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Appraising Challenges of Climate Change Threats to Agriculture and Food Security of Pakistan: A Spatiotemporal Perspective

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Abstract: Climate change (CC) is one of the foremost global concerns of the modern world. Its associated alterations in the environmental and anthropogenic phenomena are triggering numerous multifaceted problems of serious nature threatening the world community. Developing countries like Pakistan, which are already facing the problems of rapid population growth, water and food shortage, droughts and floods are relatively more threatened by CC. Due to its sensitive nature, the agriculture sector is highly vulnerable to CC effects and affected by even minute fluctuations in the temperature and moisture supply conditions. This study intends to examine the CC effects on agricultural activity and food security (FS) focusing on Pakistan. Grounded mainly on the secondary data acquired from numerous sources such as publications, surveys, research, national and international reports, public and private media sources, and websites like 'climate change knowledge portal', it tries to bring out a factual picture of the issue that can assist to develop lessons for the future planning. The collected data were integrated and analyzed using quantitative and descriptive approaches. The results reveal that climate is changing primarily due to increasing greenhouse gas emissions (GHGE) as a result of the expanding activities of a rapidly growing population. Besides other multiple and wide-ranging global and local effects, CC is also distressing the agricultural sector of Pakistan giving birth to future FS concerns and threatening its economic development. The study concludes that, if timely and effective measures to deal with the challenge were not taken, problems facing agriculture

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of the country will intensify further and it may become intrinsically hard to ensure the future FS. To overcome the issue, the study advocates the reduction in population growth rate, a drop in the GHGE, proper management and wise use of agricultural resources, and practice of the climate-smart agriculture. These goals are not too difficult to achieve if all the stakeholders show commitment and earnestness.

Keywords: Agriculture, climate change, food security, greenhouse gases, global warming, Pakistan.

Introduction

Climate is the average of the sum total of all weather conditions for a period not less than at least three decades. Weather is the temporary atmospheric condition while climate is commonly understood as a long-lasting feature of the areas. Climate change (CC) denotes the long term changes in temperatures and weather patterns caused by natural as well as human factors. In the modern world, CC refers to the fast and undesirable changes occurring in the climate chiefly because of the expansion and intensification of human activities, increasing GHGE and reduction of forest resources over the globe. These fast occurring changes in climate are harmful for the environmental cycles, environmental stability, life phenomena and human activities all over the world. Precisely climate can be expressed as;

$$C = W + T \quad (1)$$

Where; C = climate, W = weather (temperature, precipitation, air pressure etc.), and T = time (30 years or above).

While CC can be expressed as;

$$CC = W + T + A \quad (2)$$

Where, CC = climate change, W = weather, T = time, and A = alterations in the average of weather conditions.

Although, natural factors may also cause CC, but increasing human interventions in the physical environment have accelerated the pace of CC. Most of the investigators agree that since the industrial revolution of the 18th century, human activities have been the chief driver of CC. Greenhouse gasses (GHGs) emitted from the burning of fossil fuels and from other human activities have blanketed the earth. These gases include CO_2 (79.7%), CH_4 (11.1%), N_2O (6.1%), fluorinated gases (or F-gases) like HFCs, PFCs, SF_6 and NF_3 (3.1%), and water vapors. Although, among GHGs carbon dioxide has dominating share, but as a greenhouse gas (GHG), CH_4 is 25 times and N_2O is 300 times more powerful than CO_2 in causing damages. All

these gases have the property to absorb infrared radiation emitted from the earth to balance global heat budget and send it back to the earth's surface. By trapping heat, these gasses lead to global warming (GW) and CC. Due to increasing GHG effect, our blue planet is warming now quicker than at any point of time in the documented history. CC is perhaps one of the most debated and biggest issues of the modern world. Recently, it has become main focus of the researchers from various fields including geography. All environment related sectors, especially agriculture and food security (FS), are facing the challenges of CC threats across the world. Pakistan is one of the most susceptible countries to harsh and severe climatic conditions. It has often faced grave adverse effects of CC.

Certainly, natural environment is a big blessing, an authentic store house of life sustaining stuffs, and a perpetual shopping basket for us, but by polluting it to mass-production and by felling down trees to develop land, our perfectly balanced environment has now been distressed. The law of nature tells and ground realities also confirm that the intents and directions of the work of nature and the work of humans are opposite. The nature ensures stability of the environment by keeping all systems functioning normally while humans try to maximize production and profitability disregarding, upsetting and sometimes ruining environmental stability. To maximize short-term and immediate profits, humans are putting extra stress on the environment and disrupting its natural functioning, which in turn is showing reaction in the form of harmful feedbacks. Rapid CC is also a result of and a reaction of the environment against the increasing human intervention and the stress exerted on it by wide-ranging human activities. Uncertain weather patterns causing intense and prolonged heat waves, prolonged droughts, pouring rains and flash floods, rapidity in glacial melting, glacial lake outbursts, rise in sea level, increase in uncertainty of river flows, increase in water scarcity, frequent occurrence of cyclones, poor air quality, upsurge in smog formation and increase in forest fires are clear indication of rapid CC. Impacts of CC are obvious on almost every walk of life and every region of the world. The most affected areas are, however, those already facing the problems of rapid population growth, food shortage, water scarcity, droughts and floods. Pakistan is one of the top most such cases. In spite of being world's one of the lowest GHG emitters, contributing even less than 1% of the total global emissions, it stands amongst the top ten countries that are extremely vulnerable to the threats of hazardous climate events (Abbasi, 2022; GoP, 2023). According to global climate risk index 2021, Pakistan was 8th most vulnerable country to CC (Germanwatch,

2021). A UN report ranks it the 5th most susceptible country to CC effects (UN, 2023). Although, its vulnerability to CC influences has been sufficiently confessed and documented, the steps taken to deal the issue are insufficient (Chaudhry, 2017). Currently, Pakistan is world's fifth biggest country with a population of 240.5 million (PRB, 2023). Rapid population expansion and CC are big challenges for the country, which are hindering efforts to keep balance between population and resources (Malik, 2024). Agriculture (which is lie-line for Pakistan) and other resources that support its people to find sustenance are already under a lot of stress due to ever expanding population. In addition, CC threats are mounting to be another big challenge for the country. Most of its population is inhabited along the Indus River which swells and can flood during monsoon season causing heavy losses of life, crops and other assets. In the past some decades, extreme meteorological conditions have developed into a routine matter and become a regular happening, upsetting food and water security in the country. Repeated spells of extreme meteorological events like heat waves, droughts, storms, and catastrophic floods have taken big tolls on life and assets and seriously impaired the country's economic development. The marginalized groups of population such as poor, children, aged and females faced most of the brunt of such hazards. Above all, agriculture that can ensure Pakistan's future FS, is one of the greatest affected sectors facing serious challenges of CC threats. Due to that, concerned departments need to make earnest efforts to educate the farmers and to save this sector. Although, some studies have provided evidence about agriculturalist's realization of CC, mitigation strategies and adaptation, there is still a lack of ample awareness among farmers (Mehmood et al., 2022).

Furthermore, agriculture is not only limited to farms, it extends beyond the fields like food manufacturing and food services providing employment to many people. This means, any disruption in agriculture can upset all those activities and people dependent upon it. Besides heavy reliance on land, water and other factors, it is highly sensitive to weather and climate. Changes in temperature, precipitation patterns and frost timings can upset growing seasons or allow various crops to be cultivated in some specific areas, and also make farming practices more challenging in others (Walsh, 2020). The impacts of CC on agriculture are governed by the rate and harshness of the change, as well as by the degree to which farmers can adjust (Gowda, 2018). On the other hand, agriculture sector also emits GHGs which contribute to CC. Thus, a good deal of research is required to assist for future preparedness to deal CC effects on agriculture. Keeping above mentioned

ground realities in view, this study was performed with the objective to appraise the challenges of CC threats to agriculture and FS of Pakistan. Such kind of studies can help the agricultural planners and policymakers to develop appropriate adaptation measures in the context of CC.

Research Methodology

To appraise the country's overall situation of CC threats to agriculture and FS, in addition to personal field observations and farmer's opinions, the study in point is largely based on secondary data. Most of the data was gathered from different national and international reports, newspapers, research studies, and other sources such as websites like 'climate change knowledge portal for development practitioners and policy makers' etc. The taped data and facts were incorporated and analyzed by means of both quantitative and descriptive methods to outline and suggest strategies for dealing likely future challenges.

