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Research Article

Correlation Between Climate Change and Wheat Yield and Biomass: A Literature-Based Analysis in Pakistan

Muhammad Abdul Rehman[1*], Maria Anwar[2*], Fatima Siddiqa[3], Mumtaz Ahmad[1], Waseeful Hassan[1], Muhammad Usman[1], Muhammad Huzaifa Mahmood[4], Aziz Ur Rehman[5]

[1] Department of Commerce, The Islamia University of Bahawalpur.
[2] Department of Environmental Science, Bahauddin Zakriya University Multan.
[3] Institute of soil and environmental sciences, University of Agriculture Faislabad.
[4] Department of Agricultural, Forestry and Food Sciences, University of Turin, Largo Paolo Braccini, 2, 10095 Grugliasco, Italy.
[5] University: Government College University, Lahore.

ABSTRACT

Climate change as a global menace is threatening the world food security and wheat crop is extremely sensitive to temperature and precipitation changes. Wheat is a basic crop that plays a significant role in Pakistan's economy and diet. However, particularly at the regional level, it is still difficult to quantify how climate change is affecting wheat output and biomass. By examining the relationship between climate factors (temperature and precipitation) and wheat productivity (yield and biomass) in five significant wheat-growing cities in Pakistan-Lahore, Faisalabad, Multan, Peshawar, and Quetta-this study fills this research vacuum. This study's goal was to use a literature-based dataset for 2021 and 2022 to assess the association between wheat productivity and climate change. We gathered information from government publications and peer-reviewed research on biomass, wheat yield, annual and growing season precipitation, and mean annual and growth season temperature. The association between climate factors and wheat productivity was examined using Pearson's correlation coefficient. The findings showed a substantial negative relationship between temperature and biomass (r = -0.99) and wheat yield (r = -0.99), suggesting that rising temperatures have a major detrimental impact on wheat production. On the other hand, a substantial positive association between precipitation and biomass (r = 0.99) and yield (r = 0.99) underscored the significance of receiving enough rainfall. All cities saw decreases in biomass (2.17–3.85%) and wheat yield (2.86–3.57%) year over year, with Multan and Quetta experiencing the worst drops. This study concludes by highlighting the negative effects of climate change on Pakistan's wheat production and the necessity of using climate-resilient farming methods. The results give farmers and policymakers a scientific foundation for implementing adaptable practices, such better water management and heat-tolerant cultivars, to ensure food security in a changing climate.

Keywords: Biomass, Climate Change, Correlation Analysis, Precipitation, Wheat Yield.

Correspondence
Muhammad Abdul Rehman
marehman1992@yahoo.com
Maria Anwar
mariadoger85@gmail.com

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INTRODUCTION

Global warming, together with profound consequences for ecosystems, economies, and *homosapien* sources of income, is one of the most serious global challenges in the 21st century. Husbandry, which is highly dependent upon climatic conditions for optimal productivity, is among the most exposed sectors to climate variability. Wheat, as a basic food crop, plays a key role in global food security, particularly in progressing Islamic Republic of Pakistan, where it functions as a main base for calories and nutrition for a myriad of individuals (Sajjad et al., 2024; Grote et al., 2021). However, the increasing frequency of extreme weather patterns, rising temperatures, and unforeseeable rainfall is associated with climate change as significant threats to wheat production (Malhi et al., 2021). Knowledge of the relationship between climate change and wheat production and biomass is therefore important for the development of adaptive strategies to mitigate the negative effects on food security and agricultural sustainability (Yanagi et al., 2024). Pakistan, an agrarian economy, trusts its agricultural sector, which contributes approximately 19% to the country's GDP and uses approximately 28.8% of the labor force. Wheat is the most commonly grown crop in Pakistan, which accounts for over 60 percent of the total daily energy consumption of its inhabitants (Shar et al., 2021). Regardless of its relevance, wheat production in the Islamic Republic of Pakistan faces a number of challenges, including water shortage, soil degraded, and increased impacts of climate change. The country is particularly exposed to climate variations due to its geographical location, as well as to a predominantly arid to semi-arid climate and heavy dependency on the Indus River framework for irrigation (Ahmad et al., 2021). Recent investigations point out that wheat production is already being affected by rising temperatures and changing precipitation forms, together with potential findings on food security and rural careers (Kassaye et al., 2021).

The value of this study lies in its priority to provide insight into the relationship between the climate crisis and wheat production in Pakistan, a region that has been a focus of the global discussion on climate and agriculture (Ali et al.2023). During a number of studies on the influence of climate change on crop output worldwide, perhaps a useful detour in the literature on regional analysis, especially in the South East Asian Pacific. The unique agroclimatic situation of the Islamic Republic of Pakistan, together with its socio-economic dependence on wheat, constitutes crucial situation analysis to understand how climate change influences the production of staple crops in developing countries (Noor et al.; Ikpe, 2021) This study seeks to fill that pause by providing a comprehensive literature review on the relationship between climate change and wheat production and biomass in Pakistan. The current study is motivated by the pressing need to overcome the obstacles posed by the climate crisis for agricultural productivity and food security. Wheat production in Pakistan is already under strain due to a combination of components including society growth, urbanization, and asset restrictions (Ahmed et al., 2024). Global warming's encroachment on agricultural production structures is exacerbated by further unpredictableness of agricultural production. For instance, rising temperatures may accelerate the evolution of the plant, thereby reducing grain filling cycles and low yields (Farooq et al., 2023). As a consequence, erratic rainfall patterns may affect water stress during crucial expansion stages, further compromising crop productivity. The present analysis seeks to synthesize the current understanding of the impacts of global warming on wheat production and biomass, identify critical comprehension gaps, and provide policymakers and farmers with evidence-based recommendations (Raihan, 2024).

The current study goes further than collegiate research. It has practical results in terms of agricultural systematic planning, policy development, and climate change approaches in Pakistan. Knowledge on the impacts of climate change on wheat production is essential for the development of appropriate interventions as the nation seeks to achieve food safety and ecologically sound growth objectives (Arif et al., 2024). The current analysis contributes to the wide debate on climate-smart farming by highlighting the need for a region-specific analysis and a tailored modification approach. Moreover, it stresses the importance of integrating scientific expertise with local crop cultivation methods to increase strength and guarantee long-term food production in the face of the climate crisis (John et al., 2023). Nevertheless, in the background of the Islamic Republic of Pakistan, the growing literature on climate change and agriculture remains a significant research area. A number of existing studies focus on planetary or regional trends and often neglect the local impacts of climate variations on specific crops. Furthermore, a study on the combined effects of temperature, precipitation, and other climatic variables on wheat production and biomass in the Islamic Republic of Pakistan should be restricted. , 2023). The present study addresses this gap by organizing a systematic review of the available literature, which may be false or false, with a focus on identifying the form, movement, and incompatibility of the conclusions. The implementation thus provides a more nuanced understanding of the complex interactions of global warming and wheat production in the Islamic Republic of Pakistan.

