp Kumar, Sahu, Kumar, & Ansari, 2021) explored the relationship between cereal production and climate change in middle-income economies. The study found a two-way relationship between carbon dioxide emissions, temperature and cereal production; in contrast, a one-way relationship exists between cereal production, rainfall and population.

Abbas, Kousar, and Khan (2022) argued that climate change is influencing the food security of Punjab, Pakistan. They employed the ARDL technique to find long-run and short-run effects of wheat cultivated area, total irrigated area, total unirrigated area, total sown area, rainfall, wind speed, the average, minimum, maximum temperature on total wheat production of Punjab, Pakistan. The study found negative and significant impacts of average, minimum and maximum temperature on food production of the central, southern and western regions of Punjab; at the same time, maximum temperature positively affects wheat production in south Punjab. Food production is negatively associated with wind speed in all areas of Punjab, and rainfall adversely affects food production in southern and central Punjab.

However, food supply at the global and local levels is affected by extreme weather events. At the same time, climate hazards such as cyclones, floods, and riverbank destruction are responsible for the vulnerability of the status of food security in delta regions of Bangladesh (M. M. Islam & Al Mamun, 2020) and deteriorate the livelihoods of the masses, damage critical infrastructure and increase the poverty trap (Praveen Kumar et al., 2018). Moreover, Mohammad Saiful Islam, Okubo, Islam, and Sato (2022) examined the effects of extreme climate events alongwith average climate change on Bangladesh's loss of food grains and food security from 1984 to 2017. They employed the vector-autoregressive technique to find the relationship between food availability, food imports, food loss, inflation, and economic growth. The study found a negative association between the loss of food grain and food security, the subsequent rise in inflation and food imports. In addition, climate hazards and climate change create hurdles in Bangladesh's food security.

2.2 Population and Food Security

Food availability is mainly overwhelmed by the population. Malthusian theory of high population growth and scarcity of food availability is in the same line. The population is a significant driver of food security, and the rapid growth is closely linked with the prevalence of poverty, environmental degradation, demographic deferral shifts and increased food insecurity (Tyczewska, Woźniak, Gracz, Kuczyński, & Twardowski, 2018). In literature, mixed results of the population on food security are found. A study by Gebre (2012) reported significant and positive effects of the population on food security. However, the status of food security at the household level is adversely affected by the size of the households (McCordic & Frayne, 2017) at the local level. However, the population has an adverse impact on food security and per capita food availability (Ehrlich, Ehrlich, & Daily, 1993) at the country level. Lobell, Schlenker, and Costa-Roberts (2011) pointed out that due to global warming, per hector yield is increasing but at a slower rate while the population is increasing at a faster rate which can cause low per capita food availability in most of the world, specifically in under developing. The high growth of the population clues to an upsurge in food insecurity and raises undernourishment by 11.95% in sub-Saharan Africa (Asogwa & Onyegbulam, 2020). However, advanced technologies and land intensification would be adopted as necessary to reduce the number of undernourished people and raise food security status.

3. Empirical Model

3.1 Theoretical Framework

Food is the basic want for any living thing. Food concerns for a human being are acknowledged as a human right. The concept of food security is diverse, and various social, political, economic, and climatic drivers play their roles in determining food security. Food security is primarily linked to agricultural production, accessibility, stability, and food utilization. However, food security, population, economic growth patterns, and climate change are interlinked. In underdeveloped countries, supply decreases and demand for food increase with an increase in population. As a result, per capita, food availability falls. Agricultural productivity depends upon various inputs, and climate is one of them (Hanif et al., 2010). Climate is considered an essential input in agriculture production. Climate change is due to natural and anthropological deeds (Zhang et al., 2012). These climate changes have been observed prominently since 1800 because of the anti-climate activities of humans, such as burning coal, gas, and oil (fossil fuels). Burning gas, coal, and oil increase greenhouse gas emissions (GHGs) such as methane and carbon dioxide and raise the earth's ’s temperature. Many drivers of climate change affect food production, such as atmospheric conditions, climate changes, seasonal changes, and climate hazards.

