ANALYSIS OF CLIMATE CHANGES AND ITS IMPACT ON THE YIELD OF MAJOR FOOD CROPS AND FOOD SECURITY IN PAKISTAN

(2008-18)

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Abstract:

Pakistan's agricultural sector is highly vulnerable to the adverse effects of climate change, which pose a significant threat to the country's food security. This study focuses on assessing the impact of climate change variables, including maximum temperature, minimum temperature, rainfall, relative humidity, and sunshine, on the major crops of Pakistan, such as wheat, rice, and maize. The study employs feasible generalized least squares (FGLS) and heteroscedasticity and autocorrelation (HAC) consistent standard error techniques using time-series data covering the period 2009 to 2018.

The study findings reveal that the maximum temperature has a detrimental effect on wheat production, while the minimum temperature has a positive and significant impact on all crops. Furthermore, the impact of rainfall on crop yield is negative, except for wheat. To mitigate the adverse effects of climate change, there is a need to develop high-yielding varieties that are resistant to heat and drought. This study's findings suggest that policymakers in Pakistan should prioritize the development of such crops to ensure food security in the country.

Keywords: Pakistan; climate change; yield; major food crops; food security; agricultural development

Introduction

The Earth's climate is constantly changing, and the uninterrupted increase in greenhouse gases is believed to be the main cause of this change. Greenhouse gases such as fluorinated gases, carbon dioxide, methane and nitrous oxide trap heat in the atmosphere, leading to rising temperatures, changes in precipitation patterns and adverse effects on water and land resources. These changes have resulted in the frequent occurrence of natural disasters, such as floods and droughts, which cause significant impacts on human life and the environment. Therefore, it is very important to understand the causes and effects of climate change and take appropriate measures to reduce its adverse effects. Climate change is considered a global phenomenon. However, its effects are felt more in developing countries, due to their greater vulnerabilities and less capacity to mitigate the effects of climate change. As most developing countries – including Pakistan – are agro-based economies, their agricultural sector is most affected by direct contact with nature.

Therefore, the agricultural sector is one of the most vulnerable sectors to the impacts of climate change, as changes in rainfall patterns, temperature, floods, droughts, and negative effects on water and land resources can have significant impacts on crop yields, food security, and water availability. In developing countries such as Asia and Africa, where agriculture is a significant contributor to the economy, the impacts of climate change on agricultural production are increasingly being recognized,(Mendelson,2006). With the rapidly changing climate, food security and water availability are highly vulnerable, especially during the summer season, where most climate models predict an increase in rainfall (Mirza, 1997). These changes have the potential to disrupt the delicate balance of agricultural systems, affecting not only food production but also livelihoods and socio-economic development in affected regions. As such, understanding and mitigating the impacts of climate change on agriculture is crucial for ensuring sustainable food security and development in vulnerable areas.

The Himalayan glaciers, which are a major source of freshwater for several rivers in Asia, including the Indus, Ganges, and Brahmaputra, are rapidly melting. It is estimated that 75% of these glaciers will disappear by 2035, which will have significant consequences on water availability, especially during the dry season. The reduction or escalation in the intensity of rainfall due to climate change can result in droughts and floods, respectively, exacerbating the water crisis in the region (Misra, 2014). Furthermore, climate change can have a significant impact on crop productivity, which can lead to food security problems, particularly in developing countries. The changes in rainfall patterns, temperature, and extreme weather events can negatively affect crop yields, especially for small-scale farmers who rely on rain-fed agriculture. Although global warming is expected to increase yields due to the "fertilizer effect" (the stimulation of plant growth by increased atmospheric CO2 concentrations), the negative impacts of climate change on small-scale farmers and food security are likely to outweigh any potential benefits (Kirby, 2016). For example, countries which have more close to the equator will have reduced production due to global warming (Droogers, 2005). African countries will face severe droughts and further food shortages. If climate change affects the productivity of the agricultural sector in low-income countries in Asia or Africa, large numbers of people will be at risk and the problem of food insecurity will increase. Climate change is a driver of food security in the developing world, as it affects the productivity of the agricultural sector, its sustainability and other components of the food system, including storage, access and consumption (Von Braun, 2013). Overall, climate change has modest impacts on global food production, but these impacts are unevenly distributed geographically. Most losses occur in low-income countries such as arid and sub-humid South Asia and Africa. These regions practice subsistence agriculture and are not technically sound or financially sound enough to reduce the negative impacts of climate change. Furthermore, they have almost no adaptation potential (Kurukulasuriya, 2006). This adversely affects the people in these countries because of their dependence on agriculture for their livelihoods. According to estimates by the Food and Agriculture Organization of the United Nations (FAO), the global number of undernourished people is 795 million. This shows a decline of nearly 200 million over the last 20 years (FAO, 2017). South Asia and sub-Saharan Africa make up the majority of the world's hungry population (Ainslie, 2012); the region most vulnerable to climate change is South Asia (Bandara, 2014). In South Asia, more than 70% of the population (about 1.1 billion) lives in rural areas dominated by agriculture, and about 75% of these people are poor (World Bank,2018). Most importantly, agriculture accounts for about 18% of the region's GDP and industry employs more than 50% of the population (World Bank, 2017). Furthermore, climate change may pose threats to agriculture and food security by altering the spatial and temporal distribution of rainfall, the availability of water, land, capital, biodiversity and terrestrial resources. Due to changes in agricultural production, this could lead to food insecurity for 9 billion people by 2050. Research shows that climate change may alter regional and global water needs and lead to water shortages for agricultural purposes. Studies have shown that rising temperatures and changing rainfall patterns have a significant impact on food production (Kirby, 2016; Janjua, 2010; Mahmood, 2012). A recent study estimated that wheat production in South Asia will decline by 50% by 2050, which is equivalent to about 7% of global agricultural production (International Water Management Institute, 2017). The Peterson Institute claims that agricultural production in developing countries will decline by another 10% to 25% and if this continues, global warming will reduce India's agricultural potential by 40% [18]. Therefore, climate change poses serious threats to food security (Ali,*et al*, 2017), negative impacts on the productivity of various crops, food supply (Rosenzweig, 1994) and the cost of adapting to climate change is high (Kandlikar, 2000).

Therefore, food security is a prominent policy of the Government of Pakistan. Wheat, rice and maize are the main food crops of Pakistan. Therefore, food security policy mainly focuses on the production of these crops. In light of the above considerations, this study aims to investigate the relationship between climate change (maximum temperature, minimum temperature, rainfall, humidity and sunshine) and production of major crops including wheat, rice and maize. The joint is to be examined.

Review of Literature

The study of global climate models (GCMs) predicts significant changes in regional and global average precipitation and air temperature due to climate change. These changes are likely to have impacts related to groundwater recharge, which could have significant consequences for water availability in many regions. One researcher predicts that rainfall patterns, river flows and sea levels will be affected by climate change in the next century (IPCC, 2018).

Changes in the climate system could severely affect agricultural productivity over the next hundred years, which could lead to food security problems, especially in developing countries. Increased climate change is recognized as a global disturbance with potential long-term effects corresponding to more extreme weather events (Stern, 2006). Climate change is believed to affect people living in farming communities in developing countries (Maskrey, 2007). It is worth noting that only 10% of annual global CO2 emissions are from developing countries, yet they are the most susceptible to the impacts of climate change (Maskrey, 2007). Large populations of South Asian countries depend on agriculture-based rural economies. Therefore, these areas are particularly affected by climate change. This poses serious threats to their social, economic and ecological systems (Ahmad, 2011). The World Bank's South Asia Climate Change Strategy states that the poorest people in the region will be most affected by climate change due to limited resources, unfavorable geography and high dependence on climate-sensitive sources of income.

Extreme weather events (e.g. floods in Pakistan and India) with high frequency in the region in recent years are directly related to climate change and keep the poor in a perennial poverty trap (Mendelsohn, 1999). It is expected that most of the impact of climate change will affect the agricultural sector the most due to its vulnerability (Mendelsohn, 2011). The variability in climate change poses a major challenge to agricultural production and rural livelihoods, as it affects approximately 2.5 billion people who depend partly or wholly on agriculture. The agricultural sector is highly dependent on changes in climatic conditions, thus becoming a dangerous activity (Musser, 2002). Global agricultural production is challenged by climate change (Godfray, 2010). Climate change affects different crops and regions differently, but agricultural productivity is generally expected to decline (Lobell, 2007). Indeed, some decline can already be seen. According to one calculation, climate change resulted in the reduction of global maize production by 3.8% between 1980 and 2010 (Lobell, 2011).

Farmers were not equally vulnerable compared to crop, but they were the most vulnerable group to climate change (Conde, 1998). Economic losses from extreme weather conditions are increasing due to climate change (Warner, 2009). It is expected that average temperatures will rise and rainfall patterns will change. As a result, more extreme events and floods are likely to occur in the coming decades. This will greatly affect the community in terms of rescue operations, loss of human life, damage to assets and disruption of business (McDonald, 2010). It is difficult for the government to pay damages. Crop productivity is affected by climate change, which has serious implications for food security (Spash, 2007). Global warming is believed to increase yields as increased atmospheric carbon acts as a fertilizer effect, but the impacts are likely to be generally negative for poor countries. For example, there will be reduced food production in countries close to the equator due to global warming (Droogers, 2005). There will be prolonged droughts and food shortages in African countries. There will be more poverty and other social problems in the Pacific Islands and Indonesia, as these countries are more dependent on imports. A recent study by the International Water Management Institute (IWMI) predicts that wheat production in South Asia will decline by 50% by 2050. The agricultural sector is highly dependent on changes in climatic conditions, making it a dangerous activity. Climate variability is a major source of risk to agriculture and food systems.