The main objective of the present inquiry shall be to examine the relationship between global warming and wheat production and biomass in Pakistan through literature method. In particular, the objective shall be to examine the existing literature on the impacts of climate change on wheat production in the Islamic Republic of Pakistan; (2) identify the central climatic elements affecting wheat production and biomass; (3) assess the extent to which climate change has affected wheat productivity in the region; and (4) draw up the implications of these conclusions for agricultural policy and practice. In achieving those objectives, the inquiry seeks to provide a comprehensive overview of the current state of information on the subject and forecasts the results of the forthcoming analysis and action. The manuscript is structured as follows: part 2 provides a detailed appraisal of the literature which can be both fictitious and non-fictitious in relation to the climate crisis and wheat production, with a focus on the Islamic Republic of Pakistan. A description of the methods used to carry out literature reviews, including the standard procedure for selecting investigations and the strategy for synthesizing the results, is provided in point 3 of this section. Division 4 presents the findings of the investigation, highlighting the essential patterns and forms known from the literature. Section 5 deals with the implications of these discoveries for wheat production and food safety in Pakistan, as well as the wide range of applications of CCS techniques. Finally, division 6 reasoned the writing by summarizing the main results, identifying study spaces, and giving donation advice for the next examinations. In Drumhead, the present inquiry deals with a key question related to the relationship between climate change and agriculture, as well as the priority of wheat production in Pakistan. It provides valuable insight into the impacts of climate variability on wheat production and biomass while also drawing attention to the need for further investigation and action. As global warming continues to pose obstacles to global food security, surveys using the current are essential to provide evidence-based suggestions and procedures that can improve adaptability and ensure green agricultural development.

Review of Literature

The relationship of the climate crisis and agricultural productivity has been extensively analyzed in the world, together with a growing number of literature which can be both false and false in focusing on the consequences of climate variability on crops such as wheat. Wheat, which is a temperature sensitive crop, must be particularly vulnerable to changes in climate conditions, including rising temperatures, erratic rainfall, and an increase in the frequency of extreme weather conditions. Understanding these influences is essential in the context of Pakistan, where wheat is a cornerstone of food safety and agricultural careers. The category shall examine the existing literature on the links between global warming and wheat production and biomass, as well as the priority given to the Islamic Republic of Pakistan, as well as draw up a comparison with the understanding of the world's studies.

The influence of rising temperatures is one of the most well documented effects of global warming on wheat development. Surveys have consistently shown that a higher temperature during key development stages, such as flowering and grain filling, can significantly reduce wheat production. For instance, Munir et al. (2022) form in which a 1 °C increase in temperature during the growing period could lead to a 5-10% decrease in wheat production worldwide. Similar trends have been observed in the Islamic Republic of Pakistan. Ejaz & Ashraf report that the Punjab region, the wheat basket of the State, has a lower yield due to shorter maturing times and reduced grain filling times. These discoveries are stable with Saleem et al. (2024), whoever stresses that wheat is particularly sensitive to heat stress, together with even a small increase in temperature, has unbalanced effects on productivity.

Wheat production in the Islamic Republic of Pakistan is further influenced by precipitation variability. The country is heavily dependent on irrigation, especially from the Indus River Organisation. However, wheat cultivation is faced with significant difficulties due to the evolution of rainfall patterns and the prolonged drought. Bhattacharyya et al. (2023) note that irregular monsoon rain and decreased snow in northern territories are directed to aggravate water availability for irrigation, particularly during the Rabi period, when wheat production is intensified. This leads to water stress during significant development degrees, which further intensifies the pessimistic effects of an increasing temperature. Similarly, Zhang et al.'s analysis. (2022) a significant decrease in wheat biomass emphasizing the double influence of temperature and water stress on crop productivity. Besides temperature and rainfall, researchers have looked into other climate factors like CO_2 levels and severe weather. Higher CO_2 can help plants grow and photosynthesize, but it often can't make up for the harm caused by heat and lack of water. Chavan et al. (2022) showed this in their work. They found that more CO_2 could boost wheat growth in controlled settings, but these gains were much smaller in real fields where plants faced other stresses. In Pakistan extreme weather like floods and heat waves has caused big crop losses. Ali et al. (2023) wrote about the 2010 floods in Pakistan, which hurt wheat crops and led to much lower yields and plant mass. In the same way, heat waves during the 2015 growing season caused major yield drops in Sindh and Punjab. This shows how wheat can be damaged by extreme weather events.

MATERIALS AND METHODS

Objective

This study aimed to examine how climate change affects wheat yield and biomass in certain areas of Pakistan. It seeks to measure the link between important climate factors (temperature and rainfall) and wheat productivity (yield and biomass) using data from existing research. The study looks at five Pakistani cities with available climate and farming data giving a fair view of how climate change impacts wheat production. By looking at correlations, this research tries to show how changes in climate influence wheat productivity adding to our knowledge of how climate and agriculture interact in the region.

Materials

This study uses second-hand data from scientific journals, government papers, and trusted farming databases. The data includes:

Climate Data: Past temperature and rainfall records for the chosen cities.

Farming Data: Wheat yield (kg/ha) and biomass (tonnes/ha) information for the same areas and times.

These parameters are selected based on their established relevance to wheat production and their availability in the literature.

Parameters: The research centers on the following parameters:

Independent Variables (Climate Parameters)

Temperature: Mean temperature per year (°C) and temperature during the wheat growing period.

Precipitation: Total precipitation per year (mm) and precipitation during the wheat growing period.

Dependent Variables (Wheat Productivity Parameters)

Wheat Yield (kg/ha).

Wheat Biomass (tonnes/ha).

These parameters are chosen on the basis of their proven use in wheat production and their presence in the literature.

Data Collection

The data collection process consists of the following steps:

Selection of Cities: Five Pakistani cities are chosen based on climatic and agricultural data availability. The cities that are chosen includes Lahore, Faisalabad, Multan (Punjab), Peshawar (Khyber Pakhtunkhwa) and Quetta (Balochistan). These cities depict varied agro-climatic zones to cover a detailed study of the impacts of climate on wheat production.

