

Wheat Under Pressure: Assessing the Influence of Climate Change on Pakistan's Agricultural Landscape

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Abstract

This study examined the effects of climate change on wheat production in Pakistan, documenting yearly changes in the atmosphere such as floods, rainfall, and increasing temperatures. Using a combination of qualitative and quantitative methods, the objective is to analyze how various factors, including water availability, the area of wheat cultivation, carbon dioxide levels, precipitation, and temperature, impact the wheat output in Pakistan. A comprehensive review of existing literature provides context, while the VAR modeling technique is utilized for quantitative data analysis, incorporating data from the Economic Survey of Pakistan and the Meteorological Department. The VAR model indicates a significant negative impact on Pakistan's wheat production as a result of climate change. The study highlights the urgent need to implement adaptation strategies to mitigate these effects. The projected decline in wheat production has significant implications for food security and livelihoods, necessitating policy interventions and the adoption of sustainable agricultural practices. The societal impact of these findings calls for collaborative efforts among stakeholders, policymakers, and the general public to collectively address the challenges posed by climate change in Pakistan's agricultural sector.

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Abstract

This study examined the effects of climate change on wheat production in Pakistan, documenting yearly changes in the atmosphere such as floods, rainfall, and increasing temperatures. Using a combination of qualitative and quantitative methods, the objective is to analyze how various factors, including water availability, the area of wheat cultivation, carbon dioxide levels, precipitation, and temperature, impact the wheat output in Pakistan. A comprehensive review of existing literature provides context, while the VAR modeling technique is utilized for quantitative data analysis, incorporating data from the Economic Survey of Pakistan and the Meteorological Department. The VAR model indicates a significant negative impact on Pakistan's wheat production as a result of climate change. The study highlights the urgent need to implement adaptation strategies to mitigate these effects. The projected decline in wheat production has significant implications for food security and livelihoods, necessitating policy interventions and the adoption of sustainable agricultural practices. The societal impact of these findings calls for collaborative efforts among stakeholders, policymakers, and the general public to collectively address the challenges posed by climate change in Pakistan's agricultural sector.

Key words - climate change, wheat production, Pakistan, global warming, adaptation strategies, VAR modeling, sustainable agriculture, food security.

Introduction

Wheat is one of several species of edible cereal grasses of the genus *Triticum* (family Poaceae). Wheat is one of the oldest and most important of the cereal crops. Of the thousands of varieties known, the most important is common wheat (*Triticum aestivum*). The rapid expansion has necessitated the usage of fossil fuels to supply the increased demand for energy (Kukul & Irmak, 2018). However, burning fossil fuels results in the emission of gases that have a long-term impact on the planet's climate. There is little doubt that several billion people rely on wheat as a significant portion of their diet on a global scale. Since bread, noodles, and other products (such as bulgar, and couscous) may make up a sizable component of the diet in less developed nations, the nutritional significance of wheat proteins should not be understated. Nearly 55% of the food's

carbs and 20% of its calories come from wheat. It has a sizable amount of carbs (78.10%), protein (14.70% of the total), fat (2.10%), and minerals (2.10%), as well as vitamins (thiamine and vitamin B), minerals (zinc), and fat. The majority of the protein, carbohydrates, iron, and numerous B-complex vitamins like riboflavin, niacin, and thiamine are found in the endosperm of each kernel. Approximately 1 gram of fiber per tablespoon can be found in wheat germ. For people who are at risk for celiac diseases, cardiovascular disease, or diabetes, a high fibrous diet is suggested for bowel regulation (i.e., reduce constipation) (Kumar et al., 2011).

Wheat is Pakistan's most significant food crop in terms of production and acreage. Wheat accounts for 37.1% of the agricultural land, 65% of the land used for food grains, and 70% of the total agricultural output. For irrigation-based wheat farming, an average acre needs 20 to 21 inches of water. Due to its ideal geography, rich soil, and superior agricultural infrastructure, the Indus Plains have a significantly bigger area devoted to growing wheat. Spring wheat is raised as a Rabi crop in the Pakistani provinces of Sindh, Punjab, NWFP, and Baluchistan. Winter wheat is raised on a small scale in Baluchistan's northern regions. 8.371 million hectares were used for cultivating wheat, and 18.90 million tons were produced between 1997 and 1980. Punjab (71.17%) and Sindh (13.38%) are the two provinces with the largest production areas. Punjab has a slightly higher yield per acre (2,316 kg) than Sindh (2,410 kg). In Punjab, irrigated land is primarily used to raise wheat. About 10% of wheat is produced in places that receive rain (Ahmed & Schmitz, 2011).