The method of simple moving averages was applied for smoothing temperature statistics to draw it against corresponding time. It was worked out for 5-year interval and computed as the totality of N observations divided by N which was an odd number. For this purpose, below given formula was applied;

$$Moving\ average = \frac{\Sigma N}{N}$$

$$OR$$

$$\frac{Sum\ of\ 5-year\ temperature}{5}$$

Using this formula, a 5-year moving average of temperature was calculated as a total of 5-years temperature in a row, divided by 5. This was performed for the whole data and obtained average temperature values were plotted against the each corresponding interval midyear. The graphs found by plotting real values and moving average (5-year smoothing) values against time show an obvious increasing trend of temperature.

Global hunger index (GHI) was also used as a tool to know about the hunger and FS situation in the country. Using values of following four indicators, GHI score is computed on a 100-point scale, where 0 is the finest possible score indicating no hunger and 100 is the extremely nastiest score indicating alarming situation of hunger.

1. Undernourishment; the percentage of population with inadequate caloric consumption.
2. Child stunting; the proportion of children below age 5-year who have less height for their age, showing chronic under nutrition.
3. Child wasting; the percentage of children below age 5-year who have less weight for their age, indicating severe under nutrition.
4. Child mortality; the percentage of children who die before 5-years of age, indicating the deadly combination of insufficient nutrition and unsafe environments.

Following formulas are applied to standardize each indicator's value to compute GHI;

1. $\frac{\text{Prevalence of undernourishment}}{80} \times 100 = \text{standardized undernourishment value}$
2. $\frac{\text{Child stunting rate}}{70} \times 100 = \text{standardized child stunting value}$
3. $\frac{\text{Child wasting rate}}{30} \times 100 = \text{standardized child wasting value}$
4. $\frac{\text{Child mortality rate}}{35} \times 100 = \text{standardized child mortality value}$

Then GHI score is obtained as;

GHI Score = Undernourishment value + Child stunting value+ Child wasting value + Child mortality value

OR

$$GHIs = Un + Cs + Cw + Cm$$

Subsequently GHI score for each country is categorized by severity, from low to extremely alarming according to the values given in Table 1.

Table 1: GHI score categories

Level	*Category*	*Value*
1	Low	≤ 09.9
2	Moderate	10.0-19.9
3	Serious	20.0-34.9
4	Alarming	35.0-49.9
5	Extremely alarming	≥ 50

Environmental setup of the study area

Geographically the study area is a matchless country with no other such example all over the world. Its physiography, altitude and gradient, climate, drainage pattern, flora, fauna, social setup, and population composition, all are unique. It stretches from Arabian Sea in the south to the world's most glorious loftiest mountains in the north sharing boarders with the world's giant China. India with second global biggest population concentration lies on its east, Afghanistan on the west, and Iran on the southwest of Pakistan (Figure 1).

Figure 1: Location of Pakistan

It extends from 60° 50′ to 77° 50′ east longitude, and from 23° 35′ to 37° 05′ north latitude (AIPS, 2024). Stretching from northeast to southwest and covering an area of 796,096 sq. km, the country is characterized with a great variety of landforms, temperature and precipitation. It has level Indus plains in the middle and south, deserts in the south east, mountain in the north and northwest, Balochistan Plateau in the west and southwest. Altitude varies between 0 on the Arabian shore to 8,611 meters K-2 peak of Karakorum. On the same day and at the same time, it has the areas with temperature below 0°C and the areas with temperature above 40°C, the areas receiving snowfall on one side and the areas facing warm dry dust

winds on the other side. For instance, on April 30, 2024, Karachi was facing a heat wave with temperature rising to 40°C on one side while some mountainous areas were receiving snowfall on the other side. However, the factor of advantageous geographical location is meaningless until and unless the nation and its leaders realize its significance.

Climatically, Pakistan is sited in subtropical zone of the temperate region of northern hemisphere. Its climate is largely subtropical continental type that varies with physiography. It bears the brunt of a hot season which cause high temperatures, heat waves and droughts, and a monsoon season which brings rains and may cause floods. The annual climate cycle of the country is shown in Figure 2.

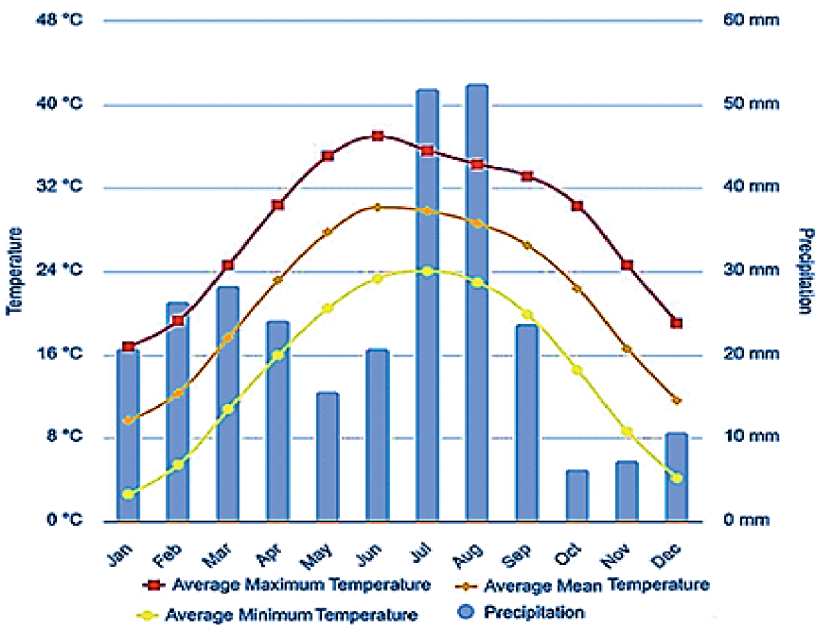

Figure 2: Monthly average maximum, minimum and mean temperature, and precipitation of Pakistan (1991-2022)

Source: World Bank (2021), Climate Change Knowledge Portal

Generally hot and dry conditions prevail near the shoreline and along the Indus lowland plains, and progressively become cooler in the northern highlands. Typically following four seasons are identified;

1. A cool dry winter season prevailing from December to February
2. A warm dry spring season prevailing from March to May

3. A hot summer season from June to August
4. A dry autumn season from September to November

Spanning over the three months of July, August and September, there is a rainy monsoon season, and over two months of October and November is monsoon retreating season.

With the exception of northern region, major part of the country gets very low amount of rainfall. It is the only northern part where monsoons can fetch upwards of 200 mm monthly rainfall from July to September. Inter-annum precipitation differs considerably, often leading to a sequential pattern of floods and droughts. El-Nino is another noticeable factor of climatic variability in the country that cause anomalies in both temperature and flood incidence and other changes associated with the El-Nino cycle (Ward et al., 2013). Figure 3 gives a general idea of the temperature regions of Pakistan. Based on the data for the period from 1901 to 2016 and using UNESCO aridity index (AI) 1979, Ahmed et al. (2019) classified Pakistan into five regions namely, hyper arid (2%), arid (60%), semi-arid (21%), sub-humid (5%), and humid (11%). Their findings about annual aridity conditions reveal that

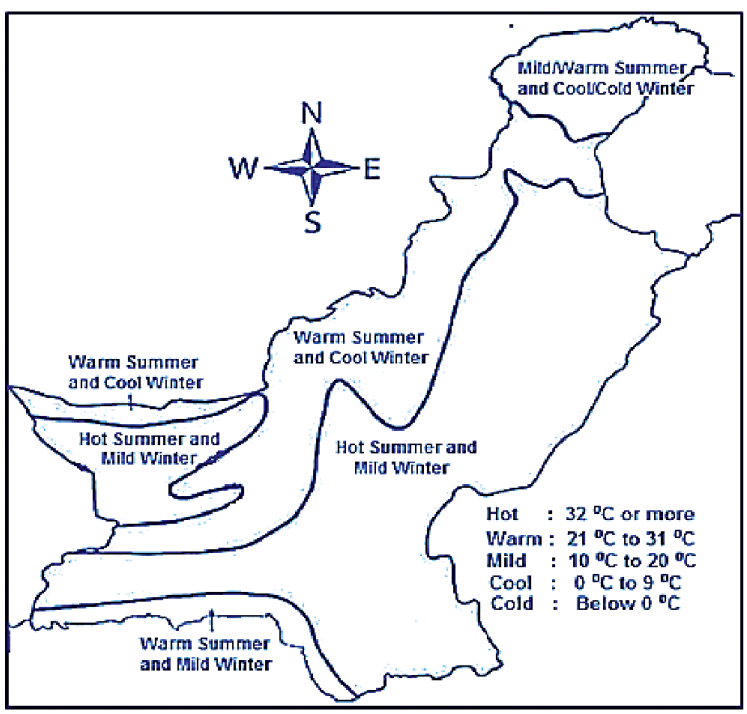

Figure 3: Temperature regions of Pakistan

arid and semiarid climate dominates over the major part of Pakistan (Figure 4). Arid conditions prevail almost all over the southern part and over a small area on the north, while major part of the remaining area is characterized with semi-arid climate. Just 16% area close to foothills of the Himalayas, where precipitation is high is sub-humid and humid. A small area in the extreme southwest is featured with hyper-arid climate where precipitation is very low and the rate of annual evaporation exceeds annual precipitation.