The increasing intensity and frequency of extreme weather conditions has affected agriculture to a large extent (Ji-kun, 2014). Farmers regularly face natural calamities, erratic rainfall and pests. For example, farmers are exposed to heavy rains, floods, pests and diseases (Zulfiqar, 2016), drought and fluctuating market prices (Kazmi, 2016). According to a report on productivity, financial, marketing, legal, environmental and human resources are the main sources of risk factors in agriculture (Musser, 2000). Stocks from multiple sources (eg unpredictable weather conditions, disease and pest events). Secondly, there are financial risks, such as the farmer's ability to pay his bills to continue farming and avoid losses. Third, trading risks, which include changes in prices for agricultural products. Fourth, there are legal and environmental risks, and finally, there are human resource constraints (eg, lack of family members to perform labor and farm management functions). As a result, productivity suffers, leading to large production losses. Therefore, it is important that farmers understand and manage production risks properly (Drollette, 2009). The results of the study show that more than 50% of farmers were exposed to risks in nature and had a high perception of flooding. In terms of economic damage, floods are the greatest natural disaster.

The conclusion of all studies revealed that farmers were the most affected in terms of crop damage, water contamination, irrigation systems, livestock and other agricultural operations. In addition, losses in agricultural income and security have increased due to the negative impacts of flooding on agricultural systems. The same results were obtained by (Deen, 2015). Due to these tremendous losses in agricultural production in 2010, 2011 and 2014, farmers considered floods and heavy rains to pose a much greater risk than other natural disasters. This perception of high risk by farmers resulted in a risk-averse attitude on the part of farmers. The results for risk aversion were related to the findings of (Ibal, 2016). They announced that most farmers in their studies were risk averse by nature. Education was crucial among socioeconomic factors because it affected farmers' risk aversion behavior. Educated farmers may be capable of successful insights and adoption to minimize or avoid risks due to their understanding and knowledge. These results for the link between education and risk aversion are correlated with the following results (Lucas, 2011). According to the study, most educated farmers in the Philippines were risk averse by nature compared to illiterate farmers. The same findings for farmers' education and risk attitudes were also reported in (Kitonyoh, 2015). However, some have reported a contrary relationship [46]. They described that as their education increased, farmers were less risk averse by nature. In terms of experience, our findings showed that there is more risk aversion in highly experienced farmers compared to those with less experience. Experienced farmers are less likely to face natural disasters because of their indigenous knowledge of the prevailing environment and climatic conditions. These findings are consistent with other findings (eg, Lucas, 2011). Their results indicate that risk aversion is greater in highly experienced farmers than in less experienced farmers. It was also revealed that farmers with high risk perception have higher risk aversion than those with low risk perception. The sense of danger is a very important feature in disaster literature. Individual and community responses to natural disasters can be identified, and a positive relationship is found between public response and adaptation to natural hazards (Bikholz, 2014). This means that when farmers' risk perception directly affects farmers' risk avoidance, they will adopt risk reduction strategies. For example, farmers with a high risk perception of floods prefer to cultivate off-land and practice diversification as a risky agricultural tool (Ullah, 2016). In the same way, farmers can use income diversification, hedging and crop allocation and many other agricultural risk management tools in advance and after the disaster. Large farmers have more land and more income and more varieties of crops. Therefore, the dummy for the group of farmers shows that large farmers have less risk compared to small farmers. Therefore, farmers' health and other factors related to disasters play an important role in determining their risk behavior. After the 2005 earthquake and the major floods of 2010, Pakistan still has poor disaster management, mitigation planning and response strategies. Agriculture and food security can be affected by climate change for a variety of reasons, such as the distribution and availability of rainfall, water, biodiversity, soil and global resources. This will lead to farm-to-table food uncertainty and strengthen the economy and ultimately affect the global economy, rice food security and the ability to sustain 9 billion people by 2050. International Institute for Applied System models Analysis (IIASA) demonstrated that regional or global water regulations can affect nature's climate, water withdrawal for agriculture, and future health (Fischer, 2007). It is also known that this need for irrigation will increase up to 45% in the year 2080. Even with the improvement of the irrigation system, as a 20% increase in water. The increase in groundwater with climate change is expected to increase by 20% above baseline (excluding climate change). The new issue of climate change shows the increasing need for irrigation water worldwide, as irrigation increases due to socio-economic development. The impact of climate change on the world's food production is not insignificant, but its geographical distribution is uneven. For example, losses are highest in Africa and Southeast Asia, which represent dry and low-humidity areas (Parry, 2001) and in poor countries with less capacity to adapt to climate change (Hassan, 2006). Pakistan is experiencing hot, dry and snowy winters. The country's geography is diverse; the country has high mountains (mountain systems in the north, center, northwest, and southwest), plains in the center, and plains, deserts, and long coastlines in the southwest. Each territory has its own climate; some places are very cold and others very hot, while some remain fashionable all year round. However, historical data shows that this region receives less rainfall compared to neighboring areas. The country has a rich river water system, which is the major source for meeting the water requirements for agriculture (Yousuf, 2014). The role of agriculture is very important in food security and poverty reduction. Rising temperatures can affect agriculture through its effect on planting times, increased irrigation, increased evapotranspiration and increased heat stress on crops. Short-lived crop varieties, seeding and seasonal seeding changes can also reduce the negative impact of the above mentioned weather hazards (Ali, 2017). Due to its uneven climate, Pakistan's climate change susceptibility index is very high compared to many countries in the world. Currently, the country is facing climate changes, such as rising temperatures, changes in rainfall patterns, climate change, floods, and earthquakes, among others. Pakistan – while not a major contributor to the emissions that created the climate change situation – has a high vulnerability index. The adaptation needs to new changes are very high (Yousuf, 2014). Since 2010, Pakistan's agriculture has faced three major floods which have had a devastating impact on the entire economy, especially on the agricultural sector. Extensive damage occurred in 2010, 2011 and 2014 to agricultural crops, livestock, forestry and fisheries due to flooding during the rainy season and also damaged basic infrastructure such as livestock barns, irrigation wells, irrigation systems, houses, waterways, people, seed stocks and agricultural implements. Prior to the harvest season for major crops, including wheat, rice, maize and vegetables, devastating floods occurred. A loss of around 13.3 million tonnes in production was recorded due to loss of yields from major crops. Estimated 2 million hectares of standing crops were destroyed, while 1.2 million livestock, including poultry, were lost during the 2010 floods [Ismail Shahid, & Luis Antonio Bittar Venturi. (2022)]. Another major flood took place in 2011 in Baluchistan and Sindh provinces which severely affected these provinces as well as the people living in them in terms of loss of life mainly in relation to agricultural activities and issues. About 80% of the population in rural Sindh depends on agricultural activities for livelihood, fishing, crops, forestry and livestock (NDMA, 2011-12). Floods destroyed crops of rice, vegetables and pulses, sorghum, cotton and livestock, as well as catastrophic loss of life in 2011. For example, some 115,500 livestock were killed; about 5 million cattle survived but were also adversely affected by disease and migration. The total realizable loss was US$1,840.3 million, of which 89% was direct damage and 11% was indirect damage. The largest damages (approximately US$1.84 billion) occurred in agriculture, mainly livestock and fisheries. Total damage was estimated at US$100,000. $3.7 billion due to the floods of 2011. Total costs were estimated at US$3.7 billion. $2.7 billion for energy recovery and rehabilitation (GOP, 2017-18). More than 2.5 million people were affected by heavy rains and flooding, and 367 people died during the current floods in September 2014. In addition, 250,000 farmers, 129,880 households and over 1 million hectares of agricultural land were affected. The cost of rehabilitation and resilience housing was estimated at US$1, US$439.7 million and US$439.7 million. $56.2 million respectively (NDMA, 2014-16). These numbers indicate that agriculture was the occupation most affected by the floods in Pakistan. There is great interest in change, which leads to many interpretations of climate change. The Intergovernmental Panel on Climate Change (IPCC) defines them as "Modifications to natural or anthropogenic systems in response to actual or anticipated climate stimuli or consequences, which mitigate or cause practical opportunities for use". Others have focused on a much broader definition, including any action that improves the social climate caused by climate change (Lobell, 2011). Previous literature indicates that a certain level of drought and land degradation can have an impact on local agriculture, and that losses due to disaster can be reduced through rational land use management (Fu, 2013). For example, a long-term land use policy was needed to combat the adverse effects of climate change in Malaysia (Alam, 2012). Similarly, various approaches have been found to combat climate change, such as using modern seeds (Deressa, 2009), changing planting dates, and changing the type of crop in South Africa (Bryan, 2009). In China, the government has shown a willingness to adapt to climate change over the past decade by initiating nationwide reforestation projects that provide significant environmental benefits (Zhou, 2014). Efforts to stabilize the global food system are suffering from a severe crisis, making agriculture vulnerable to climate change. It is expected that the negative impacts of climate change, such as increased temperatures and variations in rainfall, will reduce the benefits to productivity of the agricultural sector (Walthall, 2012). The Midwest US Corn Belt contributes significantly to this process, producing more than one-third of the world's corn. US agricultural sector is increasingly contributing to greenhouse gas (GHG) emissions and is vulnerable to changes in climate, disease and pest systems (Stern, 2006). Climate change is adapted to reduce the negative impacts of climate change. Furthermore, change can be classified spatially (local and broad) and can also include behavioral, technological, institutional, informational and economic changes (Wandel, 2000). The Kyoto Protocol and the IPCC recognized that transitions take different forms (Adger, 2003). Adaptation is explained in terms of vulnerability to climate change. Thus, adaptation to climate change is linked to perceptions of what climate change is. This is how individuals or groups must respond to climate change. An individual perception depends on their experience and knowledge and the observed impact of climate change. For example, in 11 African countries, when temperatures changed, farmers changed crop varieties, increased water conservation, and switched to non-agricultural activities (Maddison, 2007). On the other hand, when there was a change in rainfall, they changed the planting dates. Similarly, a study of 1,800 farming families in South Africa and Ethiopia found that strategies commonly adopted by farmers were to plant different crops and varieties, grow trees, practice soil conservation, and change planting and irrigation dates. (Bryan, 2009). However, it has been observed that farmers who do not adopt any adaptation strategy find that the main factors hindering their adaptation to climate change are lack of credit, lack of information and access to land (Bryan, 2009). As reported by (Kreft, S,*at al*,2015), Pakistan is considered one of the most vulnerable countries to climate change. It was ranked 21st in terms of exposure to extreme weather over the period 1993 to 2012 by the Global Climate Risk Index (GCRI) (Kreft, 2014). Pakistan has been listed by the World Bank as the twelfth most vulnerable country to climate change (Nomman, 2011). Pakistan's economy is based on agriculture, which accounts for 19.8% of the GDP and employs about 42.3% of the workforce and provides livelihood opportunities for about 62% of the rural population (Abid, 2011). In addition to its importance for Pakistan, this sector faces serious challenges related to climate change, such as rising temperatures, droughts, floods and crop failures (Nomman, 2011). In recent decades, the effects of climate change have been most affected by low-income countries (McCarthy, 2001). Pakistan faces extreme weather events including heatwaves, floods, water scarcity, droughts and increased incidence of diseases and pests (Smit, 2002). Pakistan's ranking in terms of vulnerability to climate change is poor as it was ranked 29th in the list of most vulnerable countries for 2009–2010 and in 2010–2011 on global climate change vulnerability Index (CCVI) by was ranked 16th (Khan, 2016). The severe floods from 2010 to 2014 and the drought from 1999 to 2003 are a few examples related to weather events in Pakistan. Climate change is expected to adversely affect Pakistan's economy, as extreme weather events occur earlier, such as changes in rainfall patterns, droughts and floods (Asif, 2016). Pakistan is particularly vulnerable to climate change due to its dependence on natural resources. Therefore, appropriate enforcement measures are needed (Abid, 2015). Therefore, in view of current and expected future climate changes, this study is designed to investigate the effects of climate change on major crops in Pakistan in terms of maximum temperature, minimum temperature, relative humidity, sunshine and rainfall. This research is important because Pakistan is vulnerable to climate change and the food security situation across the country is not very good.