Pakistan's major producer of wheat is Punjab, which accounts for around 71.17% of the nation's total output. Punjab produced 19178.50 thousand tons of wheat in 2021–2022 alone. Approximately 13.38% of Pakistan's total wheat production is produced in Sindh, the country's second-largest producer. In Sindh, 3639,50 tons of wheat was produced in 2021–2022 alone. Approximately 8.22% of Pakistan's total wheat production is produced in Khyber Pakhtunkhwa, making it the third-largest producer in the country. In 2021–2022, 2207, 60,000 tons of wheat were produced in Khyber Pakhtunkhwa. Approximately 3.23% of all wheat produced in Pakistan is produced in Baluchistan, the country's fourth-largest wheat producer. 865.30 thousand tons of wheat were produced in Baluchistan in 2021–22. Gilgit-Baltistan and Azad Kashmir contributed the remaining 3.98% of Pakistan's total wheat production (Ahmad & Jabeen, 2023).

Climate change has emerged as a significant concern for wheat production in Pakistan. Understanding the possible effects of climate change on wheat production is essential because wheat is the nation's main source of food (Chandio et al., 2020). A wheat plant's stem normally stands two to four feet tall, and its grass-like leaves measure eight to fifteen inches in length. Each stalk ends in a spike that is anywhere from 2 to 8 inches long. It's the most productive section of the wheat plant, with an average of 20 grains per spike and up to 300 in extreme cases caused by extreme weather (Brown & Huntington, 2003). Wheat is often planted in Pakistan in the fall, namely in the month of November. Wheat is grown on an estimated 90,450,000 ha in Pakistan, with a yield of 2,657 kg per hectare. In Pakistan, wheat is so vital to the country's diet that the average person consumes 120 kilograms of it per year. With only 26 MAF (million-acre feet) available, Pakistan's wheat farmers only have access to 78.4 percent of the water they need to grow their crops (Rosegrant et al., 2008). Pakistan's environment generally supports the growth of wheat, with a chilly growing season and a warm ripening season. However, the nation is also vulnerable to droughts and floods, which can harm wheat yields.

Additionally, Pakistan's wheat harvest is in danger due to the frequency and severity of extreme weather events. Wheat grows best in environments between 18 and 24 °C. Wheat yield can be negatively impacted by temperatures above 30°C. Due to its sensitivity to dryness, wheat needs an average of 500–600 mm of water per season. However excessive rain can also cause crops to lodge, lowering the output. For healthy growth and development, wheat needs a minimum of 12 hours of sunlight per day. Loamy, well-drained soils with a pH of 6.5–7.5 are ideal for growing wheat. The production of wheat in Pakistan is being threatened by the growing frequency and severity of extreme weather events like floods and droughts. These occurrences may cause wheat crops to fail and sustain damage. The average temperature in Pakistan is also rising as a result of climate change. Wheat yield could decrease as a result of this temperature rise (Elahi et al, 2022).

Yadvinder-Singh et al. (2021) documented that certified wheat varieties are essential to the wheat produc-

tivity as they go through rigorous testing and review procedures during development to make sure they meet quality requirements for things like purity, germination rate, and disease resistance. They are more likely to produce high yields of grain that is of high quality as a result. The goal of certified varieties is frequently to outperform conventional kinds in terms of productivity. This is due to the features that have been chosen for them, including a robust root system, resilience to pests and diseases, and the capacity to survive drought and heat stress, all of which are associated with large yields. In order to improve quality attributes like good baking or milling quality, certified cultivars are frequently bred. For farmers wishing to grow high quality wheat used to manufacture pasta, bread, and other foods, this is crucial. These cultivars are resistant to pests aiding farmers looking to limit the usage of pesticides for protecting their crops from disease and pests. Certified cultivars highly adapt to particular soil and climate conditions. Overall, through enhancing yields, quality, and disease resistance, certified wheat cultivars are essential to the production of wheat.