Eastern parts of the country's southern half get rainfall chiefly from summer monsoons in the months of June, July, August and September, whereas the northern and western portions of the southern half get precipitation mostly during winters from western disturbances in the months of December, January and March. The summer monsoons contribute about 60% of the country's aggregate annual rainfall. Almost three-fourth of the country receives below 250 mm of annual precipitation. Indus plains receive about 230 mm of average annual rainfall. Only the southern slopes of Himalayas and the northern sub-mountain region are the exceptions where yearly precipitation ranges from 760 to 2,000 mm. Besides containing some of the world's highest mountain peaks, the northern region also holds largest alpine glaciers of the world like Siachen (70 km long) and Biafo (63 km long) which feed the Indus and a number of its tributaries. In this region, temperature during winters fall to as low as -50°C and during the warmest months of May to September remain around 15°C (McSweeney et al., 2008). The southern and western parts of Pakistan include the Indus basin plains and Balochistan plateau. The Indus basin extends over 520,000 km^2 or 65% of the country's total area, covering the entire provinces of the Punjab and KP, major part of the Sindh, and the eastern portion of Balochistan. The Indus basin irrigation system holds the title of the biggest contiguous canal system in the world, comprising 95% of the Pakistan's whole irrigation system (Chaudhry, 2017).There are significant temperature variations amongst the upper and lower Indus plains. The winter mean temperature of December to February in the upper plains ranges between 2°C to 23°C and in lower plains between 14°C to 20°C, while summer temperatures of March to June varies from 23°C to 49°C in the upper plains and from 42°C to 44°C in the lower plains. The Balochistan Plateau in the southwestern portion of the country is a massive wilderness of mountain ranges with an average altitude of around 600 meter and annual rainfall less than 210 mm (Chaudhry, 2017). A number of seasonal streams cross the plateau but most of its southwestern portion is a vast expense of desert.

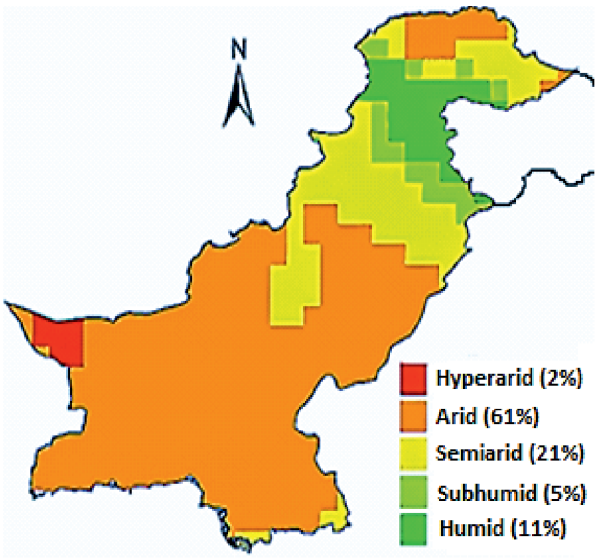

Figure 4: Aridity regions of Pakistan

Source: Ahmed, K. et al., 2019.

All in all, despite many challenges, Pakistan is blessed with a lot of resources. It is indeed, a resource rich country with spectacular landscape, sufficient fertile agricultural land, mineral resources, and human workforce. Name a resource, you can find here, but on the other hand name a disaster you will observe here. That is why the country needs to opt a balanced way of action between the two aspects, the opportunities and the adversities. To play its part in addressing the challenges of CC, Pakistan signed the Paris Climate Treaty (PCT) on November 10, 2016, and established the ministry of CC in 2019. However, due to deficiency of effectual planning and poor resource management, it is still facing the hurdles 'in balancing competing objectives between economic development and environmental protection' (ADB, 2021).

Major findings and discussion

Indicators of CC

It is widely held notion that the earth's climate has been changing since it originated. However, the change was slow until recent times and natural factors were its main cause. The industrial revolution of 18th century was a turning point when the global temperatures have started to increase at a faster pace. Most of the researchers agree

that changes in climate are occurring much faster at present than ever before, which are evident from several indicators (Chaudhry et al., 2009). Rapid CC is a confirmed reality now and its impacts on agriculture and other human activities are quite visible across the globe (Rasul et al., 2012). Figure 5 shows major causes of climate change.

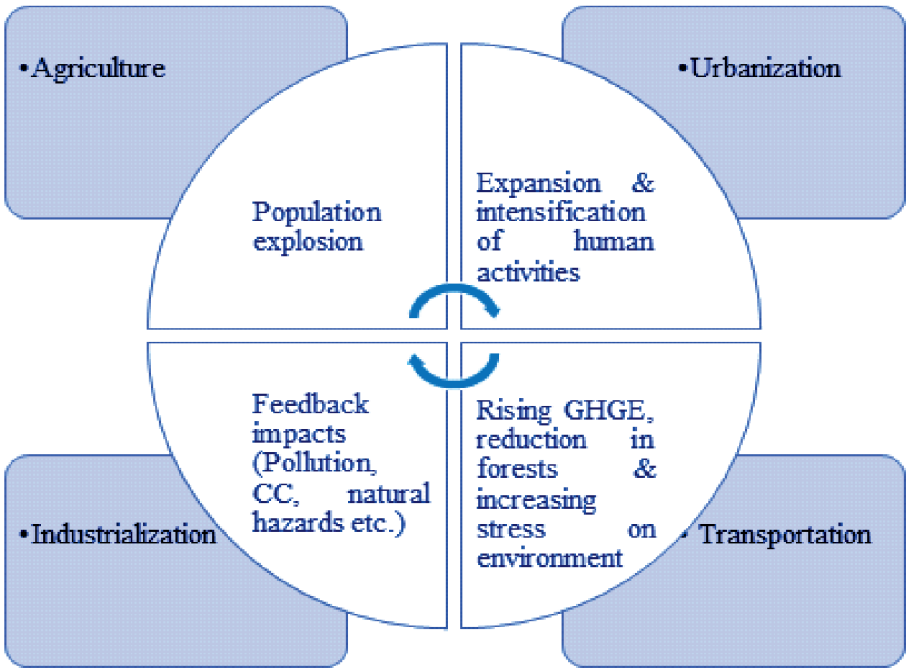

Figure 5: Major causes of climate change

A number of indicators and evidences confirm the present CC, such as;

1. Atmospheric and hydrospheric temperatures are rising causing global warming. Global and regional temperature records evidently reveal a warming trend (Figures 6 & 7).
2. Increasing uncertainty in weather patterns
3. Increasing frequency, duration and severity of heat waves
4. Shrinking of crops growing seasons
5. Increasing frequency, duration and severity of droughts
6. Increasing uncertainty and intensity of rains causing heavy flooding. Heavy and pouring rains of short duration have been observed in Pakistan during last several years particularly in 2010 and 2022.

7. Increasing frequency and intensity of storms and tropical cyclones because of continuous warming of the surface water of seas and oceans.
8. Increase in the melting rate of sea ice and glaciers. GW increases snow melting, which in turn causes further GW through reduction in earth's albedo.
9. Thermal expansion of water bodies and rise in sea level causing dangers for estuarine ecosystems and coastal populations.
10. Permafrost has also began to thaw discharging and adding more methane gas (CH_4) into the atmosphere causing further dangers of global warming (Via, 2023).

All these facts, particularly temperature and precipitation records clearly divulge that substantial changes are taking place in the global and regional climate (Table 2). Temperature data of past several years offer a direct evidence of atmospheric warming (Khan et al., 2024). In case of Pakistan, increasing trend can be clearly detected from the records of average seasonal maximum, minimum, and mean temperature for the period of 1901-2020 (Figures 8, 9 & 10). The seasonal precipitation data of Pakistan for the period of 1901-2020 given in Table 2 also indicate an altering pattern, pointing towards CC. The average seasonal precipitation mostly indicates a rising trend. The summer or monsoon rains also tell an alike trend. While, winter precipitation indicates a mixed pattern.