However, the escalation in global mean temperature has multi-dimensional impacts, as shown in the following figure 1; firstly, it is the source of an increase in sea level and a vital clue for more floods and saltwater intrusion (Habibullah, Ahmed, & Karim, 1999; Kibria, 2014). Then this saltwater intrusion can cause land degradation by water-logging and salinization. Secondly, climate change mainly instigated droughts, leading to crop failure due to less water availability (Kibria, 2014) for water-intensive crops such as maize

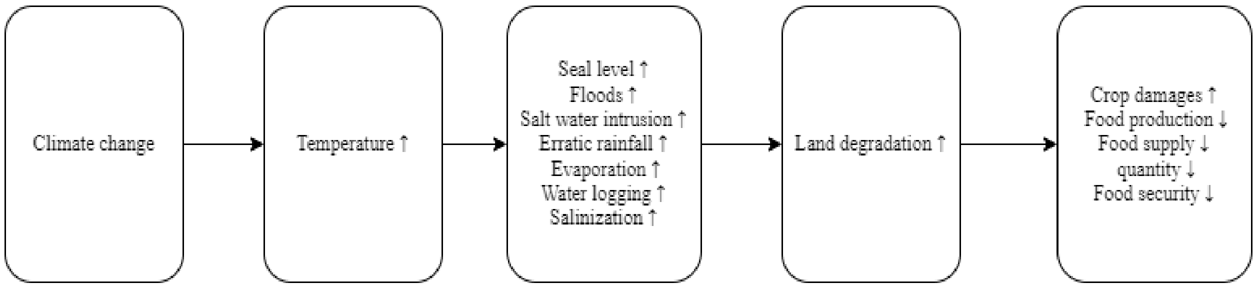

Figure 1: Theoretical Model

Thirdly, quantity and quality are also affected by crops' biological disordered and heat damage (DaMatta, Grandis, Arenque, & Buckeridge, 2010). Therefore, changing rainfall patterns, evaporation rate, groundwater availability, and other water resources available for grain production will be damaged through fluctuating rainfall patterns, rate of evaporation, and dissolved oxygen contents (Md Saidul Islam & Wong, 2017). Contrarily, the square of the temperature change (high temperature), heatwaves and subsequent droughts will severely damage the quantity and quality of food production and become the cause of a decline in food security (Fanzo, Davis, McLaren, & Choufani, 2018). These effects will be more prominent in already food insecure climate-vulnerable countries.

3.2 Model Specification and Data Sources

Considering this discussion, the hypothesis that food security is mainly determined by climate is tested. In continuation of this argument, functional forms are as follows;

(i) Food Security in the Absence of Climate Change**:**

$$FS = f\,(CP, POP, GDPPC) \qquad (1)$$

(ii) With Climate Change Scenario:

$$FS = f\,(CP, POP, GDPPC, TEMPCH,\ TEMPCH^2) \qquad (2)$$

Functional forms of the proposed models from equations 1 to 2 explain the factors affecting food security with and without climate scenarios. Here, Food Supply Quantity is used as the proxy of food security for this study. Food Supply Quantity is the number of cereals available to a person in kilograms per year. Since cereals include rice, coarse grains, and wheat, coarse grains include barley, maize, millet, sorghum, and rye. CP is the land under cereal production (hectares). POP is the total population (millions). Economic growth is measured in gross domestic product per capita (constant at 2015 US$). TEMPCH is the annual average change in temperature (Celsius degree). $TEMPCH^2$ is the square of the yearly average change in temperature (Celsius degree). Before statistical analysis, the natural logarithm has been taken of all the variables except the climate variable to linearize the proposed model. The food supply quantity and temperature change data are taken from FAO (Food and Agriculture Organization) website. The data on land under cereal production, population, and gross domestic production per capita, are taken from WDI (World Development Indicators). The study is based on four food insecure climate-vulnerable Asian countries, i.e., Pakistan, Myanmar, Bangladesh, and Nepal, from 1999 to 2018. Countries were selected based on two indices, i.e., the Global Climate Risk Index (2020) and the Global Hunger Index (2018), to investigate the relationship between food security and climate change.