2. Methodology

2.1. Climatic Features of Major Food Crops in Pakistan

Pakistan is an agricultural country where majority of the population is engaged in agriculture related activities. Agriculture contributes about 24% of Pakistan's gross domestic product (GDP) and is an important source of livelihood for rural communities. Climatic features have a significant impact on the growth and productivity of major food crops in Pakistan. The primary objective of the agricultural sector is to ensure food security and reduce poverty through increased productivity. The country is highly vulnerable to climate change due to its geographical location, high population and low technological resource base. During the 2010 floods, Pakistan suffered an economic loss of over $15 billion. Around 300,000 people were displaced and over 20 million were severely affected. Pakistan needs $6-14 billion annually to mitigate the adverse effects of climate change. Some of the gifts of climate change to Pakistan are the floods of 2013, 2011 and 2010, severe droughts of 1999-2003 and storms in Karachi/Gwadar in 2008 that led to landslides and bursting glacial lakes (GLOFS) in Pakistan.

The following are the climatic features of major food crops in Pakistan from 2008 to 2018:

Wheat: Wheat is the main crop of Pakistan and plays an important role in the economy. The average temperature during the wheat growing season (November to May) is 15°C to 25°C, and the average rainfall is 100mm to 300mm. Growth and yield of wheat are directly affected by temperature and rainfall. In recent years, wheat production has declined due to climate change, mainly due to rising temperatures and changes in rainfall patterns.

Rice: Rice is another important staple crop of Pakistan. The ideal temperature for rice growth is between 20°C and 37°C, and the ideal precipitation (Rainfall) is between 1000mm and 1500mm. The rice growing season in Pakistan is from June to September. Changing weather conditions, especially changing rainfall patterns, have negatively affected rice production in Pakistan.

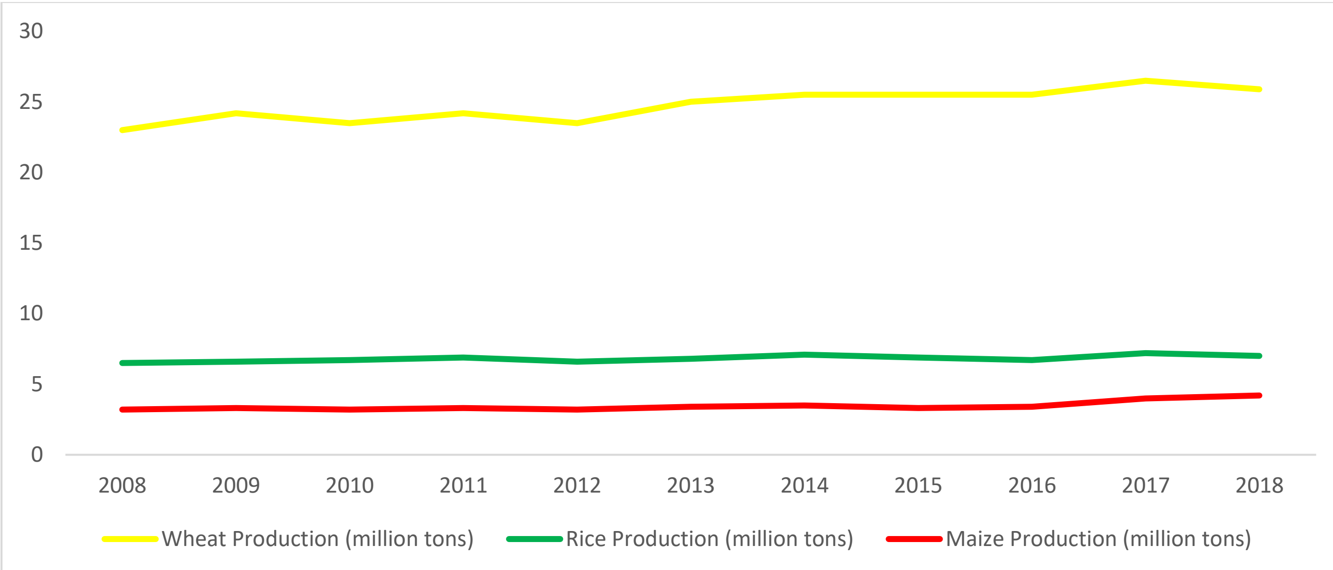
Maize: Maize is a summer crop in Pakistan and is grown in the months of April to August. The ideal temperature for maize growth is between 20°C and 30°C, and the ideal rainfall is between 500mm and 1000mm. Changes in rainfall patterns have negatively affected maize production in Pakistan.

Table: 01 Production of wheat, Rice and Maize percentage changes 2008-18 in Pakistan

Years	Wheat Production (million tons)	% Change	Rice Production (million tons)	% Change	Maize Production (million tons)	% Change
2008	23.0	-	6.5	-	3.2	-
2009	24.2	+5.2	6.6	+1.5	3.3	+3.1
2010	23.5	-2.9	6.7	+1.5	3.2	-2.9
2011	24.2	+3.0	6.9	+3.0	3.3	+3.1
2012	23.5	-2.9	6.6	-4.3	3.2	-2.9
2013	25.0	+6.4	6.8	+2.9	3.4	+6.3
2014	25.5	+2.0	7.1	+4.4	3.5	+2.9
2015	25.5	0	6.9	-2.8	3.3	-5.7
2016	25.5	0	6.7	-2.9	3.4	+3.0
2017	26.5	+3.9	7.2	+7.5	4.0	+17.6
2018	25.9	-2.3	7.0	-2.8	4.2	+5.0

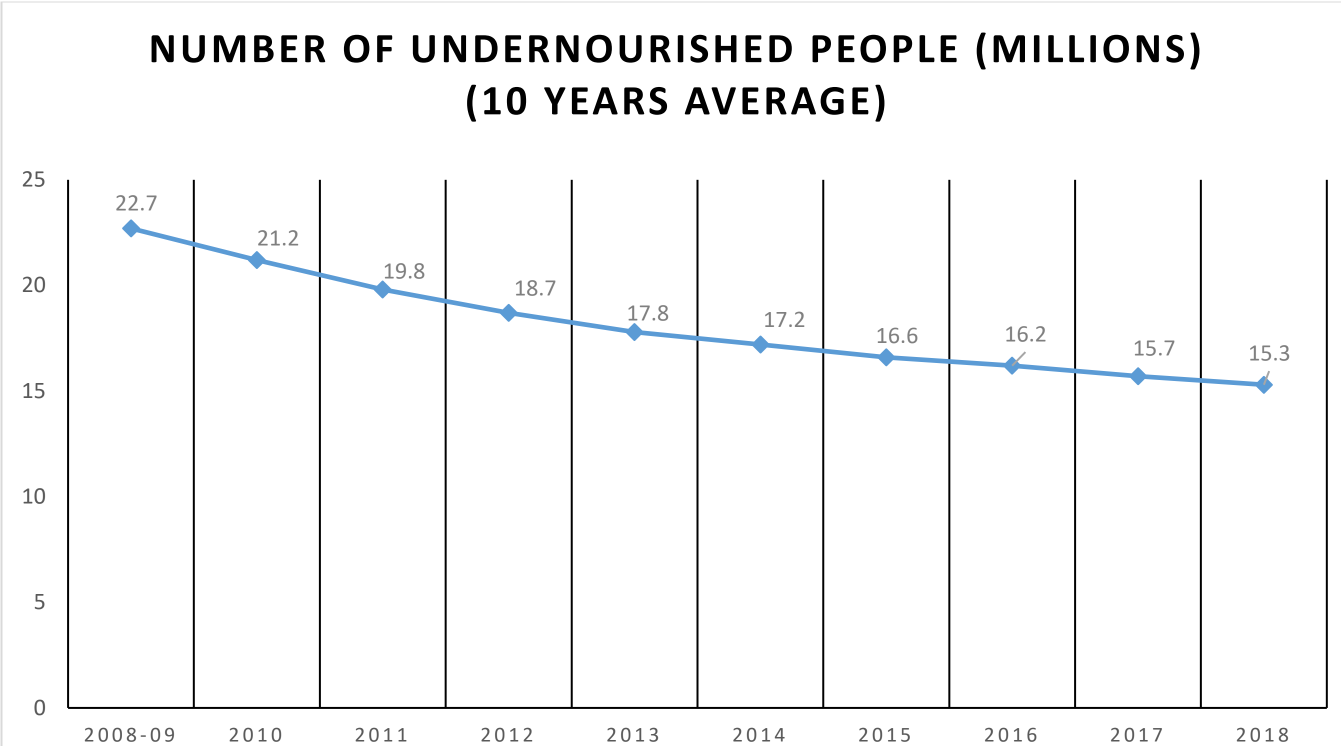
Source: Pakistan Bureau of Statistics. (2019)