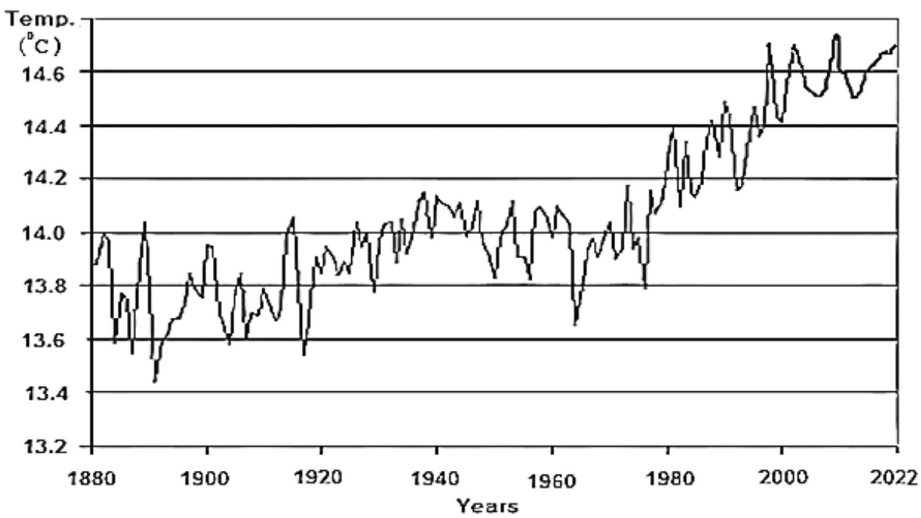

Figure 6: Average global temperature showing a clear rising trend (1880-2022)

Source: GISTEMP Team (2024). NASA Goddard Institute for Space Studies (GISS)

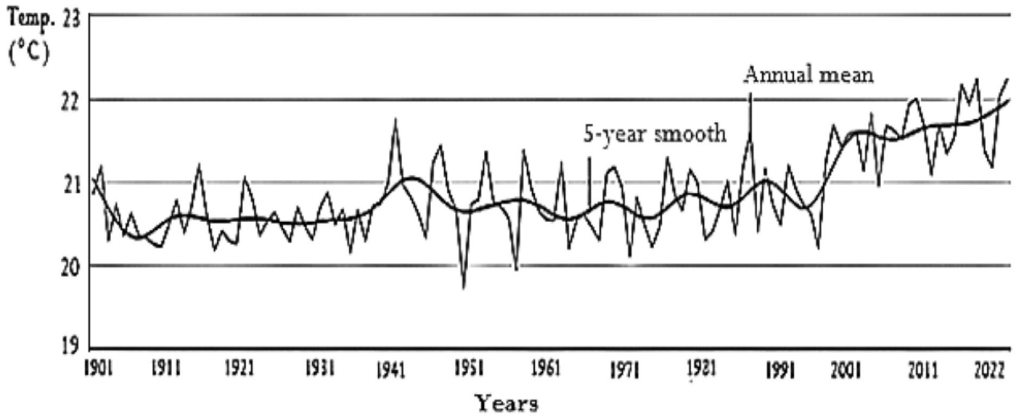

Figure 7: Observed annual average mean temperature of Pakistan (1901-2022)

Data source: World Bank (2021), Climate Change Knowledge Portal, Pakistan.

Due to intensification of industrial, transport, agricultural and other human activities, and deforestation and loss of vegetation, GHGE are increasing causing a continuous rise in atmospheric and hydrospheric temperatures. As GHGs concentrations increase, so does the global surface temperature. Warming of hydrosphere and atmosphere means more evaporation from water bodies, more moisture engrossed by the atmosphere resulting in more cloud development and happening of pouring rains. Some researches mention that more energy in the atmospheric system is driving the storms and clouds further north and southward from the equator, leaving some areas arid that were earlier used to receive precipitation while increasing rains in others (Hussain & Abbas, 2019). However, Pakistan is a special case in this regard due to the existence of the global biggest mountains on its north. The Himalayas would block the clouds from advancing further northward, grabbing them to pour heavier loads of moisture on mountains of the country, ultimately supplying more water to the rivers in rainy season. For this reason, some studies have predicted an increase in the net amount of precipitation in South Asia with changing climate (Hussain & Abbas, 2019). Still, more scientific investigation is needed to explore the matter fully. In the near past, when torrential rains occurred, our rivers got flooded for a short while causing heavy agricultural and other losses and then rapidly lost their volume of water flow touching to almost dead level in the dry season. Destructive floods of 2010 and 2022 which were caused by a number of uncertain spikes of heavy rain of shorter duration are the latest example after which the volume of water in the rivers was declined sharply below

the normal flow (Khan et al., 2024). Under the influence of global warming Pakistan is also getting warmer and rainfalls are becoming more and more uncertain and pouring in nature. Predictions made for future indicate that with CC, intensity and uncertainty of rainfalls in the country may increase further causing floods and droughts in alternate seasons threatening more to agriculture.

Table 2: Pakistan's observed average seasonal maximum, minimum and mean temperature and precipitation

Months/Season	*Periods, each with 30 year time span*			
	1901-1930	*1931-1960*	*1961-1990*	*1991-2020*
Observed average seasonal maximum temperature in °C				
DJF (Winter)	16.51	16.88	16.95	17.55
MAM (Spring)	28.62	28.89	28.82	29.57
JJA (Summer)	35.20	35.12	35.05	35.23
SON (Autumn)	28.16	28.41	28.43	28.94
Observed average seasonal minimum temperature in °C				
DJF (Winter)	2.39	2.76	2.82	3.62
MAM (Spring)	14.12	14.41	14.34	15.36
JJA (Summer)	22.78	22.71	22.64	23.09
SON (Autumn)	12.90	13.17	13.18	14.01
Observed average seasonal mean temperature in °C				
DJF (Winter)	9.43	9.80	9.87	10.57
MAM (Spring)	21.35	21.63	21.56	22.44
JJA (Summer)	28.96	28.89	28.82	29.14
SON (Autumn)	20.51	20.77	20.78	21.45
Observed average seasonal precipitation in mm				
DJF (Winter)	45.71	55.58	43.96	48.85
MAM (Spring)	63.20	67.09	71.70	70.72
JJA (Summer)	117.67	121.41	128.53	127.72
SON (Autumn)	32.20	29.46	32.97	38.57
Note: DJF = December, January, February; MAM = March, April, May; JJA = June, July, August; SON = September, October, November				

Source: World Bank (2021), Climate Change Knowledge Portal.

In the last five decades or so, the annual mean temperature of Pakistan has risen by approximately 0.5°C. The frequency of heat wave days per annum has augmented by almost five-times in the last three decades. Annual precipitation generally has shown great variability with a slight upsurge in the preceding 50 years. The sea level along the coast has risen around 10 cm in the previous century (Chaudhry, 2017).