The German watch developed the Global Climate Risk Index (GCRI) in 2006. The GCRI pays attention to climate hazards (extreme weather events) and related vulnerabilities by quantifying economic losses and fatalities due to climate variability. GCRI (2020) captures data from 181 countries around the globe. In contrast, IFPRI (International Food Policy Research Institute) developed the Global Hunger Index in 2006 to measure food insecurity in countries. The Global Hunger Index (2018) score is based on 100 points; a 0 score indicates an ideal condition means zero hunger; on the contrary, 100 shows the worst state of a country means a fully food insecure country. A less than ten score means low hunger, 10 to 20 indicates moderate hunger, 20 to 35 shows a severe condition of hunger, 35 to 50 is alarming, and equal to or greater than 50 shows extremely hunger. The GHI appears to be the most acceptable indicator to quantify food security, but the GHI is not obtainable for an extended period.

Table 2
Variable Description and Data Sources

Symbol	Definition	Source
ł FS	Natural log of food supply quantity (kg/per capita/ year)	FAO
ł CP	Natural log of land used for cereal production (hectares)	WDI
ł POP	Natural log of total population (millions)	WDI
ł GDPPC	Natural log gross domestic product per capita (constant US$)	WDI
TEMPCH	Annual change in temperature (celsius degree)	FAO
$TEMPCH^2$	Square of Annual change in temperature (celsius degree)	FAO

Note: ł indicates variables in the natural logarithm.

Now the functional forms are transformed into the following regression equations,

$$FS_{it} = \beta_o + \beta_1 CP_{it} + \beta_2 POP_{it} + \beta_3 GDPPC_{it} + \varepsilon_{it} \quad (3)$$

$$FS_{it} = \beta_o + \beta_1 CP_{it} + \beta_2 POP_{it} + \beta_3 GDPPC_{it} + \beta_4 TEMPCH_{it} + \beta_5 TEMPCH^2{}_{it} + \varepsilon_{it} \quad (4)$$

Above mentioned regression lines will be estimated in this study. Here, β_o represents the intercept of the regression line, β_1 to β_5 stands for regression coefficients and are treated as the elasticities of associated variables, the error term is denoted by ε, i represent cross-sections used in this study, and t shows the observed time.

4. Procedural Outline

The ARDL/PMG (Pooled Mean Group /Autoregressive Distributed Lag Model) is applied to achieve study’s objective. It is a prerequisite to use diagnostic tests such as panel unit root and panel cointegration.

4.1 Unit Root Test

Econometric literature reveals that longitudinal panel data sets tend to depict any trend or series that follows any particular pattern, known as non-stationarity or unit root. Therefore, Levin, Lin, and James Chu (2002) and Pesaran and Smith (1995) unit root tests have been applied to check the trend.
LLC unit root test:

$$\Delta Y_{it} = \theta Y_{i,t-1} + \grave{Z}_{it} \gamma_i + \sum_{j=1}^{p} \emptyset_{ij} \Delta Y_{i,t-1} + \mu_{it} \quad (5)$$

Im-Pesaran-Shin unit root test:

$$Y_{it} = (1 - \varphi_i)\epsilon_i + \varphi_i Y_{i,t-1} + \mu_{it} \quad (6)$$

Where, i = 1, 2…., N ; t = 1, 2,…, T

4.2 Panel Cointegration Test

The Pedroni (2001) and Kao (1999) panel cointegration tests have been employed to explore long-run connotations among selected variables. Both approaches focus on null hypothesis (Ho) that explains absence of cointegration between cross-sections. Further Pedroni cointegration test is based on panel (V, Rho, PP, ADF) statistics and Group (Rho, PP) statistics.