Figure: 01 Production of wheat, Rice and Maize percentage changes 2008-18 in Pakistan



Climate change poses a serious challenge to Pakistan by threatening its food, water, and energy security owing to a possible change in weather pattern, extreme events such as floods, droughts, and heat waves, and reduces agricultural productivity. About 5000 glaciers in Pakistan are retreating, and their retreat speed is faster than the rest of the world (GOP, 2016-17). Pakistan is among the list of countries where almost 65% of the world's population lives and is suffering from the problem of food insecurity. These countries include Congo, China, India, Indonesia, Pakistan, Ethiopia, and Bangladesh (FAO,2014). The worst countries in terms of food insecurity and which are unable to take practical steps to overcome this issue include many Asian and African countries. Moreover, they are unable to meet the millennium development goals and hunger eradication objectives (FAO, 2014). The number of undernourished people in Pakistan is given in Figure 2.

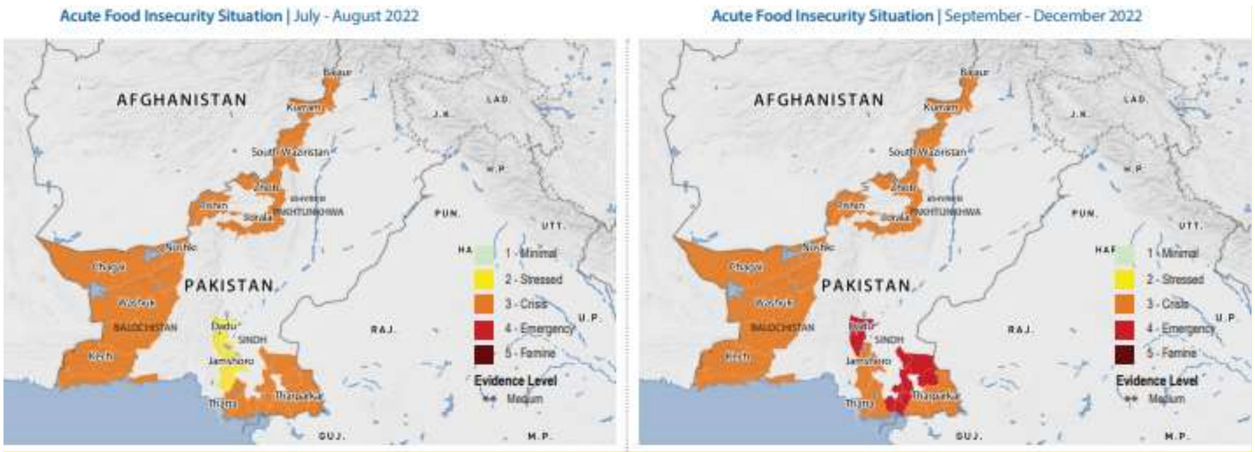
Figure 2. Number of People Undernourished (10-years average)



Source: FAO, 2022

The major food crop of Pakistan is wheat. Other important crops are rice and maize, which contributed to agriculture by a rate of 31.9% in value addition, showing 3.2% growth over the period 2011–2012. Wheat has been considered as one of the important staple foods in Pakistan since the 1960s, and it is a major contributor to GDP. Pakistan is a self-sufficient country, as reported by (Gera, 2004). Many agricultural commodities are produced by Pakistan. Disregarding the various efforts and investment by the government, it is estimated that nearly 22% of the population is food insecure (FAO, 2014). The food security situation of Pakistan is given by Figures 3 and 4.

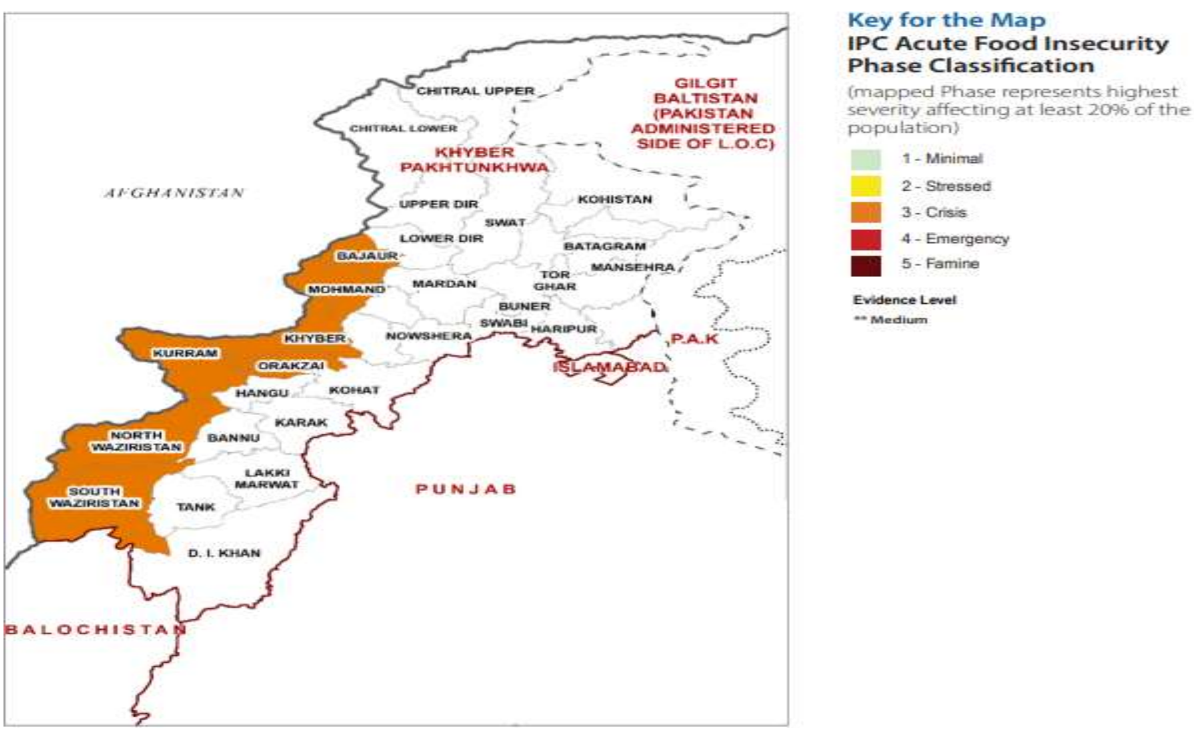
Figure 3. PAKISTAN: Food Security Snapshot Baluchistan, Khyber Pakhtunkhwa & Sindh



Source: IPC, 2022

Figure 4. Acute food security analysis map for Pakistan Provinces wise.

Acute food security analysis map for Khyber Pakhtunkhwa



In 2022, the food security situation in the seven district analyzed deteriorated due to high food and fuel prices, drought/drought, localized flooding limited areas, animal diseases, local conflicts and reduced employment opportunities. Around 1.44 million people (28% of the rural population surveyed) were placed IPC Section 3 (Crisis) or IPC Section 4 (Emergency) during the period (July to August 2022), corresponding to Kharif's harvest/moonson season. These include the surroundings 1.08 million people (21 percent of the rural population) live in and around IPC Category 3(Crises) 0.36 lakh people (7% rural population) are in CPI category 4(Emergency) in the seven districts surveyed. Bajaur, Khyber, Mohmand, North Waziristan and South Waziristan have 25-30% of their population, while Kurram and Orakzai have 40% of its population with IPC Section 3 or 4. Therefore, urgent action is required protect livelihoods and reduce differences in food consumption of people in crisis and make save lives and livelihoods in emergency.