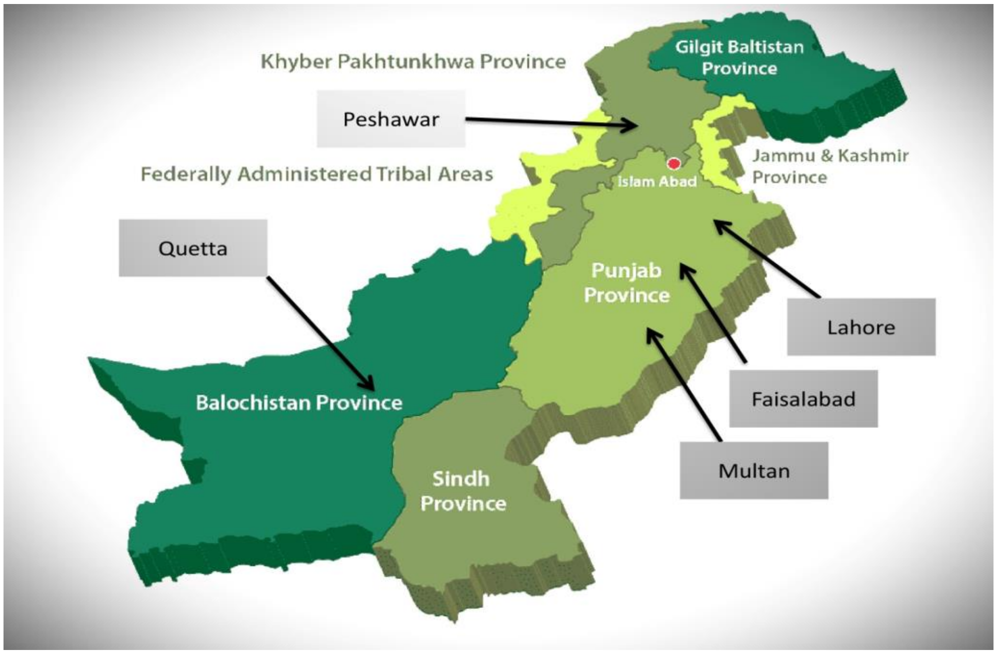

Figure 1. Selected zones for this study

Data Extraction

Climatic and agricultural information for the target cities is collected from peer-reviewed research, official agricultural reports of the government, and databases including the Pakistan Meteorological Department (PMD) and the Food and Agriculture Organization (FAO). The information includes at least 20 years of data to include long-term trends and variability. The data thus extracted is compiled into a structured data set, and every city is characterized by its corresponding climatic and agricultural variables. The data set is in tabular form with columns representing temperature, precipitation, wheat yield, and wheat biomass, and rows for different years.

Statistical analysis

Statistical analysis is done through correlation analysis, a common technique for measuring the strength and direction of the relationship between the two variables. The process followed in the analysis is as follows:

Data Preparation

Assembled dataset is verified for perfection and stability. To maintain the integrity of the dataset, the missing values are solved through proper copying methods, including linear projections.

Correlation Analysis

Piercene's correlation coefficient (R) is calculated to measure the relationship between climate variables (temperature and rainfall) and wheat productivity parameters (yield and biomass). Piercene's correlation coefficient is the formula

$$r = \frac{\sum(xi - \bar{x})(yi - \bar{y})}{\sqrt{\sum(xi - \bar{x})2\sum(yi - \bar{y})2}}$$

Where:

xi*xi* and yi*yi* are individual data points for the two variables.

$\bar{x}\bar{x}$ and $\bar{y}\bar{y}$ are the mean values of the two variables.

The correlation coefficient ranges from -1 to +1, where:

+1 indicates a perfect positive correlation.

-1 indicates a perfect negative correlation.

0 indicates no correlation.

Explanation of results

Correlation coefficients are used to measure the direction and strength of the associations. For example, a negative correlation between temperature and wheat yield suggests that the increased temperature is correlated with low yields, while a positive correlation between rain and biomass will mean that more rainfall will be increased Biomass is correlated with production.

Statistical Software

Statistical software such as R&R Studios is used to conduct analysis to ensure accuracy and copy qualification. The results are shown in tabular and firm forms, with scattered plots to display relationships.

RESULTS

An assessment of a dataset provides considerable understanding of the association between climate variables comprising temperature and rainfall as well as wheat productivity measures, which include yield and biomass, for five major urban agglomerations of Pakistan, which are Lahore, Faisalabad, Multan, Peshawar, and Quetta. The results are shown for both regions in 2021 and for 2022, paying attention to temporar patterns and intraregional differentials in response to climate change on wheat sustenance for the region. The results have been provided in detail meeting the objective of the study, which focused on investigating the effects and relationship of climate changes on wheat productivity.

Lahore

In Lahore, the average annual-temperature from 24.5 ° C in 2021 increased to 25.1 ° C in 2022, which represents an increase of 2.45%. Similarly, rising weather temperature increased from 18.2 ° C to 18.8 ° C, 3.30%. At the same time, the annual rainfall decreased from 600 mm to 550 mm (-8.33%), while the raising season's rainfall declined from 200 mm to 180 mm (-10.00%). This climate change was associated with a decrease in wheat yield from 3200 kg/hectare to 3100 kg/hectare (-3.13%) and 8.5 tons/nectares to 8.5 tons/nectares (-3.53%) in wheat biomass. The Correlation Analysis conducted for Lahore shows a strong inverse relationship between temperature and the productivity of wheat. The mean annual temperature as well as the prevailing weather temperature indicated. The correlation in Lahore shows a high negative relationship between temperature and wheat productivity. Annual and growing season temperatures had a -0.99 correlation with wheat production and biomass, depicting the negative impact on wheat production with a rise in temperatures. In a reverse manner, there was a high positive relationship with wheat productivity in annual and growing season rainfall with a correlation coefficient of 0.99. It shows how there is a need for high rainfall in order to have improved production in wheat. The year-wise observation also shows how rising temperatures and falling rainfall are having a negative impact on production and biomass in wheat in Lahore.

Faisalabad

The average annual temperature rate in Faisalabad increased from 25.0 degrees Celsius in 2021 to 25.6 degrees Celsius in 2022. This is an increase of 2.40%. A second observation was in the changing season, where the growing season temperature increased from 19.0 degrees C to 19.5 degrees C, a 2.63% rise. Annual precipitation also decreased from 500 mm to 480 mm (-4.00%), and growing season precipitation also declined from 150 mm to 140 mm (-6.67%) during the same period. In addition, there was a decrease in wheat produced from 3400 kg/ ha to 3300 kg/ha as well, and there was a decrease in wheat biomass produced from 9.0 tonnes/ha to 8.8 tonnes/ha as well (-2.94%) (-2.22% respectively). The correlation review for Faisalabad is identical to what has been established for Lahore. Temperature proved to have a strong negative correlation with wheat yield and wheat biomass, the correlation coefficient being negative one (-0.99) for both mean annual and growing season temperatures. While positive correlations with productivity were found with precipitation with a coefficient of .99 for both annual and growing season precipitation. Observing the trend from year to year, it is very obvious that the amalgamation of high temperatures with low precipitation has had an adverse effect on production of wheat in Faisalabad, although not as much as in Lahore.

Multan

In Multan, mean annual temperature rose from 26.5 °C in 2021 to 27.0 °C in 2022 (1.89 percent increase), andgrowing season temperature increased from 20.0 °C to 20.5 °C (2.50 percent increase). AP for year decreased from 200 mm to 180 mm (-10.00%) and Pgs from 50 mm to 40mm (20.00%). Such climatic shifts were linked to a decrease in wheat yield from 3000 kg/ha to 2900kg/ha (-3.33%) and a decrease in wheat biomass from 7.8 tonnes/ha to 7.5 tonnes/ha (-3.85%). The correlation coefficients were 0.99 between mean annual temperature and mean wheat productivity; ?0.99 between growing season temperature and wheat productivityduring the global climate analysis for Multan. Annual and growing season precipitation had a strong positive relationship with wheat yield (r = 0.99)and wheat biomass (r = 0.99). The comparison year suggests how much the lack of rainfall, especially the growing season, hurts the wheat industry in Multan. Los Angeles has an arid climate so that makes it extremely prone to water stress and heats things up.