4.3 Panel Autoregressive Distributed Lag Model (Panel ARDL) or Pooled Mean Group (PMG)

After confirming the long-run relationship through the cointegration test, the analysis will move towards estimating consistent parameters. Literature provides various econometric techniques like the method of Ordinary Least Square, Fully Modified Ordinary Least Square (FMOLS), Dynamic Ordinary Least Square (DOLS), and means group family-like Pooled Mean Group (PMG), Augmented Mean Group (AMG) and Common Correlated Effects Mean Group (CCEMG). However, applying OLS on non-stationary panel data will provide misleading and inconsistent estimates of explanatory variables. Therefore, estimators of Fully Modified Ordinary Least Square (FMOLS) attributed by Pedroni (2001), estimators of Dynamic Ordinary Least Square (DOLS) attributed by Stock and Watson (1989) and the estimators of Pooled Mean Group Autoregressive Distributed Lag model (PMG/ARDL) proposed by Pesaran, Shin, and Smith (1999). FMOLS can deal with the issues of serially correlated residuals and the existence of possible endogeneity in the predictors. Moreover, DOLS not only deals with the problems of serially correlated residuals and possible endogeneity in the predictors but also limits multicollinearity by using lags and leads (J. Liu et al., 2021).

In this study pooled mean group (PMG) approach has been used. Pesaran et al. (1999) introduced the technique of PMG. The PMG approach assumes that coefficients are homogenous in the long run, while these coefficients can differ among the individual cross-sections in the short run. The panel ARDL/PMG models deal with cross-sectional data sets' problems, such as cross-sectional dependency, serial autocorrelation, and cross-sectional heteroscedasticity (Arshed & Zahid, 2016). Pooled mean group (PMG) method provides estimates of Error Correction term or speed of adjustment-an important feature of PMG. However, many lags can be used to calculate PMG/ARDL and Akaike Information Criteria (minimum value) is best for lag order selection and a limited range of data and simplification; following the PMG/ARDL model has only one lag of all the variables.

$$\Delta Z_{it} = \alpha_{0i} + \alpha_{1i}\,\Delta x_{it} + \theta_i\left(\varphi x_{i,t-1} - Z_{i,t-1}\right) + \varepsilon_{it} \qquad \varepsilon_{it} \sim iidn(0, \sigma^2) \quad (7)$$

Where,

α_{1i} symbolizes short-run coefficients and would be heterogeneous for all cross-sections
θ_i indicates speed of adjustment term or error correction term would be heterogeneous for all cross-sections
φ presents short-run coefficients and would be homogeneous or constant for all cross-sections

The panel autoregressive distributed lag model is widely used when the series are cointegrated with a mixed order of stationarity. In panel data analysis, if each cross-section consists of 20 or more than 20 observations, then the specified model’s behaviour is non-stationary, non-static, or dynamic.

Hence, following PMG/ARDL model can be developed, equation 8 represents food security in the absence of climate change contrarily, and equation 9 depicts that climate change, along with additional socio-economic elements, affects food security in climate-vulnerable food-insecure countries.

$$\Delta FS_{it} = \alpha_0 + \sum_{j=1}^{k} \alpha_{1jt}\, \Delta CP_{it-j} + \sum_{j=1}^{k} \alpha_{2jt}\, \Delta POP_{it-j} + \sum_{j=1}^{k} \alpha_{3jt}\, \Delta GDPPC_{it-j} + \beta_1 CP_{it-1} + \beta_2 POP_{it-1} + \beta_3 GDPPC_{it-1} + \varepsilon_{it} \quad (8)$$

$$\Delta FS_{it} = \alpha_0 + \sum_{j=1}^{k} \alpha_{1jt}\, \Delta CP_{it-j} + \sum_{j=1}^{k} \alpha_{2jt}\, \Delta POP_{it-j} + \sum_{j=1}^{k} \alpha_{3jt}\, \Delta GDPPC_{it-j} + \sum_{j=1}^{k} \alpha_{4jt}\, \Delta TEMPCH_{it-j} + \sum_{j=1}^{k} \alpha_{5jt}\, \Delta TEMPCH^2{}_{it-j} + \beta_1 CP_{it-1} + \beta_2 POP_{it-1} + \beta_3 GDPPC_{it-1} + \beta_4 TEMPCH_{it-1} + \beta_5 TEMPCH^2_{it-1} + \varepsilon_{it} \quad (9)$$

Above mentioned four equations of ARDL/PMG will be estimated in this study. In equations 8 to 9 α_{0i} represent intercept, α_{1ji} to α_{5ji} are short-run slope coefficients of ARDL, while β_1 to β_5 symbolize long-run regression slope coefficients and are treated as the elasticities of associated variables; the error term is denoted by ε. This error term is normally distributed with zero means with constant variance, i represents cross-sections used in this study, and t shows the time. The PMG/ARDL method provides the ECT (error correction term), while the negative sign of ECT depicts that the specified model tends to converge its equilibrium. The coefficients of ECT tell us about the convergence speed towards its long-run stability. Moreover, the techniques of PLS, FMOLS and DOLS will be applied to check the strength of the results.