Figure: 05 Acute food security analysis map for Sindh

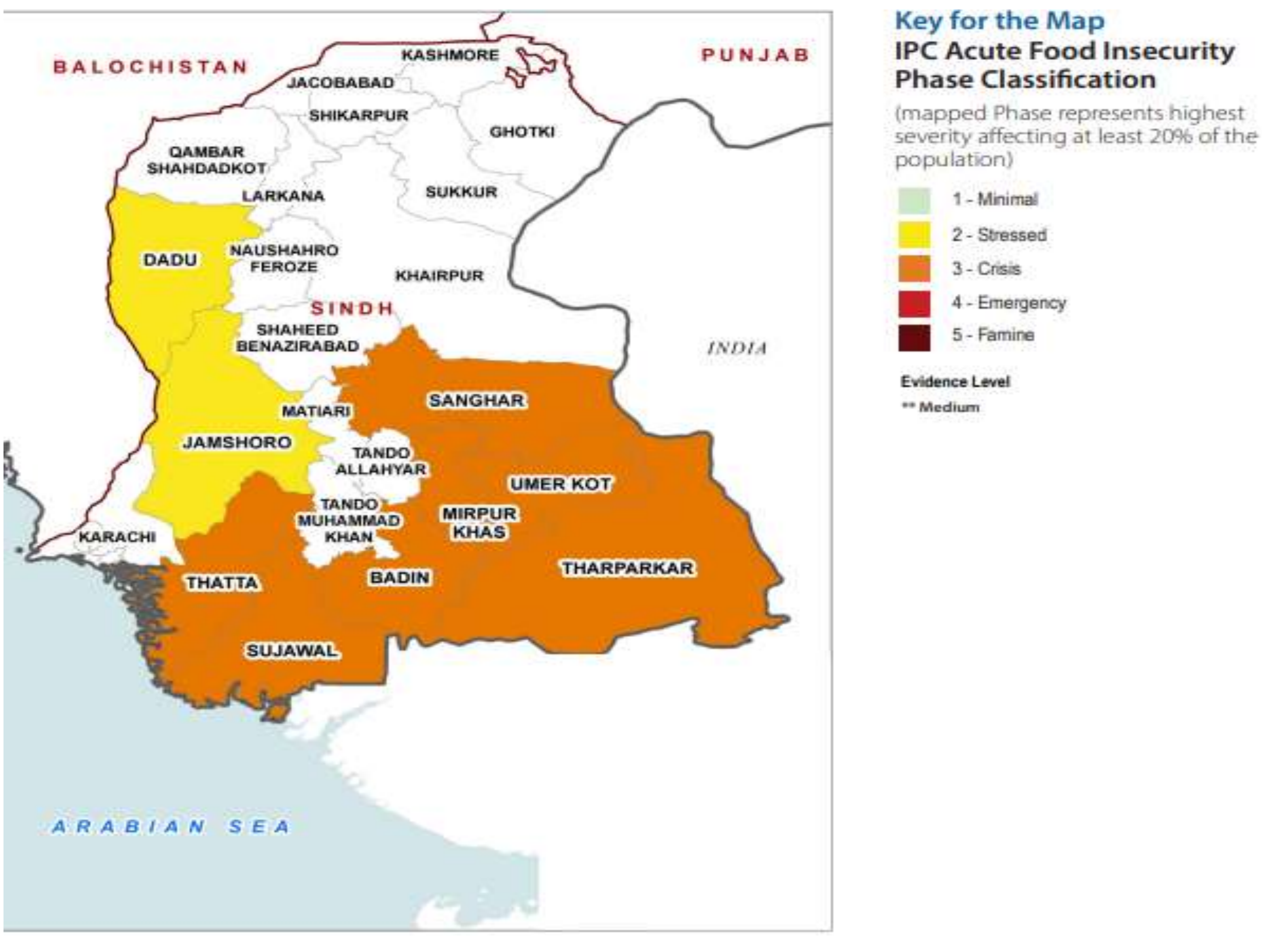


Figure: 06 Acute food security analysis map for Baluchistan

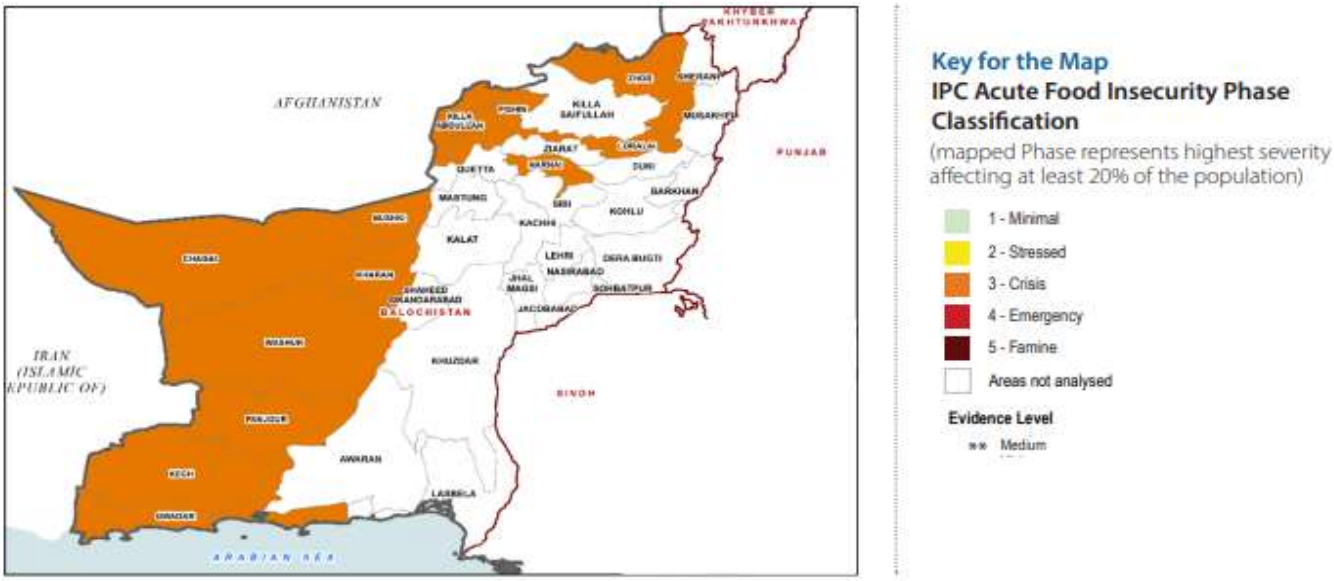
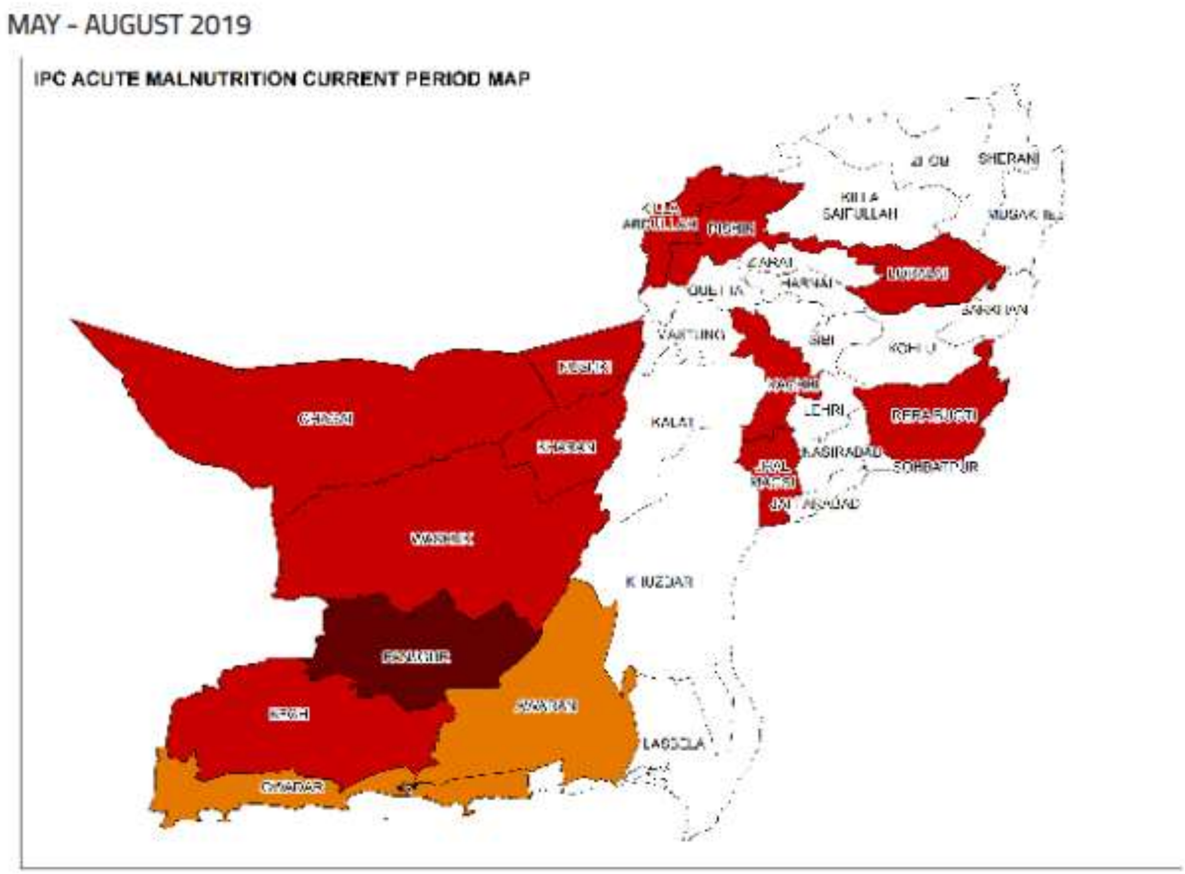


Figure: 07 more impacted area by Malnutrition is Baluchistan



Baluchistan is the most vulnerable province in Pakistan, with the highest prevalence of severe food insecurity, malnutrition and poverty. In the second half of 2022, the food security was further disrupted by rising food and fuel prices, drought, drought/flooding, livestock diseases and reduced employment opportunities. An estimated 1.29 million people, representing 33% of the analyzed rural population, are categorized in Category 3 (Critical) and Category 4 (Urgent) of the IPC for the period (July to August 2022).), namely the harvest of the kharif and rainy seasons. These include about 0.94 lakh people (24 per cent of rural population) under IPC Category 3 (Crisis) and about 0.35 lakh people (9% rural population) under IPC Category 4 (Emergency) in twelve constituent districts in the analysis. Thus, there is a need for Emergency action to protect livelihoods and reduce the gap in food intake of people in crisis and save lives and livelihoods of people in emergency situations.