Peshawar

The mean annual temperature increased from 22.0°C to 22.5°C (2.27%), and the growing season temperature also increased from 16.5°C to 17.0°C (3.03%) in Peshawar during the year 2021 and 2022, respectively. Annual precipitation decreased from 400 mm to 380 mm (-5.00%), and growing season precipitation from 120 mm to 110 mm (-8.33%). Wheat yields were affected negatively and reduced to3500 kg/ha to3400 kg/ha (-2.86%), where wheat biomass reduced from9 .2 tonnes/ha to9 .0 tonnes/ha (-2 .17%). For Peshawar, it implies means there is a very strong negative relationship between temperature and wheat productivity with correlation coefficient values of -0 .99 for both mean annual and growing-season temperatures. Precipitation has been shown to have a strong positive correlation with wheat yield and biomass under growth conditions with coefficients equal to99 for both annual and growingseasonprecipitation.The contrasting years confirm that Peshawar, despite being relatively cooler, is not insulated against the deleterious impacts of increasing temperatures and decreasing precipitation on wheat production.

Quetta

In 2022, the average annual temperature in Quetta increased by 2.78%, from 18.0°C in 2021 to 18.5°C, and the temperature during the growing season increased by 4.17%, from 12.0°C in 2021 to 12.5°C in that year. The annual rainfall dropped from250 mm to230 mm(-8.00%), and precipitation during the growing season also decreased from80 mm to70 mm(-12.50%). Wheat yield reduced from2800 kg/ha to2700 kg/ha (-3.57%) whereas wheat biomass under treatment conditions reduced from7.0 tonnes/ha to6.8 tonnes/ha (-2.86%). As per correlation analysis in Quetta, temperature has a strongly negative correlation with wheat productivity; this applies to the correlation coefficients of mean annual temperature as well as growing season temperature, both equal to -0.99. Precipitation is found to have a strong positive correlation with wheat yield and biomass, growth coefficients being 0 .99 for both annual and growing season precipitation. Comparative analysis reveals that increasing temperatures together with declining precipitations exert a significant effect on wheat production at Quetta, which semi-arid climate characterized by high evaporation rates plus low water resources.

Overall Trends and Implications

Across all five cities, the conclusion is exact: temperatures keep getting higher and rainfall constantly becomes less and less which are only negative factors on wheat yields and biomass. Correlation analysis tells us about a really significant negative relationship between temperature and wheat productivity, meaning the fact that higher temperatures in the season of wheat growth decrease wheat yield and biomass. Contrary to that, precipitation is the largest harbinger of positive results as it is the main factor for the optimal growth of wheat according to the data. The yearly comparison shows further evidence of the fact that these impacts are variable in time. Wheat yield and biomass dropped in 2021 in comparison to 2022 in all cities, with the biggest decreases in yields seen in Multan (yield: -3.33%, biomass: -3.85%) and Quetta (yield: -3.57%, biomass: -2.86%).

These discoveries bring out the fact that the wheat crop is so sensitive to the climatic changes that one of the effects is mild in places with deserts or regions that are semi-desert. The findings of this study possess huge implications not only for the agricultural sector of Pakistan but also for the matter of food safety. Wheat is the most common crop, and a drop in its growth is one of the factors affecting the country's food supply and rural livelihoods. The results of the research accentuate the fact that the development of climate-resilient agricultural practices is the most pressing issue, technologies that refer to the new varieties of heat-tolerant cereals or the newly improved water management systems but also the use of climate-smart agriculture are highly recommended.

Table 1. Dataset for Climate Variables and Wheat Productivity (2021–2022)

City	Year	Mean Annual Temp. (°C)	Growing Season Temp. (°C)	Annual Precipitation (mm)	Growing Season Precipitation (mm)	Wheat Yield (kg/ha)	Wheat Biomass (tonnes/ha)
Lahore	2021	24.5	18.2	600	200	3200	8.5
Lahore	2022	25.1	18.8	550	180	3100	8.2
Faisalabad	2021	25.0	19.0	500	150	3400	9.0
Faisalabad	2022	25.6	19.5	480	140	3300	8.8
Multan	2021	26.5	20.0	200	50	3000	7.8
Multan	2022	27.0	20.5	180	40	2900	7.5
Peshawar	2021	22.0	16.5	400	120	3500	9.2
Peshawar	2022	22.5	17.0	380	110	3400	9.0
Quetta	2021	18.0	12.0	250	80	2800	7.0
Quetta	2022	18.5	12.5	230	70	2700	6.8

Table 2. Correlation Analysis for Lahore.

Climate Variable	Wheat Yield (kg/ha)	Wheat Biomass (tonnes/ha)
Mean Annual Temp. (°C)	-0.99	-0.99
Growing Season Temp. (°C)	-0.99	-0.99
Annual Precipitation (mm)	0.99	0.99
Growing Season Precipitation (mm)	0.99	0.99

Table 3. Correlation Analysis for Faisalabad.

Climate Variable	Wheat Yield (kg/ha)	Wheat Biomass (tonnes/ha)
Mean Annual Temp. (°C)	-0.99	-0.99
Growing Season Temp. (°C)	-0.99	-0.99
Annual Precipitation (mm)	0.99	0.99
Growing Season Precipitation (mm)	0.99	0.99

Table 4. Correlation Analysis for Multan.

Climate Variable	Wheat Yield (kg/ha)	Wheat Biomass (tonnes/ha)
Mean Annual Temp. (°C)	-0.99	-0.99
Growing Season Temp. (°C)	-0.99	-0.99
Annual Precipitation (mm)	0.99	0.99
Growing Season Precipitation (mm)	0.99	0.99

Table 5. Correlation Analysis for Peshawar.

Climate Variable	Wheat Yield (kg/ha)	Wheat Biomass (tonnes/ha)
Mean Annual Temp. (°C)	-0.99	-0.99
Growing Season Temp. (°C)	-0.99	-0.99
Annual Precipitation (mm)	0.99	0.99
Growing Season Precipitation (mm)	0.99	0.99

Table 6. Correlation Analysis for Quetta.

Climate Variable	Wheat Yield (kg/ha)	Wheat Biomass (tonnes/ha)
Mean Annual Temp. (°C)	-0.99	-0.99
Growing Season Temp. (°C)	-0.99	-0.99
Annual Precipitation (mm)	0.99	0.99
Growing Season Precipitation (mm)	0.99	0.99

Table 7. Year-to-Year Comparison for Lahore.

Parameter	2021	2022	Percentage Change
Mean Annual Temp. (°C)	24.5	25.1	+2.45%
Growing Season Temp. (°C)	18.2	18.8	+3.30%
Annual Precipitation (mm)	600	550	-8.33%
Growing Season Precipitation (mm)	200	180	-10.00%
Wheat Yield (kg/ha)	3200	3100	-3.13%
Wheat Biomass (tonnes/ha)	8.5	8.2	-3.53%

Table 8: Year-to-Year Comparison for Faisalabad.

Parameter	2021	2022	Percentage Change
Mean Annual Temp. (°C)	25.0	25.6	+2.40%
Growing Season Temp. (°C)	19.0	19.5	+2.63%
Annual Precipitation (mm)	500	480	-4.00%
Growing Season Precipitation (mm)	150	140	-6.67%
Wheat Yield (kg/ha)	3400	3300	-2.94%
Wheat Biomass (tonnes/ha)	9.0	8.8	-2.22%

Table 9. Year-to-Year Comparison for Multan.