5. Estimated Outcomes and Discussion

5.1 Descriptive Statistics

The discussion starts with Table 3 of descriptive statistics in estimated results. Descriptive statistics helps to understand the behaviour of selected variables in terms of the total no of observations, maximum values, minimum values, central tendency (mean), and dispersion (SD). By the rule of thumb, if the mean value of the series is greater than the series' standard deviation (SD), then the specified variable is under dispersed and close to scattered in a given sample. In the following table, all the means of selected variables are greater than standard deviations, and therefore, the selected series are dispersed and scattered.

Table 3
Descriptive Statistics

	ł FS	ł CP	ł GDPPC	ł POP	TEMPCH	TEMPCH²
Mean	5.136	15.814	6.463	17.980	0.495	0.471
Median	5.153	16.086	6.553	17.992	0.443	0.196
Maximum	5.664	16.460	7.393	19.213	1.879	3.530
Minimum	4.681	14.625	5.079	16.524	-0.425	4.00E-06
Standard Deviation	0.228	0.568	0.598	0.781	0.476992	0.630
Observations	164	164	164	164	164	164

Note: ł indicates variables in natural logarithm

5.2 Unit Root Test

Levin, Lin, and Chu (LLC) and the cross-section Pesaran and Shin test have been applied to test the presence of stationarity in selected variables for this purpose. These tests are built on the null hypothesis that there is no stationarity. Estimates of the tests are as follows (Table 4). There is a mixed order for unit roots. All the selected variables show a non-stationary trend at a level in the LLC test, while only one variable has the property of stationarity at a level in Pesaran and Shin test. In contrast, all the selected variables become stationary by taking their first difference in the LLC and Pesaran and Shin tests leading to a fit cointegration method among selected variables.

Table 4
Levin, Lin, and Chu (LLC) and Pesaran and Shin Tests for Unit Root

Variable	Levin Lin & Chu (LLC)		Pesaran and Shin	
	At Level	**At First Difference**	**At Level**	**At First Difference**
ł FSQ	-0.24380	-12.6294*	0.40961	-10.9603*
ł CP	-0.96789	-11.0315*	1.3559***	-11.6435*
ł GDPPC	5.71764	-2.86181*	6.25998	-4.88874*
ł POP	-0.08839	-2.69241*	1.24637	-1.55042***
TEMPCH	-1.04810	-12.7447*	-1.08451	-15.3014*
$TEMPCH^2$	0.85087	-10.2043*	0.96416	-11.8741*

*, **, *** symbolizes various significance levels such as 1%, 5%, and 10% respectively. ł indicates variables in natural logarithm

5.3 Cointegration Test

The following table depicts the estimates of cointegration of Pedroni Cointegration and Augmented Dickey-Fuller t-statistics.

Table 5
Pedroni Cointegration and Kao Residual Cointegration Tests

	Statistics	**Probability**
V – Statistic (Panel)	-0.933924	0.8248
Rho – Statistic (Panel)	0.091584	0.5365
PP- Statistic (Panel)	-1.468524***	0.0710
ADF – Statistic (Panel)	-1.582682**	0.0567
Rho – Statistic (Group)	0.510526	0.6952
PP-Statistic (Group)	-1.705309**	0.0441
ADF- statistic (Group)	-1.821261**	0.0343
Augmented Dickey-Fuller t- test	-2.792555*	0.0026

*, **, *** symbolizes various significance levels such as 1%, 5%, and 10% respectively.