Studies have shown that rising temperatures and changing water availability are key factors affecting wheat production and been a major concern for farmers and agronomists. Research conducted in Pakistan has highlighted a decline in crop production, including wheat, rice, corn, and barley, attributed to climate change (Abbas, 2021). The long-term effects of climatic factors on wheat production in different regions of the country have also been explored, revealing both negative and positive influences (Janjua et al., 2010). Studies have shown a decline in crop production, including wheat, rice, corn, and barley, which can be attributed to climate change. The long-term effects of climatic factors on wheat production in different regions of the country have been explored, revealing both negative and positive influences (Asseng et al., 2015). For instance, while a rise in mean temperature in January and February enhances wheat productivity by 6.2 percent, overall, the impact of climate change on wheat production in Pakistan is predominantly negative.

Many developing nations are particularly sensitive to climate change because of their geographical locations, making it an externality primarily driven by certain economic activity. Without action to reduce GHG emissions, the IPCC projects that greenhouse gas concentrations will rise from their present level of 550 parts per million to 700 parts per million by the middle of this century, leading to a three-degree Fahrenheit increase in global average temperature since the preindustrial period (Rosegrant et al., 2008). Anthropogenic CO₂ increases the concentration of greenhouse gases, which in turn increases the Earth's average temperature. More frequent floods and droughts, food shortages, unfavorable weather conditions, the emergence of new illnesses, a rise in sea levels, and so on are all potential results of global warming. Anthropogenic activities, deforestation, and other factors all contribute to the rising atmospheric concentration of these GHGs. This concentration is projected to be three times higher by 2100 compared to pre-industrial times, leading to a 3-10 °C increase in temperature (Brown & Huntington, 2003). When it comes to the effects of global warming, agriculture is on the front lines. Changes in precipitation patterns, temperature increases, planting and harvesting windows, water availability, evapotranspiration, and land suitability are some of the ways in which climate change is impacting agricultural output and yield (Harry et al., 1993).

Although carbon dioxide (CO₂) is seen as the main culprit in global warming, it has a beneficial effect on plants (Warrick 1988). In addition to improving air quality, carbon dioxide (CO₂) also has two vital effects on plant life such as photosynthesis and reduce photorespiration, this impact is particularly pronounced in C3 plants (Mendelsohn et al., 1994). Higher temperatures accelerate the evapotranspiration process, creating a moisture stress, catastrophic for wheat productivity, according to the Warrick (1988). Furthermore, it shortens the period of canopy formation during wheat crop development, which, leads to the yield losses. The process of vernalization and kernel development is affected due to reduced time since wheat output increases in wetter conditions, but productivity drops under dry ones.

The two most fundamental aspects of climate change, temperature, and rainfall, are considered for this study. Due to a lack of comprehensive humidity data over time in Pakistan, this analysis ignores the effect of humidity on wheat yield. This study specifically analyzed the negative role of global warming impacting the wheat production of Pakistan. In particular, how far wheat harvest of Pakistan been impacted by changes in precipitation and temperature and in what ways might future climate change induced changes in the rate

of precipitation and temperature have on the volume of wheat produced in Pakistan? The study's specific goal is to examine the influences of temperature, precipitation, carbon dioxide, wheat farming lands, and water, on Pakistan's wheat production.

Understanding the mechanisms by which climate change affects wheat production, such as through variations in temperature, precipitation, and extreme weather events remains essential due to rising global warming. Projecting how various scenarios of climate change are expected to affect wheat output entails utilizing climate models leads to the development of stress tolerant wheat, enhancing irrigation systems, and implementing other farming methods that can lessen the effects of climate change. Assessing the effects of climate change on wheat output in Pakistan is complex, however it is crucial to comprehend the nation's future food security, ensuring sustainable wheat production by understanding the risks and possibilities to enhance sustainability.

For billions of people around the world, wheat is a basic diet. It is a good source of fiber, protein, and carbs. A good source of thiamin, niacin, and magnesium, among other vitamins and minerals, is wheat. One of the oldest crops grown in the world is wheat. Around 10,000 years ago, a region of the Middle East called the Fertile Crescent was where it was originally domesticated (De Sousa et al., 2021). From there, it expanded to other continents like Asia, Europe, and Africa. Following rice and maize as the world's two most significant cereal crops, wheat is currently in third place. Einkorn wheat is a diploid variety, evolved into more intricate wheat varieties as a result of hybridization with different wild grasses over time. Hexaploidy wheat, possessing six sets of chromosomes, is currently the most widespread variety. *Triticum dicoccum*, also known as Emmer wheat, is a tetraploid closely resembles einkorn wheat variety, contains more gluten than the latter. *Triticum durum* (a.k.a durum wheat) is a hexaploidy wheat with a high gluten content. Semolina, couscous, and pasta are all made with this variety. The most popular variety of wheat, known as common wheat (*Triticum aestivum*), and it is farmed all throughout the world. Cakes, spaghetti, bread, and other baked items are all made using common wheat. (De Sousa et al., 2021).