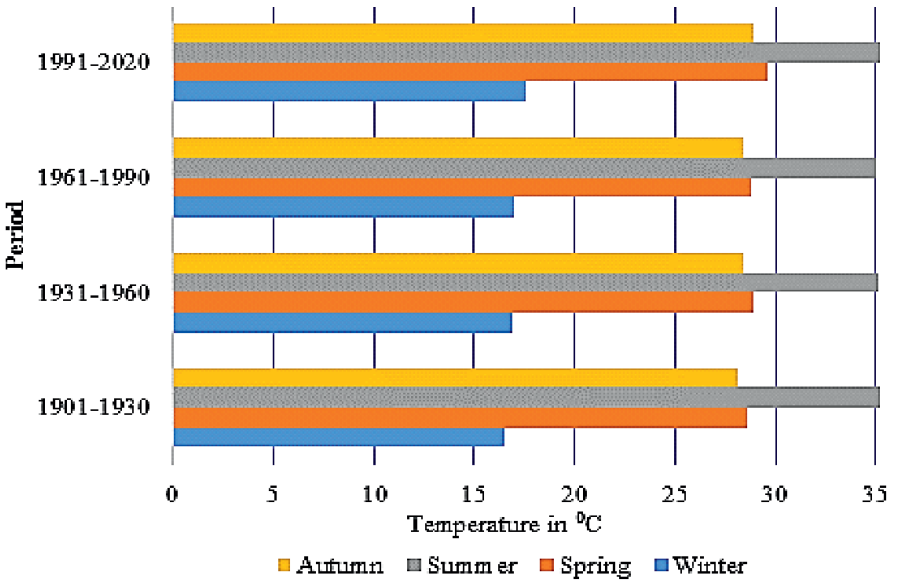

Figure 8: Observed average seasonal maximum temperature of Pakistan

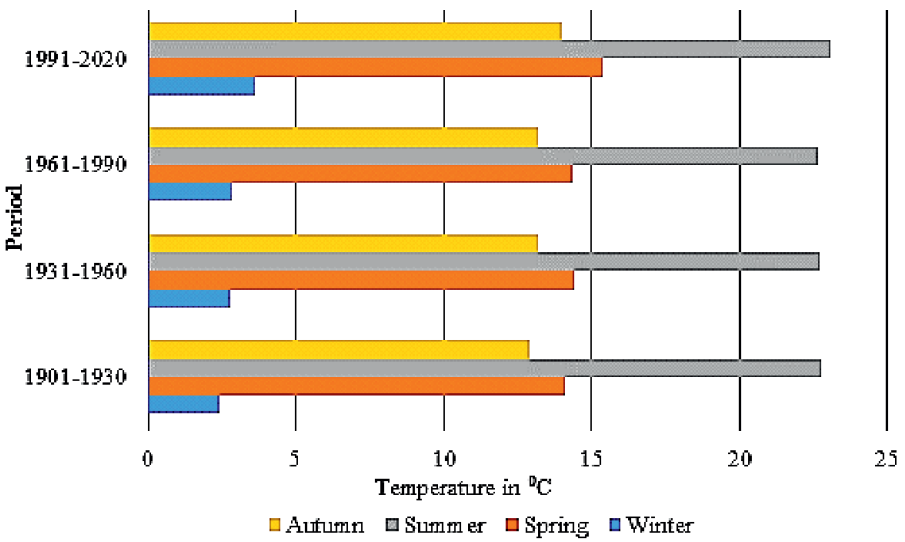

Figure 9: Observed average seasonal minimum temperature of Pakistan

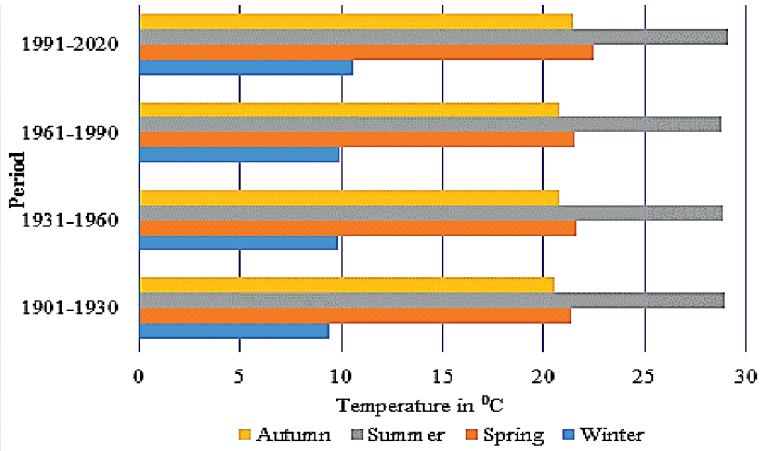

Figure 10: Observed average seasonal mean temperature of Pakistan

Future predictions indicate that by the closure of current century, Pakistan's annual mean temperature is likely to increase by 3°C to 5°C for the central global emission scenario, whereas higher world emissions may result an increase of 4°C to 6°C. The average annual precipitation is not likely to have a considerable long term trend, but is anticipated to show high inter-annum variability. The sea level is anticipated to upsurge by an additional 60 cm by the completion of the current century and is most likely to intrude Indus River delta and low-lying coastal areas (Chaudhry, 2017). In future CC context, Pakistan is likely to face more inconsistency of river flows because of augmented variability of precipitation and glacial melting. Due to increased rates of evaporation, demand for irrigation may increase further. Wheat and rice yields may decline and cultivation might be driven northward subject to water availability. Warming of air and water, rise in sea level and storm surges may harm infrastructures, and agriculture and other livelihoods, specifically in coastal areas of the country.

4.2. Challenges of CC threats to agriculture

Recently, CC has become a big challenge for agriculture sector of Pakistan. Spreading over an area of 30.5 million hectares, almost 47% of the national area is classed as agricultural land, which is more than the world average of 38% (FAO, 2023). Nearly 70% of Pakistan's exports are directly or indirectly obtained from agriculture. In this sector, livestock has leading share of about 62.68% (14.36% in GDP), followed by crops 32.72% (7.5% in GDP), forestry 2.23% (0.51% in GDP), and fisheries 1.39% (0.32% in GDP) in agriculture value addition. In the fiscal year 2022-23, agriculture

employed 37.4% of the country's workforce and contributed 22.91% of the GDP (GoP, 2023). There are two main cropping seasons *Rabi* and *Kharif* in the country, with overall water availability of 72.7 MAF (FAO, 2023). Above 80% of the country's cultivable land is irrigated and below 20% is rain fed (Chaudhry, 2017). Around 60% of the rain fed (*barani*) areas are used to grow *Rabi* (winter) crops such as, wheat, gram, barley, rapeseeds, lentils, and canola mustard. Pakistan's five topmost crops are wheat, rice, maize, cotton and sugarcane.

Table 3 and figure 11 show the year to year fluctuations in the area and output of these crops produced chiefly by subsistence growers without much care of agricultural land causing its degradation. The two main staple crops are wheat and rice that cover 37% and 11% of the total cropped area respectively. Cotton and sugarcane are the two main cash crops that contribute significantly to the country's GDP. Pakistan is world's 5th biggest producer of cotton. The crop production and processing related activities contribute about 10% to GDP and 30% to country's farmer's employment, a lot of which are rural womenfolk (ADB, 2021). The country had approximately 225 million livestock heads of worth Rs. 5.5 trillion in 2023. Pakistan is also the world's 5th biggest milk producer with a gross yearly production of 67 million tonnes, and 4th biggest exporter of leather articles earning about US$950 million per year (FAO, 2023).

Table 3: Area under major crops and their production in Pakistan

Year	*2018-2019*	*2019-2020*	*2020-2021*	*2021-2022*	*2022-2023*
Wheat (area in 000 hectares & production in 000 bales)					
Area	8,678	8,805	9,168	8,977	9,043
Production	24,349	25,248	27,464	26,208	27,634
Rice (area in 000 hectares & production in 000 tonnes)					
Area	2,810	3,034	3,335	3,537	2,976
Production	7,202	7,414	8,420	9,323	7,322
Maize (area in 000 hectares & production in 000 tonnes)					
Area	1,374	1,404	1,418	1,653	1,720
Production	6,826	7,883	8,940	9,525	10,183
Sugarcane (area in 000 hectares & production in 000 tonnes)					
Area	1,102	1,040	1,165	1,260	1,319
Production	67,174	66,380	81,009	88,651	91,111
Cotton (area in 000 hectares & production in 000 tonnes)					
Area	2373	2,517	2,079	1,937	2,144
Production	9,861	9,148	7,064	8,329	4,910

Source: GoP, 2023, Pakistan Economic Survey 2022-23

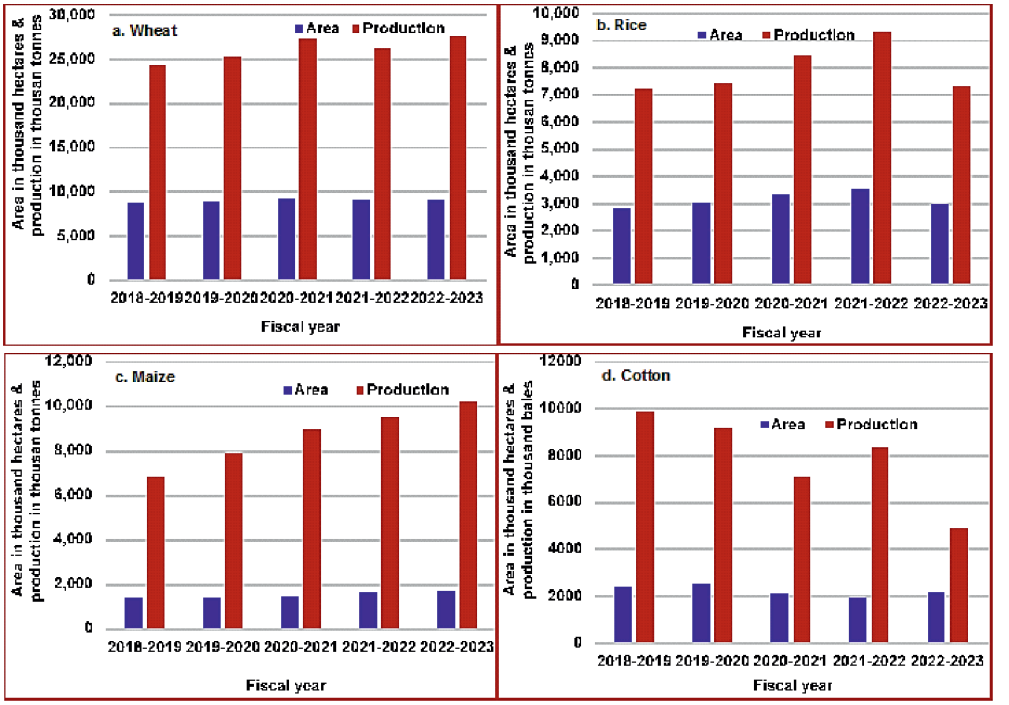

Figure 11: Year to year fluctuation in the area and production of major crops due to CC