A famous test named the Pedroni cointegration test (Pedroni, 2001) has been applied. The results are divided into panels (Rho, V, PP and ADF) and group (Rho, V, PP and ADF) statistics. These two tests (panel and group) are formulated as there is no cointegration among variables. Probability values show that cointegration exists at various significance levels such as 1%, 5%, and 10%. Out of 8 test statistics, four are significant and revealed that cointegration exists in both models. Additionally, the Kao test of residual cointegration (ADF t-stat) also provides evidence of cointegration in the model.

Various basic PMG/ARDL model specifications for food security have been developed and estimated. First, this study estimates PMG/ARDL without climate change. Then in the subsequent stage, the authors gauged the footprints of climate change on the quantity of food supply (food security) by applying the PMG/ARDL, FMOLS and DOLS models.

5.4 Without Climate Change

The long-run estimates of the PMG/ARDL in the absence of a climate change scenario are presented in Table 6, and for the robustness of the model, Panel Least Square (PLS), Fully Modified Ordinary Least Square (FMOLS), and Dynamic Ordinary Least Square (DOLS) also employed. Overall, key explanatory variables of each model (population, land for cereal production, economic growth) have a substantial relationship with food security. However, the nature of the association of these variables is different.

The PMG/ARDL model results explain that a 1 % increase in land used for cereal production surges the number of cereals by almost 99%, ceteris paribus in the long run, as compared to PLS, FMOLS and DOLS, the increase in food supply quantity is estimated as 69%, 62% and 86% respectively. Therefore, the supply of more suitable land for cereal production raises the status of food security in selected countries. The coefficient of the population parameter indicates a negative and significant association with food supply quantity except in the DOLS model. The estimates of PMG/ARDL reveal that a 1% increase in population decreases the quantity of food supply of cereals by 106%, ceteris paribus, in the long run. In addition, a 1% increase in population decreases the quantity of food supply of cereals by 43% and 22% in PLS and FMOLS, respectively. The result supports the hypothesis of the study, and it also provides strong evidence that the increase in population has a substantial impact on food security conditions in selected food insecure climate-vulnerable countries. Hence, regulating population growth in selected Asian countries is obligatory.

Estimates of economic growth have affirmative and significant effects on the food supply quantity of cereals in all four models. In addition, a 1% increase in gross domestic product per capita increases the quantity of food supply of cereals by 62%, ceteris paribus in the long run and 30%, 38% and 35% in PLS, FMOLS and DOLS, respectively. The agriculture sector plays a latent role in the gross domestic product and national income of these selected countries highly dependent on agricultural gross domestic product. It also suggests that any change in the agriculture sector will obligate blunt effects on national income and food security. The ECT is negative and significant, indicating that the specified model tends to converge towards its long-run equilibrium with a speed of 38 %.

5.5 With Climate Change

The overall climate change footprints in selected countries can be seen in Table 7. The coefficient of land under cereal production (CP) exhibits positive and significant associations with food security (FS) in all four models (PMG/ARDL, PLS, FMOLS and DOLS). A 1% increase in land under cereal production (CP) increases the quantity of food security (FS) by 88% in the long run. Contrarily, the role of CP in FS is 58%, 63% and 62% in PLS, FMOLS and DOLS, respectively. The land for cereal production has affirmative and significant effects on food security. It is evident that an increase in land for cereal production also increases cereal production. The results are similar to available literature (Abafita & Kim, 2014) but contradict Belloumi (2014), who found a negative impact of land under cereal production (CP) on food security (FS).

Table 6
Results of ARDL, PLS, FMOLS and DOLS

Variable	Dependent variable: ł FS PMG/ARDL (LR)	PLS	FMOLS	DOLS
	Coefficient	Coefficient	Coefficient	Coefficient
ł CP	0.989173*	0.691442*	0.623350*	0.864995*
ł POP	-1.056752*	-0. 432355*	-0.224069***	-0.359659
ł GDPPC	0.624455*	0.304693*	0.383736*	0.358074*
R-squared			-665.815054	-7385.367202
Adjusted R-squared			-691.964664	-10231.490344
ECT	-0.379795*			
D(ł CP)	-0.070680		0.989173*	
D(ł GDPPC)	-0.400420**		0.624455*	
D(ł POP)	-4.895167***		-1.056752	
C	1.817079*			
No. Of Observations	164	164	164	164

*, **, *** symbolizes various significance levels such as 1%, 5%, and 10% respectively. LR stands for long run.