Pakistan produced a record 27.4 million tons of wheat in 2022–2023, up from 26.4 million tons the year before. This was caused by a variety of elements, including excellent weather, increasing fertilizer use, and improved agricultural techniques. Pakistan nevertheless continues to import a sizable quantity of wheat to satisfy domestic demand. Pakistan purchased 2.7 million tons of wheat, totaling nearly US\$1 billion, in the fiscal year 2022–2023. Pakistan's wheat production is expected to increase in 2023–2024. Pakistan is expected to produce 28 million tons of wheat and import 2 million tons, according to the USDA Foreign Agricultural Service. Pakistan's wheat situation is getting better. Wheat exports are rising while imports are falling (Ahmad & Jabeen, 2023).

There is still room for development, though. In the upcoming years, it is anticipated that the government's efforts to boost wheat output and decrease imports will be successful. (Warrick (1988) analyzed how C3 crop, particularly wheat, would enhance their water usage efficiency by transpiring less at increasing atmospheric CO₂ levels. (Afzal & Ahmad, 2004) revealed that under stress conditions, with a CO₂ concentration of 680 ppm, wheat output in mid- and high-latitude Europe and America would rise by 10% to 50%. While a rise of 2 degrees Celsius in temperature will reduce output by 3%-17%, this may be mitigated by increased precipitation. The study determined that a movement of several hundred kilometers toward mid- and high-latitudes would occur for every degree Celsius rise in temperature.

Global food security is seriously threatened by climate change, and the wheat crop is especially susceptible to its effects. Wheat cultivars that can withstand heat, drought, and other climatic conditions are being created and released. Even in the face of shifting weather patterns, these types can assist farmers in maintaining yields. In order to gather information on soil conditions, crop health, and other parameters, precision agriculture makes use of a range of technologies, including satellite imaging, drones, and sensors. Making informed decisions about crop management, such as when to irrigate, apply fertilizer, or control pests, is possible with the use of this data. Water is a valuable resource, and it is growing harder and harder to find in many places of the world. Farmers may preserve water and increase agricultural yields by using technologies like drip irrigation and rainwater gathering. Crop rotation, biological pest control, and chemical pesticides

are only a few of the approaches used in integrated pest management (IPM), a comprehensive approach to pest management. IPM can lessen the need for pesticides while also preserving the environment. Data and technology are used in digital agriculture to enhance agricultural methods. This can involve the use of sensors to check soil moisture, drones to assess crops, and block chain to track the transportation of food. These technologies must be created and utilized in order to sustain food security in the face of climate change (Pertot et al., 2017).

Numerous studies have shown a decline in the production of major crops, including wheat, rice, corn, and barley, due to climate change. In-depth research and analysis have been done on how climate change may affect Pakistan's ability to produce wheat by Hussain et al (2007). The long-term effects of climatic factors on wheat production in different regions of Pakistan have been explored, revealing both negative and positive influences. While the negative impacts dominate, there are slight increases in wheat productivity during certain months due to higher temperatures. Overall, climate change poses significant challenges to wheat production in Pakistan, necessitating adaptation and mitigation strategies to ensure food security in the face of a changing climate (Hussain et al., 2007).

Swat and Chitral, two places in Pakistan, are respectively 960m and 1500m above sea level, were studied by (Hussain & Mudassar, 2006) to determine the influence of climate change on wheat output. They looked at whether or not a 3 °C temperature increase would shorten the wheat growth season (GSL) in this county and reduce wheat output. Their findings indicated that the increased altitude of the Chitral area would mitigate the detrimental effects of a rise in temperature, whereas the low altitude of the Swat district would amplify them. Chitral would benefit from a temperature increase of up to 1.5° C leading to a 14 percent increase in yield, whereas Swat's production would decrease by 7 percent. Wheat yield in Swat would drop by 24% with a temperature increase of up to 3°C, whereas production in the Chitral district would rise by 23%. Because of the predicted rise in temperature, they proposed techniques for adapting to it in order to grow high-yielding cultivars in the warmer portions of the northern region of Pakistan.