The policy makers of Pakistan mainly focus on wheat, as it is an important staple food. In Pakistan, wheat is an important food crop due to its extensive use as a food in daily life and as a cheaper source for animal feeding. Out of a 22.45 million ha cultivated area, only 6.34 million ha land is irrigated by canal water, and nearly 12.52millionha is cultivated through tube wells and other sources. There is no availability of water for the remaining 3.59 million ha (GOP, 2017). The sowing season for wheat in Pakistan is November. About 9045 thousand hectares of land are used to cultivate wheat, while the yield is about 2657 kg (Khan, 2011). According to the World Bank, as of 2021, Pakistan has a total land area of approximately 79.6 million hectares, out of which around 22.2 million hectares are classified as arable land, suitable for agricultural production. As for the irrigated land, according to the Pakistan Bureau of Statistics, in 2019-2020, the total area under irrigation in Pakistan was approximately 23.1 million hectares. Out of this, around 14.4 million hectares (62.4%) were irrigated by canals, 6.2 million hectares (26.8%) were irrigated by tube wells, and the remaining 2.5 million hectares (10.8%) were irrigated by other sources such as wells, springs, and rainfall. Different crops have different irrigation requirements, and the percentage of irrigated land also varies according to the crop type. For example, according to the Pakistan Bureau of Statistics, in 2019-2020, the percentage of irrigated land for major crops was as follows:

Wheat: 97.2%, Rice: 97.4%, Sugarcane: 78.6%, Cotton: 72.1%, Maize: 55.5%

It's important to note that these numbers can vary depending on factors such as rainfall, drought, and government policies related to water management. Wheat harvest is very important in Pakistan as consumption per head of wheat is around 120 kg. Currently, about 26 MAF (million acre feet) of water is available for growing wheat, which is about 28.6% less than the required amount (Nelson, 2009). Almost all models predict that climate change will negatively affect wheat production in South Asia. The fourth IPCC report indicated that agricultural production in South Asia will decrease from 1820 m3 to 1140 m3 in 2050 from 2001 to 2050. Furthermore, gross water availability per capita will also decrease. There is a fear of water supply in many parts of the country. It is expected that in the near future the availability of water will decrease rapidly, as well as the productivity of the agricultural sector.

2.2 Source of data

This study aimed to assess the impact of climate change variables of temperature (maximum and minimum), precipitation, humidity and sunshine (wind) on the production of major food crops like wheat, rice, and Maize yield cultivation in Pakistan. This study is based on secondary data for the period from 2008 to 2018. District wise annual data on reported crops were collected from various issues of Agricultural Statistics Pakistan published annually by Pakistan Bureau of Statistics. Daily weather/climate forecasts from the Pakistan Meteorological Department during the same period (PMD, 2016). The weather data included data from 10 weather stations. Daily data on weather variables were adjusted according to growing season from sowing to harvest that varied across counties to represent the country as a whole.

2.3. Model Specification

It is expected that each crop needs specific conditions for growth and survival such as soil moisture (water), optimum temperature, sunlight and air humidity. According to a study, the temperature (maximum and minimum) of photosynthesis increases as it grows and leads to an increase in yield (Sombroek, 2016). However, it has been stated that very high temperatures have a negative effect on metabolic processes in plants, such as the stability of proteins and (enzymatic) reactions in cells, leading to metabolic imbalances (Mathur, 2014). In addition, high temperature also affects the activity of photosynthesis II and RuBisCO, and also causes the reduction of photosynthesis. On the other hand, too low a temperature can cause damage in plants (Bhandari, 2014). During the monsoon season, heavy rains can be a serious problem for farmers. This can lead to soil erosion, soil erosion and nutrient depletion in the soil. Each crop is expected to need specific conditions to grow and survive, such as soil moisture (water), ideal temperature, adequate insulation and air humidity. According to one study, the temperature (maximum and minimum) increases with increasing photosynthesis, which leads to growth and increased yield (Sombroek, 2016). However, it has been claimed that very high temperatures have a negative effect on metabolic processes in plants, such as the stability of proteins and (enzymatic) reactions in cells, leading to metabolic imbalances (Mathur, 2014). Furthermore, high temperature also affects the activity of photosystem II and RuBisCO, and reduces photosynthesis as well. On the other hand, extremely low temperatures can cause frost damage to plants (Bhandari, 2014). During the rainy season, heavy rains can be a big problem for farmers. It can cause soil erosion, surface erosion and nutrient loss. Devastating floods can damage crops, leaving farmers with no food available for consumption and sale, thus causing production and food security problems (Lichtenstein, 2016). Similarly, water plays an important role in crop production. Plants need enough water for balanced growth. Too low or too high humidity is not beneficial for high yields. When there is enough water, plants can absorb nutrients from the soil and produce more crops. Water directly controls the plant-water relationship and regulates it through leaf growth, photosynthesis rate, fertility, disease incidence and ultimately crop yield. Furthermore, dry weather can seriously threaten dry matter production through the possibility of stomatal fungus on leaves (TNAU, 2016). The main determinant of plant growth is sunlight, as it affects the process of photosynthesis. As we know, plants are directly dependent on sunlight for healthy growth and development, completion of their life cycle, and most importantly, food preparation. In contrast, excessive solar radiation has similar negative effects on crops (eg excessive heat) (Smestad, 2016). Thus, climate change is expected to have several important impacts on crop yields. In view of the above considerations, this study estimates that the model below will meet the objectives of the study. Generalized least squares (FGLS) and heteroscedasticity and autocorrelation (HAC) consistent standard error techniques are employed, and the dependent and independent variables are conceptualized.

$$Y_{it} = \alpha_0 + \alpha_1 Max_{it} + \alpha_2 Min_{it} + \alpha_3 Rain_{it} + \alpha_4 Hum_{it} + \alpha_5 Sun_{it} + \alpha_6 Year_{it} + \varepsilon_{it} \quad (1)$$

Where Y_{it} =Yield(kg/Acre) of crop *i* in year t; α_i = Coefficient to be estimated; Max_{it} = Average monthly maximum temperature (◦C) during cropping season for crop *i* in confirmed year *t*; Min_{it} = Average monthly minimum temperature (◦C) during cropping season for crop *i* in year *t*; $Rain_{it}$ = Average monthly rainfall(mm)during cropping season for crop *i* in year *t*; Hum_{it} =Average monthly humidity (%) during cropping season for crop *i* in year *t*; Sun_{it} = Average sunshine (hours per month) during cropping season for crop *i* in year t; ε = error term.

3. Results and Discussion

3.1. Descriptive Statistics

Descriptive statistics were calculated in Table 1, to identify significant characteristics of all variables in this study. The objective of this study is to investigate the yield, growing area and production of all major crops. In terms of yield, it was found that among the three crops, the average wheat yield was the highest. According to this study, lower average yields of the three crops: Maize > Wheat > Rice. In terms of production, wheat comes first, Maize are second and the third are rice. In terms of area of Average production, wheat came first, followed by Maize and rice, second, and third, respectively. In terms of climate variability, the highest temperatures were observed in the rice season and the lowest in the wheat season. On the other hand, the highest minimum temperatures were observed in the rice growing season, while the lowest minimum temperatures were observed in the wheat growing season. In terms of precipitation, rice has the highest precipitation during the growing season; maize ranked second respectively, while wheat received the lowest overall rainfall. Due to relative humidity, the lowest was observed in the maize harvest. Finally, in terms of sunshine, the maximum sunshine was observed during the rice sowing season and the lowest during the wheat season. This study will also identify climate changes that significantly affect food crops in Pakistan.

Table 2. Descriptive statistics, 2008–2018.

		Statistics					
Variables	Major Crops	Mean	Std.Dev.	Min	Max	Skewness	Kurtosis
Cultivated Area(hectare)	Wheat	9012.6	127.165	8785	9206	-1.01175	1.406955
	Rice	1080.5	202.4681	2845	3424	-0.58481	-0.76239
	Maize	3156.7	42.50621	1018	1135	-0.7798	-1.22736
Production(tons)	Wheat	24820.2	1049.43	23517	26306	-0.0363	-1.7087
	Rice	4942.5	436.977	6017	7199	-0.7720	-0.9948
	Maize	6764.6	957.51	3274	6209	-0.6554	-0.6743
Yield(kg/hectare)	Wheat	2754.3	104.87	2577	2860	-0.8169	-0.7222
	Rice	4537.9	690.82	1933	2319	-0.2769	1.1931
	Maize	2138.2	104.84	3336	5513	-0.6394	-0.4682
Maximum temp(^{0}C)	Wheat	36.89	0.537503	35.9	37.6	-0.38739	-0.77455
	Rice	45.02	0.310132	44.6	45.5	0.008533	-1.23414
	Maize	32.39	3.46	24.95	38.67	0.04	2.12
Minimum temp(^{0}C)	Wheat	10.85	3.11	1.37	15.64	-1.62	5.10
	Rice	24.84	1.71	19.68	29.16	-0.34	3.38
	Maize	18.29	3.87	9.93	28.42	0.34	2.10
Rainfall (mm/year)	Wheat	22.28	17.58	0.00	71.18	0.79	2.75
	Rice	70.89	60.02	0.00	322.58	1.32	4.59
	Maize	33.56	21.82	3.57	112.90	1.09	3.75
Humidity (%)	Wheat	57.43	6.51	36.02	70.21	-0.73	3.38
	Rice	58.57	5.90	44.85	74.05	0.10	2.80
	Maize	51.34	5.78	37.20	64.20	-0.20	2.35
Sunshine (h/day)	Wheat	229.33	21.90	160.90	280.70	-0.24	3.30
	Rice	259.49	23.01	175.09	380.00	0.14	7.10
	Maize	249.24	24.12	176.37	290.2	0.36	2.45

Source: Authors own estimation based on Pakistan Meteroloigcal Department (PMD, 2018, 20).

3.2. Trend Graph

In addition to examining descriptive statistics, graphs were also constructed with time (t) as the explanatory variable to assess the variability and continuity (horizontal and vertical) of change among the five climate variables over the entire period (2008-2018). Temperatures were slightly variable, and small temperature fluctuations were observed in all cultures (Figure 8). Mean maximum temperature varied slightly, and small variations were observed in maximum temperature for all cultures (Figure 8). However, the minimum temperature in harvested rice plantations showed a significant increase (Figure 9). The trend in minimum temperature appears to be increasing. Rainfall fluctuated greatly, especially in rice growing season, and trends show an increasing rate. During the wheat and maize growing seasons, rainfall showed a slight decrease in overall trend, while rainfall also showed slight variations in the rice growing season (Figure 10). The trend in relative humidity for all the selected crops appeared to be decreasing slightly, and the overall trend greatly fluctuated in the maize growing season (Figure 11). Interestingly, the sunshine for rice and maize crops exhibited a decreasing trend for all seasons, with slight fluctuations for all the crops (Figure 12).