According to the literature, as in our model, the population negatively and significantly impacts food security under climate change (Tariq et al., 2014). The availability of food supply quantity per capita will decrease with the population increase per Malthus theory, and it can be interpreted as a 1% increase in population, reducing the quantity of cereal's food supply by 86% in PMG/ARDL and 24% by considering PLS. The slope coefficient of GDP per capita has an affirmative and substantial relationship with food supply quantity; however, the magnitude varies from model to model. For example, its contribution is 58% in the long run while 13%, 37% and 60% in the rest of the other models.

To gauge the footprints of climate change, the variation in annual average temperature has been selected and is positively associated with food supply quantity, and this result supports carbon fertilization in the long run. The yearly average temperature changes by 1°C, and the cereal's food supply will increase by almost 11 kilograms per capita per year in the long run. The results are supported by Lobell et al. (2011).

Table 7
Results of ARDL, PLS, FMOLS and DOLS

	Dependent variable: ł FS			
	PMG/ARDL (LR)	**PLS**	**FMOLS**	**DOLS**
Variable	**Coefficient**	**Coefficient**	**Coefficient**	**Coefficient**
ł CP	0.885576*	0.581839*	0.634802*	0.619468**
ł POP	-0.860396*	-0.241000*	-0.191566	0.233609
ł GDPPC	0.538933*	0.135716*	0.379294*	0.603025*
TEMPCH	0.115687**	0.109729**	0.031523	-0.204891*
$TEMPCH^2$	-0.099250**	-0.032205*	-0.053056	0.217683*
R-squared		-0.125861	-728.202528	-5935.410303
Adjusted R-squared		-0.154185	-766.835775	-10798.975371
Observation	164	164	164	164

*, **, *** symbolizes various significance levels such as 1%, 5%, and 10% respectively. ł indicates variables in natural logarithm levels. LR stands for the long run.

They explored that pointed per hector yield is increasing due to global warming in underdeveloping countries. The DOLS model shows an adverse and significant connection with food supply quantity. In the same line, few research studies have reported the negative impacts of climate change on crop production or agricultural production (Peng et al., 2004; Qureshi, Hanjra, & Ward, 2013). Contrarily, the square of annual average temperature change has a negative and significant relationship with crop yields and food supply. If the temperature changes by 1°C, there will be a decrease in the cereal's food supply by almost 10 kilograms per capita per year in the long run. The impacts of climate change vary by crop varieties, farm management, use of fertilizers, technology, and prices on agriculture production (Downing, 1993).

Moreover, frequent climate hazards such as frost, drought, heat stress and storms constantly threaten crop production. Climate change increases soil erosion and desertification, and consequently, cropping systems deteriorate in developing countries. Climate change, along with limited varieties of crops, use of modern technology, and less concentration of reforestation, is the biggest reason for low agricultural output and food insecurity in these countries.

PMG/ARDL model also provides short-run estimates and error correction terms. Following table 8 shows the short-run coefficients and ECT terms. Error correction term or speed to convergence is significant, and a negative sign indicates that the model will be converged towards its long-run equilibrium. The adjustment coefficient is 0.40. On average, this model can converge towards its equilibrium within forty years. Moreover, economic growth has adverse and significant effects on food security in the short run. At the same time, land for cereal production (CP), population (POP), temperature change (TEMPCH) and square of temperature change ($TEMPCH^2$) do not play a significant role in influencing food security in these climate-vulnerable food-insecure countries.

Table 8
Short-run Dynamics

Short-run Estimates				
Variables	**Coefficient**	**Standard Errors**	**t-Statistics**	**Probability**
ECT	-0.402871*	0.143116	-2.814997	0.0056
D(ł CP)	-0.068809	0.051800	-1.328360	0.1864
D(ł POP)	-3.966873	2.316120	-1.712723	0.0891
D(ł GDPPC)	-0.377746**	0.189799	-1.990239	0.0486
D(TEMPCH)	-0.026250	0.018400	-1.426631	0.1561
D($TEMPCH^2$)	0.029670	0.022783	1.302271	0.1951

*, **, *** symbolizes various significance levels such as 1%, 5%, and 10% respectively. ł indicates variables in natural logarithm levels.