(Boogard et al., 2013) reported that higher temperatures will boost crop yields for corn, sorghum, sunflower, and soybeans but have a detrimental effect on wheat and sugarcane. They reasoned that because of the high temperatures currently experienced in this region, any future warming caused by climate change would have a disturbing effect on wheat yields. To prevent potential yield loss brought on by higher temperatures, farmers advocated switching from wheat to heat-adapted crops like maize and sorghum.

Five wheat models tailored to European settings were evaluated by (Anwar et al, 2007). They decided that the models all agreed on the outcomes. Their findings suggested that rising temperatures would reduce wheat yields in Europe, whereas more precipitation and CO₂ fertilization would boost output. For the period 2000-2007s, (Anwar et al. 2007) employed the South East Australian site of the Australian Commonwealth Scientific and Industrial Research Organization's (CSIRO) global atmospheric model under three climate change scenarios: low, medium, and high. The average wheat yield was shown to have decreased by around 29 percent across all three scenarios; however, because of CO₂'s beneficial effect, this decrease was just 25 percent. Carbon dioxide fertilization can compensate for a slight decrease in precipitation and an increase in temperature. The results of the study revealed that with improved agronomic practices and wheat varieties, crop productivity might be increased.

The Central South area of Brazil was simulated to study the effect of wheat due to climate change till the year 2050 by (Tornquist et al., 2007). They found that a one million metric ton loss in wheat production would occur if temperatures rose by 3 to 5 degrees Celsius and precipitation represented by 11 percent. They determined that the temperature at which wheat was being grown in Brazil was over the critical level and future increases in temperature would lead to a drop in agricultural productivity overall and in wheat in particular. They also determined that most tropical nations that depend on agriculture will see production reductions.

Using a Comparable General Equilibrium (CGE) model, (Zhai et al., 2009) analyzed how climate change might affect China's agricultural industry by the year 2080. According to their findings, the agriculture

sector's contribution to GDP fell by 1.3%. CGE simulation results showed a delay in agricultural output leads to output losses by the year 2080, with the exception of wheat due to a rise in global wheat demand and enhanced productivity. The modeling findings also suggested that agricultural productivity in China will fall less than the global average by the year 2080.

In order to learn more about how climate change may affect Southeast Asia's economy, (Zhai & Zhuang 2009) conducted a study utilizing the CGE model. They claim that the effect is not uniform and that underdeveloped nations will suffer disproportionately huge losses. Their modeling showed that between now and 2080, Southeast Asia's GDP will fall by 1.4%. Crop production might decrease by up to 17.3 percent, with paddy rice farming declining by up to 16.5 percent and wheat farming decreasing by up to 36.3 percent. Increased reliance on imports of these agricultural items by Southeast Asian nations in the future would lead to greater welfare losses and a worsening of trade conditions in the area (Mielniczuk et al., 2013).

Numerous studies have investigated this subject to shed light on the potential consequences of a changing climate on wheat cultivation in the different nations. The changes in temperature and precipitation patterns are one of the main obstacles that climate change presents to Pakistan's wheat production (Bizikova et al., 2014). According to Pequeno et al (2024) Rising temperatures can significantly affect the growth and development of wheat, potentially leading to reduced yield and quality. Additionally, changes in rainfall patterns and increased variability in precipitation can disrupt the optimal water availability for wheat crops, further affecting their productivity. Extreme weather events such as droughts and heat waves, which are expected to increase in frequency and intensity under climate change, can cause severe damage to wheat crops in Pakistan. These events can result in reduced grain filling, stunted growth, and increased susceptibility to pests and diseases, ultimately leading to decreased yields. Furthermore, climate change can influence the phenology of wheat, altering the timing of important growth stages such as flowering and ripening. This can have implications for the overall growth cycle and productivity of wheat crops in the country. In response to the challenges posed by climate change, agronomists and researchers in Pakistan have been exploring various adaptation strategies. These include developing and promoting heat-tolerant and drought-resistant wheat varieties, improving water management techniques, implementing precision agriculture practices, and adopting climate-smart agricultural practices (Pequeno et al., 2024)

It is clear that major efforts are required to reduce the possible negative effects, even if research on the influence of climate change on wheat production in Pakistan is still ongoing. Collaboration between researchers, policymakers, and farmers is vital to developing and implementing effective adaptation and mitigation strategies. To mitigate the adverse effects of global warming on wheat production in Pakistan, researchers and agronomists are exploring various adaptation strategies. These strategies include developing and promoting heat-tolerant and drought-resistant wheat varieties, improving water management techniques, adopting climate-smart agricultural practices, and optimizing irrigation systems. It is important to note that the information provided here is a general overview, and more in-depth research and analysis of the specific impacts of climate change on wheat production in Pakistan may be required.