While the areas like Pakistan with poor governance, more poverty, and dearth of access to basic services are highly vulnerable to CC threats. Growing population, dwindling forests and global increase in GHGE are playing basic role in CC in Pakistan. In such areas, farmers, pastoralists, and fishing communities are at high risk of CC effects. Climate is a key factor in agriculture because it determines the kinds of crops that can be produced in a specific region. Temperature, precipitation patterns, soil moisture, atmospheric humidity, and length of growing seasons, all affect agricultural yields. Pakistan's agriculture is facing several challenges of CC threats. During last some decades, the impacts of extreme climate events have raised multifaceted issues for this sector. The most perilous are following;

1. Heat waves, high rate of evaporation and rising water demands for crops and livestock
2. Productivity losses due to water shortage and shrinking of the span of growing season
3. Agricultural losses caused by aridity, droughts and desertification

4. Agriculture infrastructure, crops and livestock damages caused by floods
5. Soil erosion and loss of arable land due to flash floods
6. Farmland conversion due to high production cost and low earnings from agriculture
7. Sea water encroachment and loss of deltaic and other coastal lands
8. Farmer's health issues and reduction of their efficiency

Agricultural production is influenced by direct and indirect effects of CC on growth processes of crops. Its major direct effects include changes in temperature, precipitation patterns, and CO_2 availability. The foremost indirect effects include alterations in the availability and seasonality of water resources, soil erosion, soil organic substance transformation, alterations in the nature of pests and diseases, the entrance of non-native species, and shrinkage of agricultural lands due to desertification, submergence of coastal areas, and low returns. Such impacts are likely to impair yields of major staple crops not only on local or regional level but also on global level. An experimental study conducted by Tebaldi and Lobell has estimated a decline of 5% in world's wheat and 6% in maize production even if the requirements of PCT of 2015 are met and warming is controlled to 1.5°C (Tebaldi & Lobell, 2018). Almost alike can happen with others crop yields also. Future predictions indicate that by the year 2040, as the temperature rises, the agricultural yields will decrease by about 8% to 10% (Cradock-Henry et al., 2020). Another, and perhaps less highlighted impact of CC on agricultural output is via its effect on the health and productivity of agricultural workers. A study indicates that agricultural workers productivity during peak months has already decreased by 10% due to warming and is likely to drop further 10% by 2050 (Dunne et al., 2013). It is thus, very likely that all these parameters and processes jointly will have a substantial effect on national food supply and consumption patterns both via direct effects on internal agricultural practices, and via effects on the worldwide supply chain (ADB, 2021).

The damages caused by heat waves, droughts, water shortage, changing precipitation patterns and floods to main staple, cash and other crops production, and livestock are of particular concern for Pakistan. Temperature is continuously rising and precipitation pattern is changing over time. A rise of 1.4°C to 3.7°C in temperature is projected in near future in the country. This will increase incidence of uncertain and heavy rains, rapid glacial melting, and flash flooding. Previous

studies reveal that crops grown in Pakistan are exceedingly sensitive to temperature changes, extreme heat waves and water availability (Mustafa et al., 2021). Rising temperatures are causing an increase in water demands which are also aggravating water distribution and management issues in the country. Even minor alterations in precipitation patterns for long periods can change the crop production in Pakistan by putting more pressure on the sources of irrigation water. A rise of 0.5°C to 2.0°C in temperature could result about 8% to 10% drop in yields (Dehlavi et al., 2015). The frequency of days with temperature over 35°C is predicted to increase in future. With the exemption of northern mountains region, projected falls in yields are widespread, particularly for five leading crops mentioned in Table 3 (Yu et al., 2013; Chaudhry, 2017). Although, the impacts of CC on livestock are less clear and more studies are required in this regard, the droughts from 1999 to 2002 in the Sindh and Balochistan provinces took a death toll of about 2 million animal heads and necessitated the emergency aid of drinking water and feed for farming populations. Likewise, the prolonged drought period between 2015 and 2017 caused serious damages when the livestock production was fell by 48% in the severely affected districts (FAO, 2023). This alarming situation was an indication towards the potential danger of future upsurges in drought frequency and associated damages to livestock production. For this reason, research based further measures are required to be taken to provide more certainty in future trends of the country's water resources.

On the other hand, floods are also equally damaging to our agriculture as they inundate fertile areas, destroy livestock, demolish crops, and cut down yields. This was witnessed in the massive flood of 2010 when about 2.4 million hectares of standing crops of cost around US$ 5.1 billion were destroyed (FAO, 2023). Then in July and August 2022, Pakistan faced another record episode of pouring rains followed by massive flash flooding that ruined crops, livestock and everything in its way. It crumbled lives and livelihoods of the inhabitants, specifically those residing in rural areas and depending on agriculture. Although, the provinces of Sindh and Baluchistan were worst affected, about 33 million people in 94 districts across the country were affected, 1,700 lives were lost, and 7.6 million people were displaced (GoP, 2023). The impacts on critical agricultural infrastructure, standing crops, grain storages and animals were devastating. Around 4.4 million acres of standing crops were destroyed and one million animals were lost. Overall losses amounted to about US$ 30.13 billion, of which agricultural losses were US$ 12.9 billion (43% of the total). In total agricultural losses and damages, share of crops was 82%, livestock

7%, and fisheries 1% (GoP, 2023). Such kinds of threats associated to CC are a big challenge for the country in future as well.

In sum, it is an established fact that with CC there will be grave impacts and implications on farming. Although, the magnitude of these impacts is uncertain, but there is an agreement among the researchers that some effects are definite. Such as, all areas will become warmer; soil moistness will drop with rising temperatures, and evapotranspiration leading to sustained drought conditions in some places and flooding in other places where rainfall intensity increases; and sea level will upsurge with thermal expansion and rapid glacial melt. All such influences are severe and are anticipated to further aggravate diminishing interest of farmers in agriculture across the country. For such reasons, high priority is required to be given to address the potential CC impacts and adaptation needs in this sector. The situation accentuates the need to effectively deal with these challenges, which demand more than urgent consideration.

4.3. Challenges of CC threats to food security (FS)

Realistically CC is inevitable and poses big threats to food supply (Devendra, 2012). In Pakistan, CC is a direct threat to food production (Malik, 2022). As per FAO definition "when all people, at all times, have physical and economic access to sufficient, safe, and nutritious food for a healthy and active life" they are said to be food secure (FAO, 2003). According to FAO (2009), FS involves four dimensions, availability, stability, affordability and utilization, all are affected by CC (Figure 12).

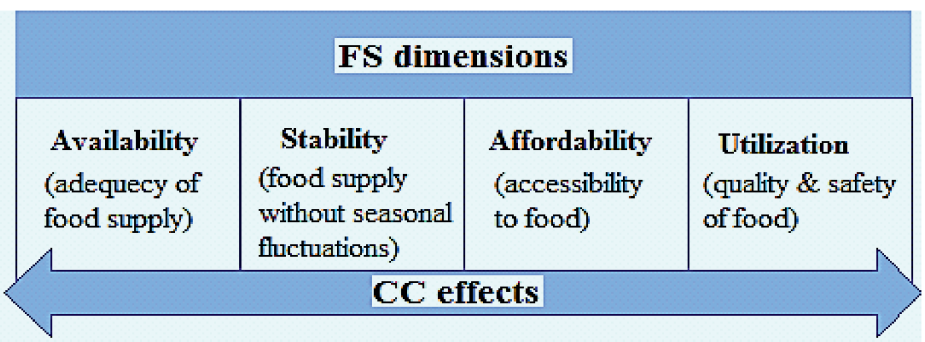

Figure 12: Food security dimensions

In Pakistan, agriculture not only ensures FS but also supplies raw materials to the industries. It is also one of the major sources of foreign exchange earnings.

According to a report of UN Economic and Social Commission for Asia and the Pacific (ESCAP), Pakistan could lose about 9% of its annual GDP because of CC (UN-ESCAP, 2022; DAWN, 2022). Extreme weather events of heat waves, droughts, untimely rains and floods have badly affected our agricultural production. These events are posing big threats to FS through stunting crop yields and reducing the availability and affordability of food.