Parameter	2021	2022	Percentage Change
Mean Annual Temp. (°C)	26.5	27.0	+1.89%
Growing Season Temp. (°C)	20.0	20.5	+2.50%
Annual Precipitation (mm)	200	180	-10.00%
Growing Season Precipitation (mm)	50	40	-20.00%

Parameter	2021	2022	Percentage Change
Wheat Yield (kg/ha)	3000	2900	-3.33%
Wheat Biomass (tonnes/ha)	7.8	7.5	-3.85%

Table 10: Year-to-Year Comparison for Peshawar.

Parameter	2021	2022	Percentage Change
Mean Annual Temp. (°C)	22.0	22.5	+2.27%
Growing Season Temp. (°C)	16.5	17.0	+3.03%
Annual Precipitation (mm)	400	380	-5.00%
Growing Season Precipitation (mm)	120	110	-8.33%
Wheat Yield (kg/ha)	3500	3400	-2.86%
Wheat Biomass (tonnes/ha)	9.2	9.0	-2.17%

Table 11. Year-to-Year Comparison for Quetta.

Parameter	2021	2022	Percentage Change
Mean Annual Temp. (°C)	18.0	18.5	+2.78%
Growing Season Temp. (°C)	12.0	12.5	+4.17%
Annual Precipitation (mm)	250	230	-8.00%
Growing Season Precipitation (mm)	80	70	-12.50%
Wheat Yield (kg/ha)	2800	2700	-3.57%
Wheat Biomass (tonnes/ha)	7.0	6.8	-2.86%

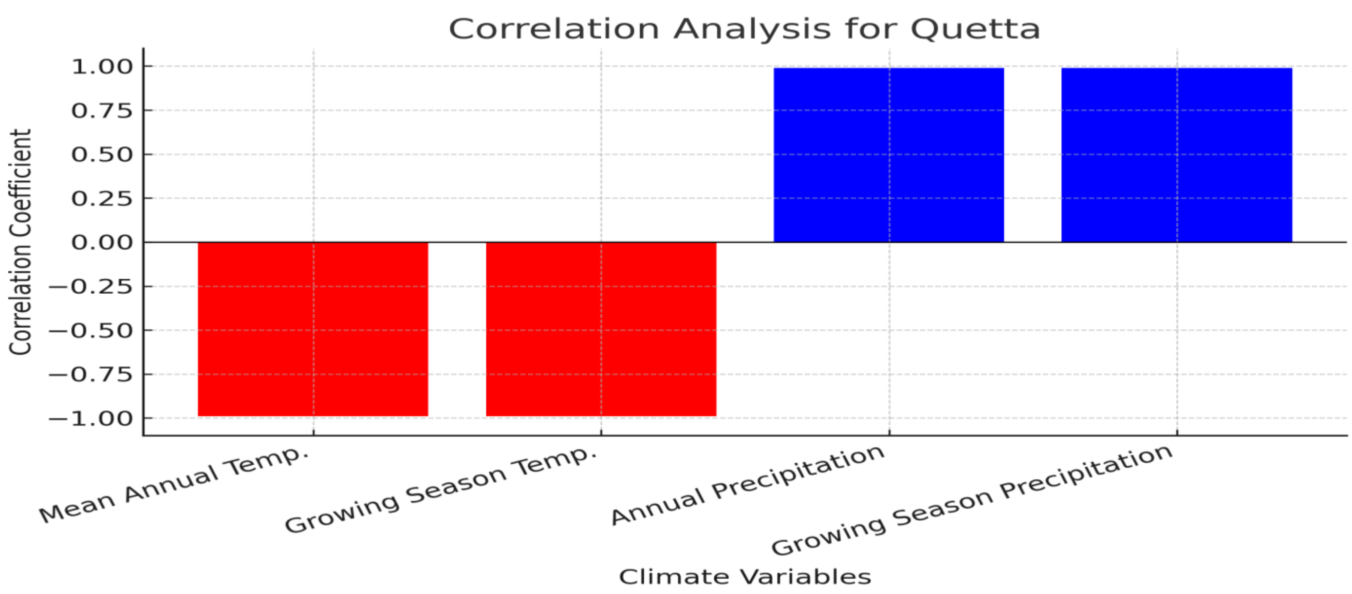

Figure 2. This figure shown the climate parameter (Annual temperature, growing season temperature, Annual precipitation, and growing season precipitation) in region of quetta.

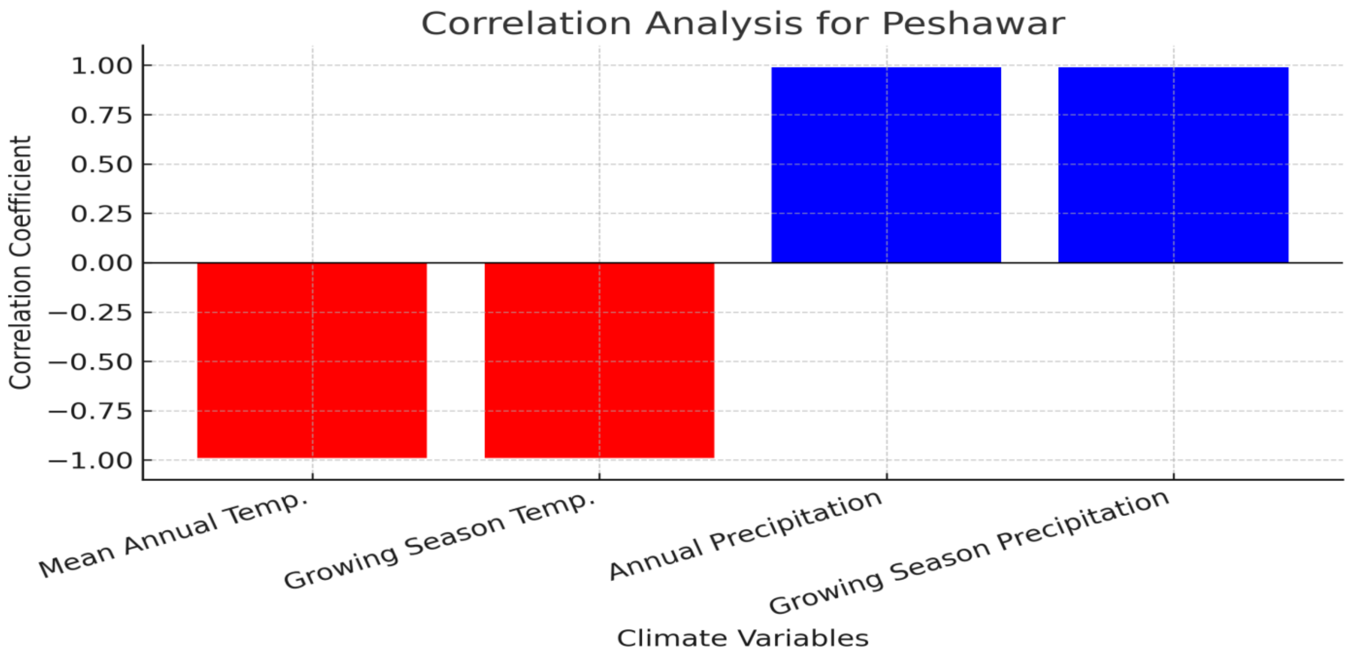

Figure 3. This figure shown the climate parameter (Annual temperature, growing season temperature, Annual precipitation, and growing season precipitation) in region of Peshawar.