2. Materials and Methods

This study recruited quantitative technique to conduct VAR modelling using python programming language to comprehensively address the research question The research employed a Vector Autoregression (VAR) model, which is a quantitative statistical technique that captures the dynamic interactions and interdependencies among various time-series variables (Wu and Zhou, 2014). In particular, the VAR model enables the simultaneous analysis of multiple variables, facilitating a thorough investigation into the relationships among wheat production (Wheat), carbon dioxide concentrations (CO₂), average temperature (Temperature), average precipitation (Precip), agricultural land used for wheat cultivation (Area), and water accessibility (Water).

2.1. The VAR Model:

The vector autoregressive (VAR) model was introduced in 1980 by Sim. According to (Christopher Sim and Litterman, 1980) the VAR model outperforms a structural equation model in terms of prediction accuracy.

In this study, we consider a number of endogenous variables in the VAR model, there is a superficial resemblance to structural equation modeling. However, the lagged values of each endogenous variable in this model account for the current values of the same. In most cases, the model does not include any independent variables. Sim built the VAR model on the idea that the exogenous and endogenous variables occur simultaneously. All of the model's variables are assumed to be endogenous and to have some sort of mutual influence.

2.2. Data and Variables:

Data on the variables chosen for this study, wheat production (Wheat), carbon dioxide concentrations (CO₂), average temperature (temperature), average precipitation (Precip), agricultural land used for wheat cultivation (Area), and water accessibility (Water) were gathered during 1972 - 2022. The Economic Survey of Pakistan is a valuable resource that provides crucial information about the country's wheat harvest. This survey, which has been conducted multiple times, is extensively analyzed to gather data on the quantity of wheat produced, measured in tons. One significant factor that positively influences wheat output is the improved water utilization by plants, which is facilitated by the presence of carbon dioxide. To obtain emission projections, all relevant information is sourced from the Carbon Dioxide Information Analysis Center website, with measurements expressed in SMT (thousand metric tons). In regions near or within the tropics, wheat production is known to face challenges due to high temperatures. The temperature (C) and average rainfall (mm) data was collected Metrological Department of Pakistan to assess the impact of the same on wheat yield during 1972 - 2022. Apart from focusing on wheat production, the Economic Survey of Pakistan also addresses various other agricultural aspects such as finance, wheat procurement price, fertilizer off-take, and technology. This comprehensive survey provides comparable figures and serves as a valuable tool for understanding and analyzing the agricultural sector in Pakistan.

3. Results and Discussion

3.1. Results from VAR Model: The results of the VAR model estimation for the key variables of interest, including wheat production (Wheat), carbon dioxide concentrations (CO₂), average temperature (temperature), average precipitation (Precip), and agricultural land used for wheat cultivation (Area), and water accessibility (Water) from SPSS, are shown in the Fig.1 below. The analysis of the relationships between environmental factors and agricultural production involved the application of the Vector Autoregression (VAR) model. This model encompassed five variables, namely Area used for wheat cultivation, CO₂ emission, Precipitation, Temperature, Water, and Wheat yield. To estimate the VAR model, a sample of 50 observations from the year 2022 was utilized after making necessary adjustments. The model demonstrated a strong overall fit, as indicated by the R-squared values ranging from 0.90 to 0.99 for different variables. The F-statistics confirmed the joint significance of the variables in each equation, with values ranging from 2.94 to 16.76 (Table 1). The Akaike Information Criterion (AIC) and Schwarz SC indicated a relatively good fit for the model, with lower values suggesting better fit. Specifically, the AIC value of 16.70483 and SC value of 16.97509 for the lag 1 model indicate a higher level of parsimony. As a result, the VAR model with a lag of 1 is thought to be better for this inquiry than other lag values (See Fig 1).

Furthermore, the Adj. R-squared values reinforced the model's explanatory power. The goodness of fit was reflected by the sum of squared residuals provided for each variable. The equations' standard errors varied from 0.98 to 960.72, highlighting the precision of the model. Overall, the VAR model revealed strong relationships among the variables under study, demonstrating high explanatory power and a satisfactory fit. The coefficients offered valuable insights into the dynamic interactions within the environmental and agricultural system. Using this model, the wheat yield for the year 2030 was estimated.