Furthermore, CC shockingly affects the livelihoods and health of farmers and poor and vulnerable communities. It is instigating food insecurity (FI) not only in Pakistan but also across the world. According to FAO, crop losses caused by 2010 floods in Pakistan amounted to US$ 4.5 billion (Abbasi, 2022). Similarly, a loss of US$ 3. 725 billion in agriculture was caused by 2022 floods. A fall of 41% in cotton and 21.5% in rice production was observed (FAO, 2023). The production of gram, sorghum (jowar) and barley declined by 24.7%, 23.4% and 2.6% respectively (GoP 2023). Due to loss of homes and livelihoods, an increasing number of people have started shifting from villages to cities detaching themselves from agriculture. Many of such movers, which are also called as 'climate refugees' or 'environmental refugees', are unskillful and start working as minimum-wage labor, again serving miserable life.

Besides, extreme weather patterns are disturbing crop sowing and harvesting timings. It has been noted that heat waves have decreased the production of staple crops, particularly of rice and wheat in many areas. A combination of heat and droughts has dwindled the average output of wheat, maize, soybeans and other crops. Due to heavy reliance of the country's economy and rural population on agriculture, the losses in this sector have spillover effects particularly on livelihoods, poverty levels and FS. The results of Integrated Food Security Phase Classification (IPC) survey performed in April 2023 by FAO and IPC partners for 43 flood affected districts of Sindh, Baluchistan and KPK revealed that nearly 10.5 million people (29% of the rural inhabitants) were food insecure, while the number was estimated to increase to 11.81 million (32% of the rural inhabitants) from November to January 2024 (FAO, 2023).

As Pakistan is highly vulnerable to CC impacts, through affecting agriculture, alterations in climate ultimately adversely affect socio-economic conditions of its inhabitants, making them food insecure. Pakistan is already facing a big challenge of high poverty rates and hunger. CC is one of the main causes of poverty and hunger. It has raised the consumption and prices of energy resources and other agricultural

Table 4: Selected indicators of socio-economic conditions of population

Sr. No.	*Indicators*	*Value*	*Data source*
	GDP of Pakistan in 2022	374.70 billion US$	World Bank Data, 2022
1.	GDP of Pakistan in 2023	340.64 billion US$	GoP, Pakistan Economic Survey, 2022-23
2.	HDI in 2023-24	0.540	UNDP, 2024
3.	Global ranking of Pakistan on HDI in 2023-24	164 out of 193 countries	UNDP, 2024
4.	Poverty rate in 2023	39.4%	Source: World Bank, November 2023
5.	Ranking of Pakistan on PI	52	Source: World Bank, 2023
6.	GHI score of Pakistan in 2023	26.6	Source: Concern worldwide & Welt Hunger Hilfe (WHH), 2023
7.	Ranking of Pakistan on GHI	102 out of 125 countries	Source: Concern worldwide & Welt Hunger Hilfe (WHH), 2023
8.	Food insecure households	13%	FAO, 2023
9.	Food insecure population	37%	FAO, 2023

Note: GDP = Gross Domestic Product, HDI = Human Development Index, PI = Poverty Index, GHI = Global Hunger Index.

inputs making food production more expensive. Rising food and energy prices are pushing more and more population into the poverty trap. The people living under the poverty line (earning 3.6 US$/day) have reached to 39.4% in 2023 (World Bank, 2023). Increasing poverty rates reduce food purchasing capacity of the people giving birth to FI and hunger. The indicators given in Table 4, particularly the global hunger index (GHI), also indicates that the socio-economic conditions of the inhabitants of Pakistan are not too pleasing and many people are food insecure. FI refers to the inability of people to constantly meet nutritional and caloric requirements. It leads to hunger, which is measured by the prevalence of undernourishment.

GHI is an established metric for assessing FI in developing countries like Pakistan. It is frequently used as tool to assess and track the hunger at world and country level. It tells about food availability, nutritional status of children, and child mortality attributed to under-nutrition. In this study, it has been used as an indicator to estimate FS situation. Figures 13 & 14 show Pakistan's GHI indicators value score and GHI score trends respectively. Though, a decreasing trend of GHI of Pakistan revealed, but it is still high enough indicating a worst situation of FS in the country. In 2023, Pakistan's 13% households and 37% population was recorded

as food insecure (Table 4). According to GHI of 2023, Pakistan ranks 102 out of 125 countries (for which GHI was computed) with a GHI score of 26.6, indicating a level of hunger categorized as 'serious' (Figure 15). Pakistan's position among world countries by 2023 GHI is also shown in Figure 16.

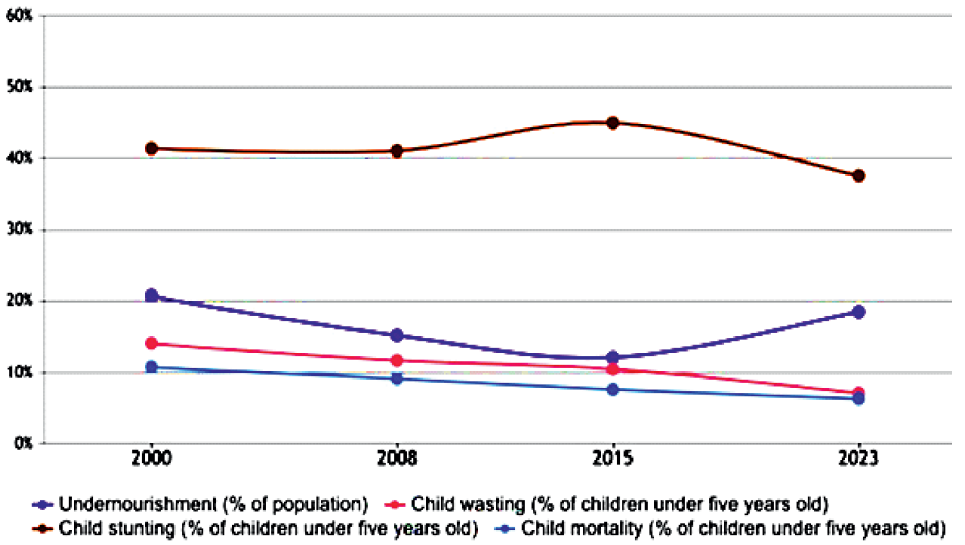

Figure 13: Pakistan's GHI indicators value score trends

Data source: WHH, 2023.

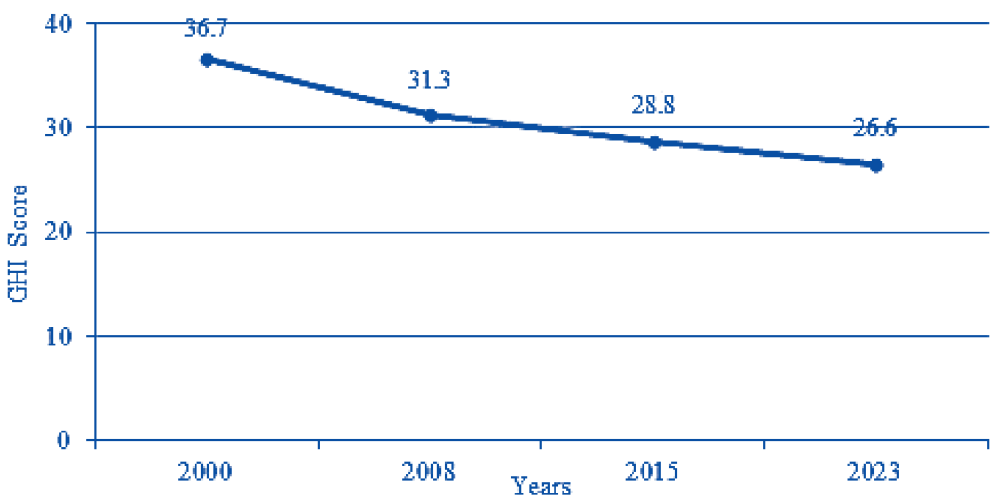

Figure 14: Pakistan's GHI score trend

Data source: WHH, 2023.