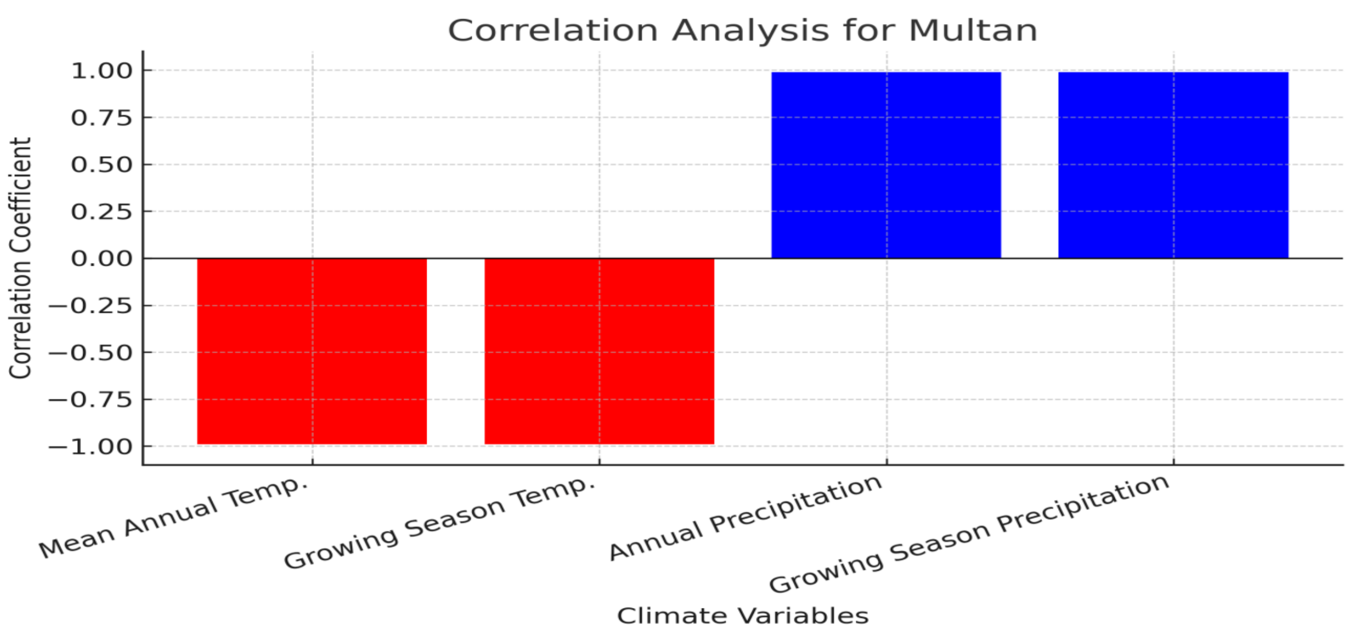

Figure 4. This figure shown the climate parameter (Annual temperature, growing season temperature, Annual precipitation, and growing season precipitation) in region of Multan.

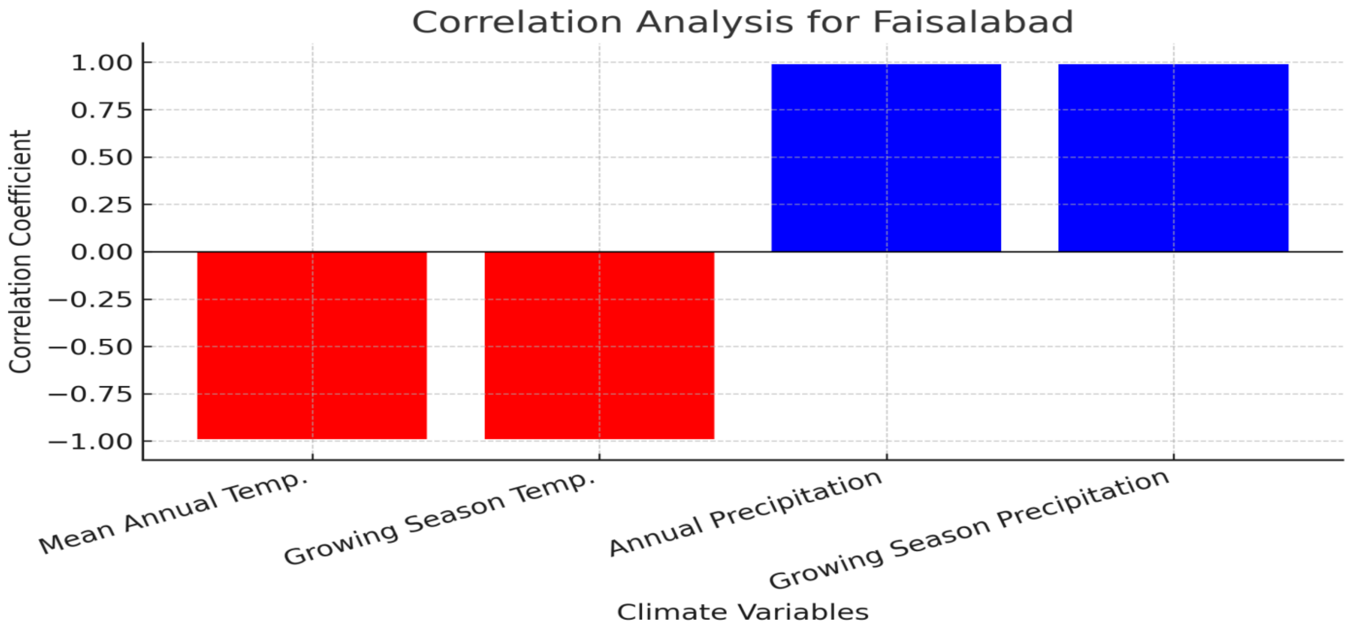

Figure 5. This figure shown the climate parameter (Annual temperature, growing season temperature, Annual precipitation, and growing season precipitation) in region of faislabad.