Figure 8. Trend of mean maximum temperature for Pakistan, 2008–2018.

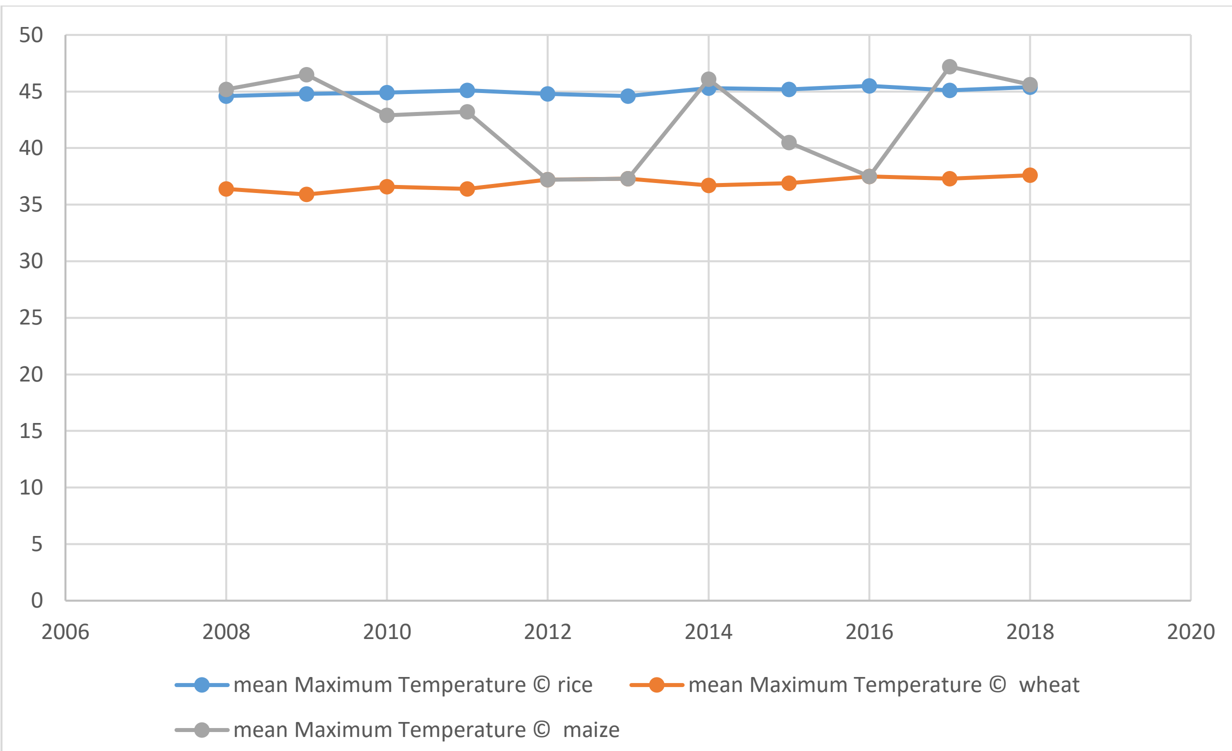


Figure 9. Trend of mean minimum temperature for Pakistan, 2008–2018.

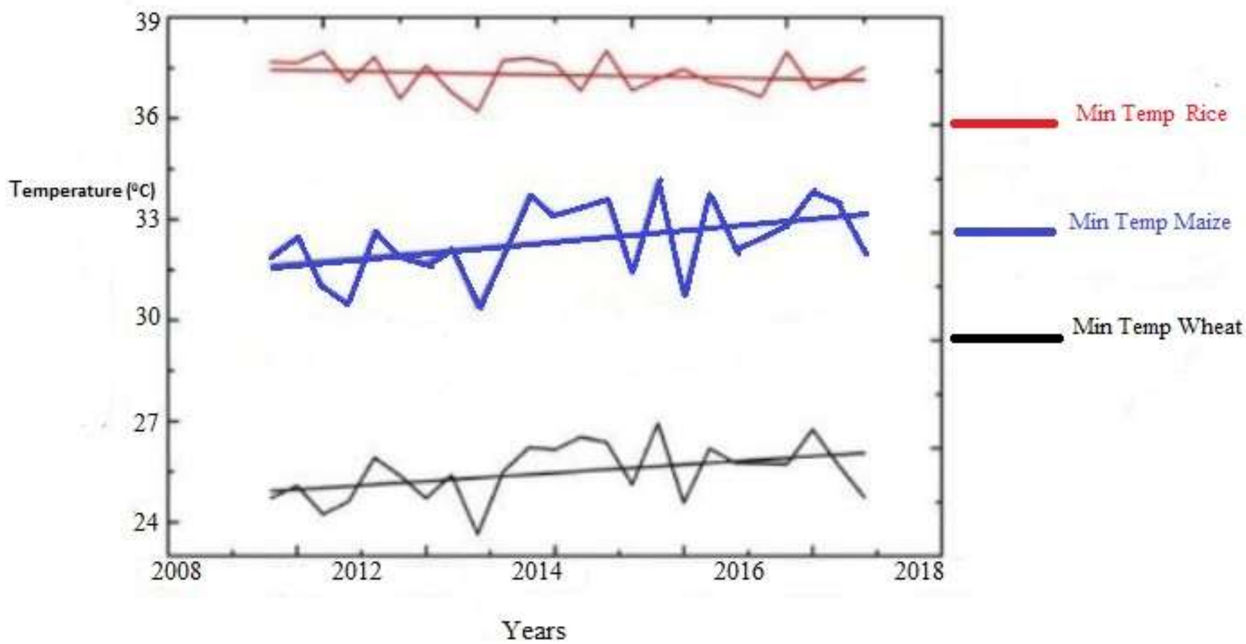


Figure 10. Trend of rainfall for Pakistan, 2008–2018.

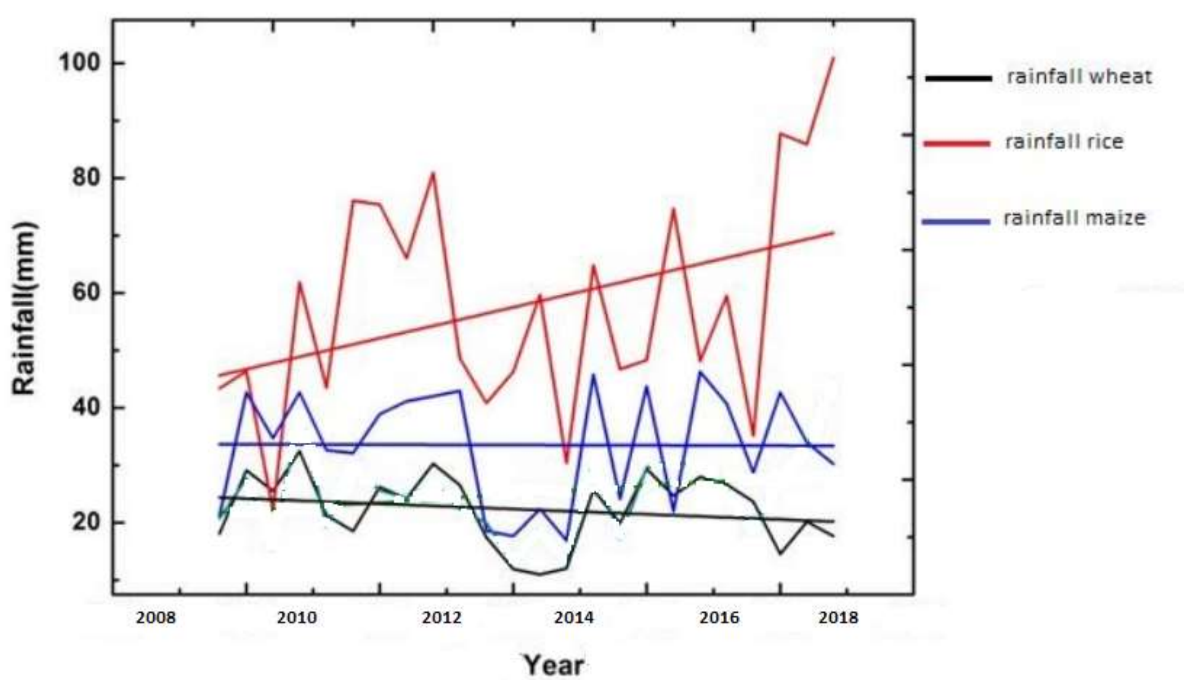


Figure 11. Trend of relative humidity for Pakistan, 2008–2018.