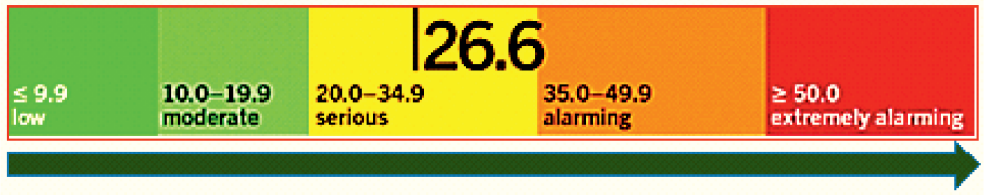

Figure 15: Pakistan's hunger index score in 2023

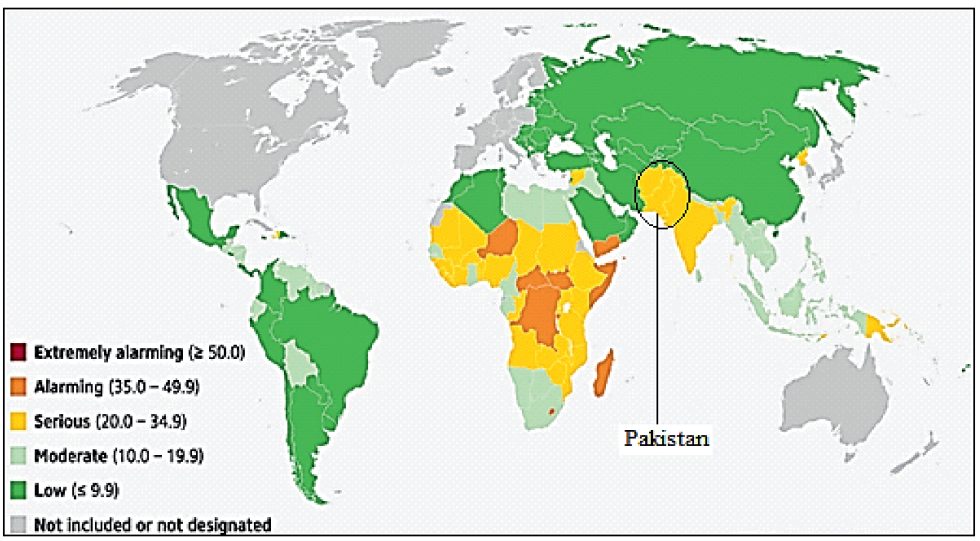

Figure 16: Pakistan's position among world countries by 2023 GHI

Source: Concern Worldwide & Welt Hunger Hilfe (WHH), 2023.

4.4. Suggested adaptations to reduce the impacts of CC threats to agriculture and FS

Since agriculture and FS are highly threatened by CC, ensuring FS at national level should be a top priority of the government. **S**everal adaptation measures, hitherto, have been suggested by the researchers and concerned departments to reduce the impacts of CC threats to agriculture and FS (Chaudhry, 2017). Most of the researchers, however, agree that the role of agricultural production system can be crucial in making sure FS. That is why, adaptation to climate smart agriculture (CSA) strategies have become vital for FS in Pakistan (Ramay, 2022). A number of adaptation measures including the development and cultivation of crop varieties with more resistance to CC, opting late sowing according to shifting of seasons, introduction of efficient farming and irrigation methods have been mentioned in

Table 5 for the agriculture of Pakistan, specifically in the context of present CC impacts. The risks of losses can be reduced further by adjusting the routine economic activities in accordance with the CC.

Table 5: CC threats and proposed adaptation strategies for Pakistan's agriculture sector

Sr. No.	*CC threats*	*Suggested adaptation technologies/measures*
1.	Fall in crop output because of heat stress and rise in temperatures	Introduction and usage of crop varieties with more tolerance against heat and droughts like mustard Switching to delayed cultivation/opting late sowing
	Shortage of water due to scanty rainfall and augmented evapo-transpiration induced crop-water needs, especially in rain fed arid areas	
2.	Irregular and unpredictable and sometime un-seasonal precipitation patterns severely upsetting crop yields	Practice efficient irrigation methods (Such as drip and sprinkler irrigation) upgrade the irrigation water supply systems to reduce delivery wastages losses Use laser land leveling to cut water losses
	Decline in accessible irrigation water because of altering precipitation patterns and rising demand	
3.	Declining quantity and quality of groundwater because of excessive pumping which is adversely influencing crop yields and fertility of soil	Upgrade integrated water management scheme along with necessary legislation and backed by awareness increasing campaigns
4.	Augmented rate of recurrence and intensity of hazardous climatic events of heat waves, droughts, flooding and storms causing wide-ranging harms to agriculture and livestock sectors	Development of enhanced multi-hazard prompt warning systems
5.	Lack of understanding how CC is affecting availability of water for agriculture & crop production	Carry out awareness-raising campaigns for the farmers & policy designers to create appropriate and enough understanding of the issue
6.	Increase in saltwater incursion, especially in the Indus delta because of dropped freshwater supplies	Improve water management to ensure required freshwater supplies for maintaining a healthy ecosystem in the area.
7.	Impacts of sea level rise and storm surges on coastal areas	Adopt both hard (technological) and soft (ecological) preventive measures to offset the effect of sea level rise and storms, such as construction of dikes & sea walls, and increase in vegetation cover

Source: Chaudhry, 2017; Asian Development Bank (ADB), 2014.

In addition, launch of effective awareness-raising programs among all the stakeholders about the impacts of CC and accordingly adjustment options, and

development of efficient warning systems are necessary to minimize the losses. More importantly, protection of arable land from erosion and particularly from conversion into non-farm uses due to low-farm incomes is essential for sustainable agriculture and for future FS.

Conclusion

The study concludes that rising temperatures, altering precipitation patterns, and other indicators corroborate an evident CC in Pakistan. The findings establish that the country is highly prone to negative impacts of CC and potentially threatened by several big challenges, particularly with respect to its water, agriculture and other resources, and FS. These challenges are tuning to be graver over time. Thus, there is an urgent need to deal them in an effective manner before further worsening of the situation by the deadly combination of changing climate and expanding population. There is almost a consensus that CC cannot be completely stopped, but it can be certainly decelerated and its associated challenges can be tackled. What we need is a strenuous endeavor by the government and people at all levels of the chain. In this regard, a unified approach can provide ample help, which may include introduction of heat and drought resilient crop varieties, remodeling of irrigation infrastructure by using water saving technologies, construction of more water storages, integrated management of catchment areas, reforestation of drainage basins, building of dikes, and further advancing weather forecasting and early warning systems. However, to avoid the hazardous consequences of CC, 'net zero' CO_2 emission is required to be achieved sooner. This means, on balance, no more CO_2 is deposited into the air than is taken out. Initiation of reforestation and afforestation programs, banning substandard vehicles, and switching on to the usage of renewable means of energy are some of viable and effective measures required to be taken immediately. Use of energy is an important input and component of agricultural activity. Low cost energy is required for variety of agricultural uses such as for the operation of farm machinery, pumping water, ploughing land, and so on. For this reason, diversification of energy mix including development of renewable energy resources and small hydroelectricity projects should also be a part of integrated approach. But, it must be kept in mind that there is no shortcut to deal the climate extremes, and only some relief can be given to the susceptible populations in terms of mitigation, adaptation, and capacity building. Following bottom-up approach, capacity building of endangered communities can help them get ready and adjust to climate extremes

and anomalies. Farmer's capacity to adapt to CC is crucial so that crop yields are not affected sizably. Empowerment of local communities is also important so that they can contribute and provide information in local milieu. Climate finance can be used for this purpose and the National Disaster Management Authority (NDMA) can play a vital role in this regard. Pakistan should also urge advanced countries to fulfil the promise of arranging funds for developing countries under the PCT. When CC related disasters happen, transportation, food, water, and safe temporary camps become essential and immediate need of the affected people which must be provided on emergency basis. For all this, honesty and good governance is a key factor. Given all these facts, following suggestions are made;

The key mitigation strategy includes reduction of GHGE from industrial, transport, agriculture and other sectors. Agriculture related mitigations in biological terms include, reduction in fertilizer associated emissions, CH_4 discharges from rice paddies, emissions from land-use changes, seizing carbon in agro-ecosystems, and using fossil fuel substitutes. All countries in general and advanced industrial countries in particular should play their clear-cut role in reducing GHGE.

Adaptation of sustainable forest management strategies is essential to lessen the hazardous impacts of GHGs and associated CC. Role of forests is critical in CC, as they eat-up CO_2 and other heat trapping GHGs. By seizing these gases in tree masses, forests stop them from contributing to GW.

A Shift towards the use of renewable energy is also important to minimize GHGE. World nations should prepare a joint and effective strategy for this purpose.

Adapting resource conservation strategies and promoting wise use of resources can help to minimize the risks of CC. The Islamic principles about the protection of environment and resource use can also be followed as guiding lines, such as 'The earth is green and beautiful and Allah has appointed you curators over it', 'plant and protect trees' and 'do not waste water even if you are at the bank of a river'.

Adaptation of recommended technologies and climate smart agriculture is an important need of the time. Some details of such measures are given in Table 5 and Figure 5.

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