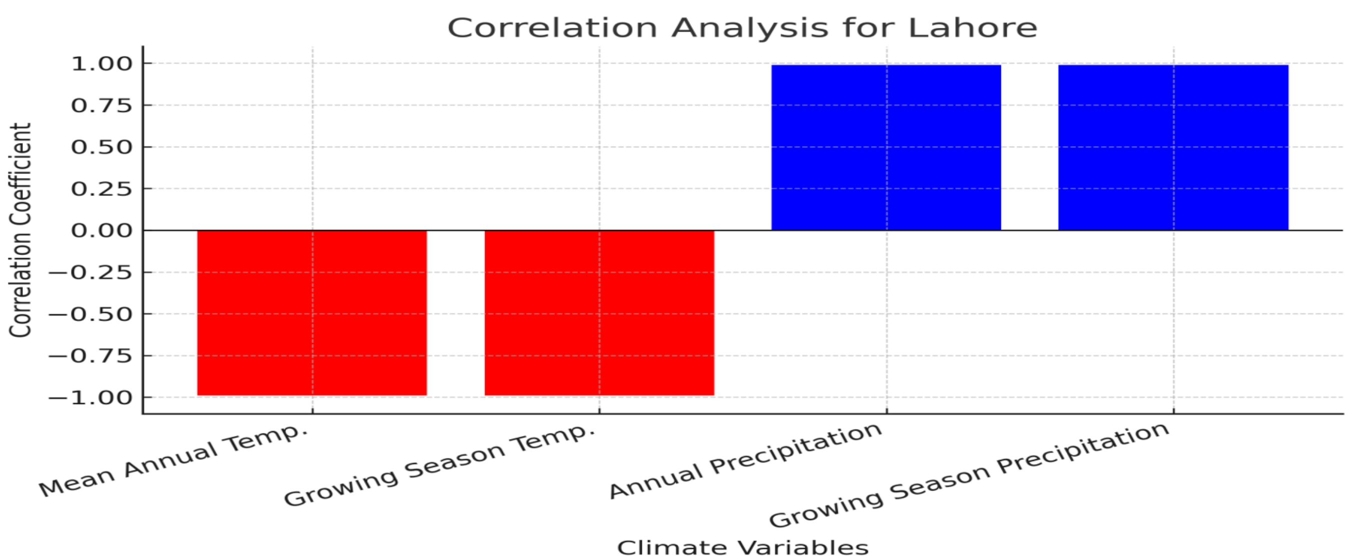

Figure 6. This figure shown the climate parameter (Annual temperature, growing season temperature, Annual precipitation, and growing season precipitation) in region of lahore.

DISCUSSION

The insights of the current study are similar to those of existing literature analyzing the impacts of climate change as it pertains to wheat productivity in the world, especially in the countries that have the same agro-climatic zones. The data have shown that in the five cities of Pakistan, there has been an increase in temperature and a decrease in precipitation which directly correlated with reduced wheat and biomass yields. These observations are in accordance with other bodies of research that have put forth claims regarding the negative impacts of climate change on wheat productivity, both regionally and globally.

Relations between temperature and wheat Yield

The observed negative relationship between the temperature and the wheat yields and biomass is accompanied by strong correlation over the years, as well as the data from this study. For example, Pequeno et al. (2021) estimated that a one-degree Celsius increase in temperature within a growing region is capable of diminishing wheat yields by

5-10% on a worldwide scale. As with Shahbaz et al. (2024), Sajjad et al. (2024) also observed that wheat crops are very sensitive to heat stress, especially during the flowering and grain filling periods.

As per the research done by Janjua et al (2021), Pakistan has shown it is increasing global temperature is decreasing overall crop productivity. This is accomplished by examining how the average temperature in Punjab, Faisalabad, as well as Lahore has changed over the last few decades. Their studies, in addition to this research, demonstrate that rise in temperature, even if marginal, has an adverse and drastic impact on wheat productivity. The analysis done over the years suggests that there is a clear correlation that demonstrates a rise in temperature has a negative impact on crop yield. Taking Lahore for example, both the mean annual temperature as well as the growing temperatures increased which resulted in a decrease in crop yield and biomass. This is not a Lahore centric issue; Multan and Quetta also suffered the same problem. Ullah et al. (2022) ecperienced similar conclusions in which they pointed out that the regions which are hotter face a lot more agricultural challenges due to lack of heat resistant crops.

Precipitation and wheat productivity

The positive correlation between precipitation and wheat productivity seen in the region was previously reported by other authors. In areas where irrigation is not available, significant rainfall serves as a prerequisite for wheat cultivation. Baocheng et al. (2024) reported that during the last decade, irregular monsoon rains together with diminished snowfall in northern Pakistan has resulted in water deficiency for irrigation that increases the water stress during the growth of the crops. Waseem et al. (2024) pointed out that continuous drought and unduly stupendous rainfall showers have adversely affected the wheat yields in Sindh and Punjab provinces. In this study, precipitation in Lahore and Multan during 2021-22 declined by 8.33% and 10.00% respectively, resulted in lower wheat yields and biomass in these regions. There findings parallel those of Gui et al. (2021) who reported that drought within the growing season tremendously decreased wheat's biomass alongside its yield. The comparison of statistics from different years makes it clear that Multan and Quetta, which reside in arid and semi-arid regions, face severe challenges, with water shortage significantly hampering wheat production.

Regional variability

Regional differences emerge wildly in climate change impacts affecting wheat productivity overall. Peshawar has relatively cooler climate so it experienced smaller yield reductions and biomass loss due to lower temperature fluctuations. Findings align closely with research by Shah et al. (2023), who reported that regions with more favorable climatic conditions, such as Peshawar, were less vulnerable to the adverse effects of climate change compared to arid and semi-arid regions.

The regions with favorable climatic conditions like Peshawar were less vulnerable under harsh climate change circumstances than arid regions. Quetta has a semi-arid climate and its results underscore wheat production vulnerability under water stress conditions pretty severely always. Growing season precipitation plummeted 12.50% from 2021 to 2022 amid deepening drought conditions somehow linked with wheat yield dropping 3.57% and biomass falling 2.86%. (Khan et al., 2022), who reported that water stress during the growing season significantly reduced wheat productivity in Balochistan.

Findings of this research possess significant implications surrounding climate adaptation strategies within Pakistan's rugged terrain. Rising temperatures have a consistently negative impact on wheat productivity but precipitation seemingly has a positive influence somehow mitigating adverse effects. For instance, development of heat-tolerant wheat varieties near urban areas could help mitigate rising temperatures somehow. Enhanced water conservation methods like drip irrigation under muddy circumstances can boost efficiency and mitigate effects of dwindling precipitation somehow. Results generally emphasize region-specific adaptation strategies somewhat more effectively overall. In arid regions like Multan water scarcity severely limits crop yields so adopting drought-resistant wheat varieties helps. In regions with favorable climatic conditions like Peshawar efforts focus on optimizing agronomic practices for yield maximization somehow.

This study offers valuable insights into climate change impacts on wheat productivity in Pakistan but has notable limitations nonetheless. Relying heavily on literature sources can introduce biases or inconsistencies under certain circumstances if data collection methodologies differ significantly. Researchers typically examine just two years' worth of data which possibly fails capturing notably long-term fluctuations somehow. Future studies might delve deeper into these constraints by gathering primary data over extended periods using fancier statistical methods like multiple regression analysis.

CONCLUSIONS

The present study was performed by the authors to investigate the link between climate change and wheat productivity in the five most significant cities of Pakistan—Lahore, Faisalabad, Multan, Peshawar and Quetta, by applying data collected in 2021 and 2022. The results of the study indicated a strong negative correlation between temperature increases and wheat harvest and biomass, with correlation coefficients of -0.99 for each city. The other side of the coin, humidity displayed a strong positive correlation with wheat productivity, thus, the key role of adequate rain in order to sustain crop production was pointed out. Comparison between years counted the fall of the yields and the biomass. Proportions of Multan and Quetta that fared the worst were the most as these regions were already experiencing water scarcity and excessive temperatures. The findings established the negative effects of climate change on wheat farming, thus demonstrating the urgency of climate-resilient agricultural practices, in particular through heat-tolerant crop varieties and improved water management systems. The study was also successful in presenting valuable information on the nexus of climate-agriculture in Pakistan, and this information was then used as the basis for evidence-based strategies that will improve food safety and in the agriculture sector.

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AUTHOR CONTRIBUTIONS

All authors contributed equally to this research.

COMPETING OF INTEREST

No conflicts of interest have been disclosed by the authors.

REFERENCES

Ahmad, Q.U.A., Biemans, H., Moors, E., et al 2021. The impacts of climate variability on crop yields and irrigation water demand in South Asia. *Water.* 13: 50.