Impacts of climate change vary from country to country; therefore, it is well-intentioned to explain these changes in the context of selected countries. The PMG/ARDL model provides individual country-specific short-run estimates with error correction terms (ECT). These estimates explain the differential impacts of policy variables. According to Table 9, the values of ECT, Bangladesh, Myanmar, Nepal, and Pakistan can recover from any shock, and their speed of adjustment (ECT) is twenty-nine (29) years, seven years (07), seventy-four (74) years and forty-nine (49) years, respectively. Climate Change has an affirmative effect on the food security of Bangladesh, Nepal, and Pakistan.

In contrast, food security status is found vulnerable in Bangladesh, Myanmar and Nepal with the change in temperature; contrarily, the average annual change in temperature is positively and significantly associated with food supply quantity. Moreover, the double change in the temperature will have an adverse effect on the status of food security in Pakistan. In contrast, a double change in temperature will have an affirmative impact on the food security of Bangladesh, Myanmar and Nepal. Hence, it can be concluded that climate change's effect varies from region to region depending upon its severity and intensity.

Table 9
Country-Specific Short-run Dynamics

Variable	**Bangladesh**	**Myanmar**	**Nepal**	**Pakistan**
	Coefficient	**Coefficient**	**Coefficient**	**Coefficient**
ECT	-0.290199*	-0.077839*	-0.747528*	-0.495920*
D(ł CP)	0.021560	-0.006068	-0.210075*	-0.080655
D(ł POP)	-6.365087	2.192312	-3.238382**	-8.456335
D(ł GDPPC)	-0.640491	0.056734	-0.181009**	-0.746219*
D(TEMPCH)	-0.013427*	-0.041993*	-0.067487*	0.017908*
D($TEMPCH^2$)	0.000297	0.083012*	0.051101*	-0.015732*
C	1.852733***	0.394534**	3.364078	2.665772**

*, **, *** symbolizes various significance levels such as 1%, 5%, and 10% respectively. ł indicates variables in natural logarithm levels.

6. Conclusion and Policy Recommendations

Climate is adversely affecting all sectors of the economy, specifically the agriculture sector around the globe. The latent effects of climate change concerning food security have remained debated since the late 1980s. The study sheds light on food-insecure climate-vulnerable Asian countries. The study found a substantial impact of climate change and other socio-economic variables on food security. Overall, the effect of the population has an adverse and significant impact on food security. There is a dire need to regulate the population to achieve SDG 2 and SDG 13. Increased population has adverse effects on per capita food availability but also becomes the cause of lower per capita income (economic growth). In summary, the panel ARDL/PMG results are pretty interesting. For example, climate change has a remarkable and affirmative impact on food security in the long run, while adverse but insignificant effect has been found in the short run. Following the estimated results, this study recommends SDG-oriented policy frameworks for achieving zero hunger (SDG 2) in food-insecure climate-vulnerable countries. The agriculture sector in selected countries is reasonably traditional, irrigation systems are outdated, and rising temperatures threaten the agriculture sector and food supply. Therefore, as a first step, heat-resistant and high-yielding crop varieties are needed to ensure food security in these Asian economies as the rise in temperature is affecting adversely agricultural production in these countries. Secondly, agricultural lands are converted into housing societies to expand urban centres as the urbanization rate in these Asian countries is high. Therefore, governments should focus on optimal land-use policies to increase cereal production in the face of climate change. Cereal food supply is found to be supplemented with an increase in the availability of agricultural land. Thirdly, population policy intervention should be practised to regulate these countries' populations. The results show that an increase in population poses a peril to the food security of these countries' vast majority.

Authors Contribution
Fahmida: literature, methodology, data collection, interpretation
Amatul Razzaq Chaudhary: critical review
Uzma Hanif: concept, critical review, editing

Conflict of Interests/Disclosures
The authors declared no potential conflicts of interest w.r.t the research, authorship and/or publication of this article.

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