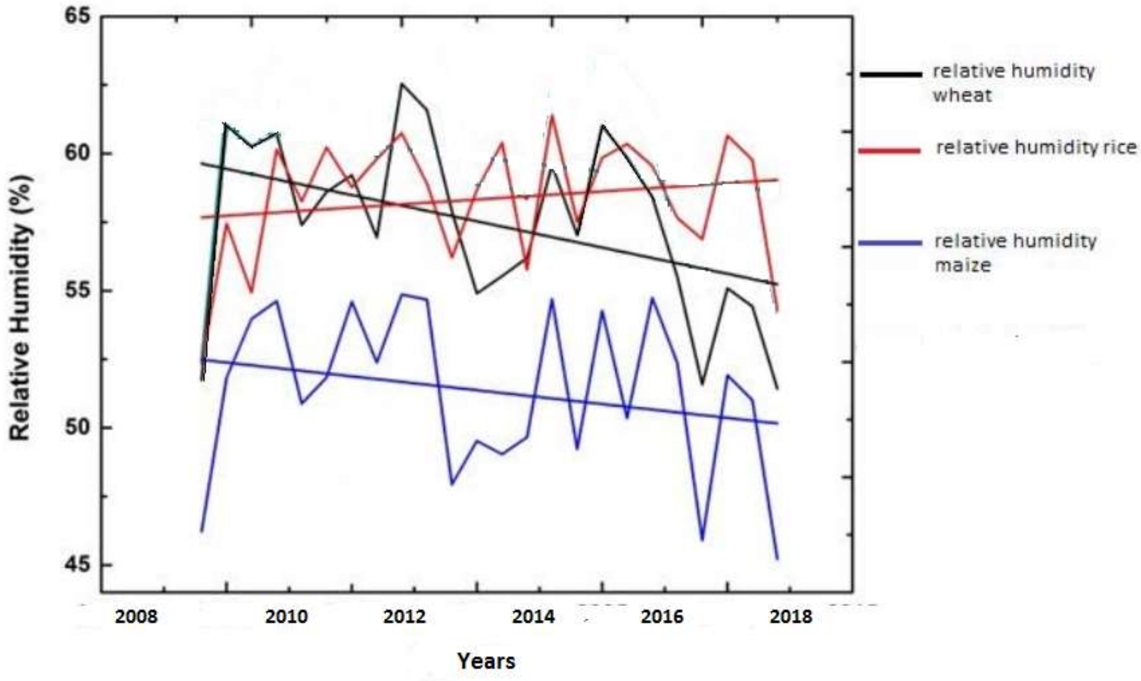
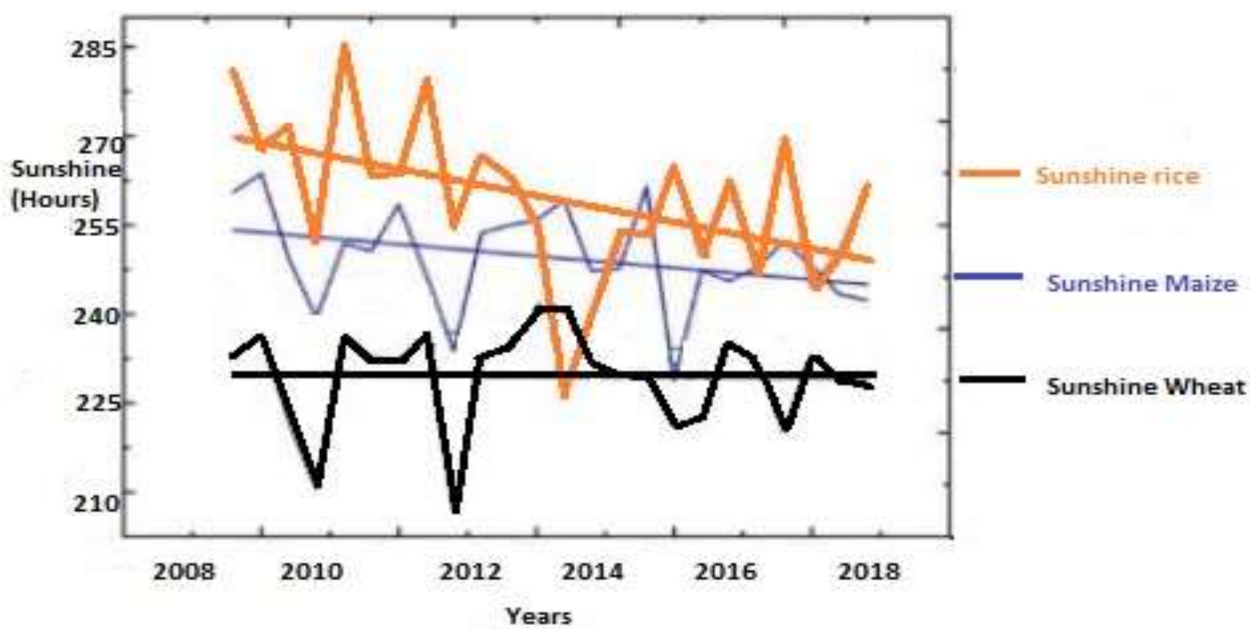


Figure 12. Trend of sunshine for Pakistan, 2008–2018.



3.2.1. Climate and Wheat Crop

Wheat is the leading staple food crop of Pakistan, and hence the food security policy focuses mainly on the production of wheat. Wheat is deemed important due to its extensive use as a food and a relatively cheaper source for animal feed. The sowing period for wheat is winter and it is harvested in summer. Low temperature is conducive for the growth of wheat, while high temperature can cause a delay in seedling growth. Similarly, rainfall pattern causes damage to the production of wheat at harvesting time, ultimately leading to a situation of food insecurity in the country (Janjua, 2010). A decrease of 1.9% was observed in wheat production from 25.979 million tonnes to 25.478 million tonnes during the period from 2013–2014 to 2014–2015. The main reasons for the decreased production were prolonged winter season and irregular rainfall (GOP, 2015). The HAC method was used to identify the impacts of climate change on the yield of the wheat crop. The findings of the study are shown in Table 2. Maximum temperature showed a significant and negative influence on yield. Minimum temperature also showed a statistically significant influence, and the contribution was also found to be positive on yield. In the case of rainfall, itshowedanon-significantinfluenceandanegativecontributiontotheyieldofwheat. Both the relative humidity and the sunshine expressed or showed non-significant influence, while relative humidity displayed negative effects. The sunshine showed a positive effect on yield. The adjusted R2 value implied that almost 30% of the yield variation of the wheat crop is influenced by the climatic variability. It was found that changes in temperature can significantly affect the production of wheat (Tariq, 2014).

Table 2. The regression results of different major crops of Pakistan evaluated by ordinary least square (OLS) and feasible generalized least square (FGLS).

Variables

3.2.2. Climate and Rice Crop

Rice is the second-largest staple food crop and exportable item for Pakistan. From the 2014–2015 fiscal years, rice export earned US$1.53 billion for Pakistan. There was a 3% recorded increase in the growth of rice over the period of 2013–2014 to 2014–2015 (GOP, 2015). To determine the influence of the climatic variables on the rice crop yield, the FGLS method was employed. The results are presented in Table 2, which showed that the effects of all the climatic parameters except the maximum temperature were observed to be significant for the yield of the rice crop. Minimum temperature caused a negative effect and non-significant influence on the yield of the rice crop. Both rainfall and sunshine also negatively contributed to the yield of this crop and were non-significant. Relative humidity contributed positively, but it showed a non-significant influence on rice yield. However, the adjusted R2 value showed that 33% variability in the yield of the rice crop is explained by climatic factors. A study was conducted in which it was found that climatic variables significantly affect the yield of rice, but vary among different rice crops. Moreover, the effects of maximum temperature and minimum temperature are pronounced as compared to rainfall (Sarker, 2012). It is confirmed that rising maximum mean temperature would result in an increase in rice production, while the increase in minimum temperature would lead to an enhancement in the production (Shakoor, 2015). Rice production trends could be estimated or expected by the use of the Autoregressive Integrated Moving Average (ARIMA) model, but it did not reflect climate influence (Awal, 2011). Other studies also stated that an increase in temperature and rainfall negatively affects rice production (Mahmood, 2012; Peng, 2004; Rathor, 2000).

3.2.3. Climate and Maize Crop

Maize is an important food crop and a raw material for many products. The production of maize decreased by five percent from 4.6944 million tonnes to 4.695 million tonnes during the period 2013–2014 to 2014–2015 (GOP, 2015).The HAC method was performed to determine the climate change and maize yield relationship, and the findings are presented in Table 2. Results revealed that both maximum temperature and minimum temperature were found to be positive and non-significant. Relative humidity showed a statistically significant contribution to the yield of maize crop, but it negatively influenced the yield of crops. Both rainfall and sunshine showed no statistically significant contribution, and negatively influenced the yield of the maize crop. The adjusted R2 value indicated that about 39% of the variation in the maize crop yield is explained by the climatic parameters.

4. Conclusions

Climate change is a global environmental threat to all economic sectors specifically the agricultural sector. Pakistan has faced extreme weather events like untimely and heavy rainfall and flash floods in mountainous areas affecting huge damage to the major crops and properties of farmers. It is expected that the above-mentioned situation will increase as a function of climate change. Paying attention to the significance of agriculture to the country's economy and rural livelihoods, the importance of climate change adaptation approaches is critical. Even though the adaptation strategies are very important, all farmers do not use such strategies. The majority of rural households and connected urban populations in developing countries as well as in Pakistan are highly dependent on agriculture. Therefore, adaptation to the negative impacts due to climate variability may be essential to encourage food security for the country and to protect the subsistence of rural households. The prime aim of this study was to analyze the impact of climate change (e.g., maximum temperature, minimum temperature, rainfall, relative humidity, and sunshine) on major food crops of Pakistan, including wheat, rice and maize. The HAC and FGLS methods were employed to achieve the objectives and obtained mixed results. Some climate variables affect the crop yield negatively and significantly, while others are not significant. The most influential climatic variables for wheat crop production in Pakistan were observed to be maximum temperature, rainfall, and relative humidity. The finding confirmed that maximum temperature is significant and negatively influenced the yield of wheat crop, while rainfall and relative humidity are both insignificant and negatively influenced wheat crop yield. The influence of maximum temperature is significant for the rice crop. Both temperature and relative humidity displayed positive inter relation with crop yield. Overall, climate change has adverse impacts on the yield of major food crops. Almost 60% of the Pakistani population is living below the poverty line. Moreover, the population is growing rapidly and the country will face the problem of food security in the near future. The government needs to take firm action to overcome this problem and ensure sufficient food for the masses.

5. Limitations and Future Research Direction

The national level data might not depict the true picture of the impact of climate change on different agro ecological zones. Therefore, to take the regional differences into account, region-specific studies should be conducted. We know that Pakistan is a diverse and rich land, and in this way the discrepancies would be removed, resulting in a balanced picture of the country.

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