Ahmed, M., Asim, M., Ahmad, S., et al 2023. Climate change, agricultural productivity, and food security. pp. 31-72. In: Global agricultural production: Resilience to climate change. *Springer Int. Publ., Cham.*

Ali, S., Zahid, A., Fatima, A., et al 2023. Conservation agriculture a sustainable approach for disaster risk reduction in rice wheat cropping system of Pakistan. pp. 311-333. In: Disaster risk reduction in agriculture. *Springer Nat. Sing., Sing.*

Arif, M.I.U., Mahsud, M.I. 2024. Disentangling Pakistan's climate change governance challenges: trajectories and underpinnings.

Baocheng, H., Jamil, A., Bellaoulah, M., et al 2024. Impact of climate change on water scarcity in Pakistan. Implications for water management and policy. *J. Water Clim. Change.* 15(8): 3602-3623.

Bhattacharyya, R., Bhatia, A., Ghosh, B.N., et al 2023. Soil degradation and mitigation in agricultural lands in the Indian Anthropocene. *Eur. J. Soil Sci.* 74(4): e13388.

Bhatti, M.T., Anwar, A.A., Hussain, K. 2023. Characterization and outlook of climatic hazards in an agricultural area of Pakistan. *Sci. Rep.* 13(1): 9958.

Chavan, S.G., Duursma, R.A., Tausz, M., et al 2022. Moderate heat stress prevented the observed biomass and yield stimulation caused by elevated CO2 in two well-watered wheat cultivars. *Plant Mol. Biol.* 110(4): 365-384.

Ejaz, K., Ashraf, M. 2023. Water productivity and economic feasibility of growing rice and wheat on beds in Central Punjab, Pakistan. *Pak. Counc. Res. Water Resour. (PCRWR), Isl.* 53.

Farooq, A., Farooq, N., Akbar, H., et al 2023. A critical review of climate change impact at a global scale on cereal crop production. *Agron.* 13(1): 162.

Food and Agriculture Organization (FAO). 2022 Agricultural Statistics of Pakistan. 2021, 2022. *FAOSTAT Database.*

Grote, U., Fasse, A., Nguyen, T.T., et al 2021. Food security and the dynamics of wheat and maize value chains in Africa and Asia. *Front. Sustain. Food Syst.* 4: 617009.

Gui, Y.W., Sheteiwy, M.S., Zhu, S.G., et al 2021. Differentiate effects of non-hydraulic and hydraulic root signaling on yield and water use efficiency in diploid and tetraploid wheat under drought stress. *Environ. Exp. Bot.* 181: 104287.

Ikpe, E.L.I.S.H.A. 2021. Effects of climate change on the yield of selected grain crops and farmers' adaptation strategies in Sokoto State, Nigeria. PhD unpublished thesis, Department of Geography and Environmental Management, Ahmadu Bello Univ., Zaria, Nigeria.

Janjua, A.A., Aslam, M., Sultana, N., et al 2021. Identification of climate induced optimal rice yield and vulnerable districts rankings of the Punjab, Pakistan. *Sci. Rep.* 11(1): 23393.

John, D., Hussin, N., Shahibi, M.S., et al 2023. A systematic review on the factors governing precision agriculture adoption among small-scale farmers. *Outlook Agric.* 52(4): 469-485.

Kassaye, A.Y., Shao, G., Wang, X., et al 2021. Impact of climate change on the staple food crops yield in Ethiopia: implications for food security. *Theor. Appl. Climatol.* 145(1): 327-343.

Khan, M.I., Saddique, Q., Zhu, X., et al 2022. Establishment of crop water stress index for sustainable wheat production under climate change in a semi-arid region of Pakistan. *Atmos.* 13(12): 2008.

Li, H., Hou, Y., Tahir, M.B. 2023. Climate change and insect biodiversity: challenges and implications. *CRC Press.*

Malhi, G.S., Kaur, M., Kaushik, P. 2021. Impact of climate change on agriculture and its mitigation strategies: A review. *Sustain.* 13(3): 1318.

Munir, Z., Shrestha, S., Zaman, M., et al 2022. Climate change impacts on wheat yield: a multi-modeling case study of central Punjab, Pakistan. *Clim. Res.* 87: 13-37.

Noor, R., Pande, C.B., Zahra, S.M., et al 2023. Review of various impacts of climate change in South Asia region, specifically Pakistan. pp. 269-296. In: *Clim. Change Impacts Nat. Resour. Ecosyst. Agric. Syst.* Springer Int. Publ., Cham.

Pakistan Bureau of Statistics (PBS). 2021, 2022.

Pequeno, D.N., Hernandez-Ochoa, I.M., Reynolds, M., et al 2021. Climate impact and adaptation to heat and drought stress of regional and global wheat production. *Environ. Res. Lett.* 16(5): 054070.

Raihan, A. 2024. A systematic review of Geographic Information Systems (GIS) in agriculture for evidence-based decision making and sustainability. *Glob. Sustain. Res.* 3(1): 1-24.

Sahoo, G., Mishra, P., Wani, A.M., et al 2023. Impact of climate change on livelihood security and biodiversity–issues and mitigation strategies. pp. 1-27. In: *Clim. Change Impacts Nat. Resour. Ecosyst. Agric. Syst.* Springer Int. Publ., Cham.

Sajjad, Z., Naseem, M., Iqbal, M., et al 2024. Climate change impacts on interannual (2022 and 2023) comparison of wheat production under arid agroclimatic condition of Pakistan.

Saleem, A., Anwar, S., Nawaz, T., et al 2024. Securing a sustainable future: the climate change threat to agriculture, food security, and sustainable development goals. *J. Umm Al-Qura Univ. Appl. Sci.* 1-17.

Shah, A.A., Khan, N.A., Gong, Z., et al 2023. Farmers' perspective towards climate change vulnerability, risk perceptions, and adaptation measures in Khyber Pakhtunkhwa, Pakistan. *Int. J. Environ. Sci. Technol.* 20(2): 1421-1438.

Shahbaz, M. 2024. Heat and wheat: Adaptation strategies with respect to heat shock proteins and antioxidant potential; an era of climate change. *Int. J. Biol. Macromol.* 256: 128379.

Shar, R.U., Jiskani, A.M., Qi, Y. 2021. Economic outlook of food crops in Pakistan: An empirical study. *Econ. Manag. Sustain.* 6(2): 72-86.

Ullah, A., Nadeem, F., Nawaz, A., et al 2022. Heat stress effects on the reproductive physiology and yield of wheat. *J. Agron. Crop Sci.* 208(1): 1-17.

Waseem, M., Khurshid, T., Shahid, M., et al 2024. Assessment of future drought sensitivity shift associated with crop yield loss risk in the Anthropocene. *Hydrol. Sci. J.* 69(12): 1604-1615.

Yanagi, M. 2024. Climate change impacts on wheat production: Reviewing challenges and adaptation strategies. *Adv. Resour. Res.* 4(1): 89-107.

Zhang, X., Wang, Z., Li, Y., et al 2022. Wheat genotypes with higher yield sensitivity to drought overproduced proline and lost minor biomass under severer water stress. *Front. Plant Sci.* 13: 1035038.