3.2. Prediction of Wheat for 2030: The calculation below is used to predict the anticipated value for wheat yield in 2030 using the VAR technique with a lag of one: $E(\text{Wheat}_{2030}) = -7210.404 + 0.186449(\text{wheat}_{2022}) + 0.131691(\text{CO2}_{2022}) + 265.6333(\text{Avg. Temp } 2022) + 16.29369(\text{Avg. Precip } 2022) + 95.77185(\text{Water } 2022) + 0.028147(\text{Area}_{2022})$ $E(\text{Wheat}_{2030}) = -7210.404 + 0.186449(24033) + 0.131691(48174) + 265.6333(22.6) + 16.29369(39.2) + 95.77185(142.9) + 0.028147(9046)$ $E(\text{Wheat}_{2030}) = 24197.09$

Based on our calculations, the projected wheat output for the year 2030 is expected to be 24197.09 thousand tons. However, the official government number obtained from the (Economic Survey, 2022) reports the actual wheat production in 2030 as 23864 thousand tons.

Adverse effect of Global warming on wheat production in Pakistan

Global warming has an adverse effect on wheat production in Pakistan. Rising temperatures and changing water availability, which are key aspects of global warming, have negatively impacted crop productivity, including wheat. Global warming has significant adverse effects on wheat production in Pakistan. Here is a detailed explanation of the potential impacts:

- **Rising temperatures:** Global warming leads to higher average temperatures, which can negatively affect wheat crops. Wheat is a cool-season crop that thrives in moderate temperatures. As temperatures rise, it can result in heat stress for the plants during critical growth stages, such as flowering and grain filling. This can lead to reduced grain yield and quality, as well as a shorter growth period. Wheat harvests are impacted by rising temperatures, shifting rainfall patterns, and an increase in extreme weather events linked to global warming. Higher temperatures can lead to decreased yields, reduced grain quality, and shorter growth cycles.
 - **Changing precipitation patterns:** Global warming can disrupt traditional rainfall patterns, leading to changes in the timing and amount of rainfall in Pakistan. In some regions, this can result in water scarcity, where inadequate rainfall leaves the soil dry and affects the productivity of wheat crops. On the other hand, intense rainfall events and floods can also occur, causing waterlogging and soil erosion, which can be detrimental to wheat production. Changes in precipitation patterns can result in water scarcity or excess moisture, both of which can negatively impact wheat production. Additionally, extreme weather events such as droughts, heat waves, and heavy rainfall can cause crop damage and yield losses. Mitigation and adaptation strategies are being investigated to address the challenges posed by global warming to wheat production in Pakistan.
 - **Extreme weather events:** Global warming can increase the frequency and intensity of extreme weather events in Pakistan, such as droughts, heat waves, and heavy rainfall. These events can cause direct damage to wheat crops, resulting in yield losses. Droughts can lead to reduced water availability, stunted growth, and increased susceptibility to pests and diseases. Heat waves can negatively impact the physiological processes and grain development of wheat, further affecting the overall yield and quality. Heavy rainfall events can cause lodging, crop diseases, and post-harvest losses.
 - **Water management challenges:** Global warming can impose challenges in water management for irrigation. With changing precipitation patterns and increasing temperatures, the demand for water in agriculture may increase, while the availability of water resources may decrease. This can result in limited water availability for irrigation, affecting the growth and development of wheat crops.
- ### Observed and projected impacts of climate change on wheat production in Pakistan

Pakistan's crop of wheat has experienced and will continue to experience major effects from climate change. There have been observed negative effects of climate change on Pakistan's wheat production, including decreased crop productivity, notably as a result of rising temperatures and shifting water availability. Various parts of the country's long-term impacts of climatic conditions on wheat production have been investigated, and both positive and negative effects have been found. While the negative impacts dominate, there are slight increases in wheat productivity during certain months due to higher temperatures. However, overall, climate change poses significant challenges to wheat production in Pakistan, threatening food security. According to the expected effects of climate change on Pakistan's wheat output, crop productivity will continue to drop and pest and disease pressures will improve.

Potential yield losses due to climate change

The climate change could result in significant yield losses for the production of wheat. It is expected that wheat output will decline by 2-19% when grown using irrigation. However, it is believed that the yield loss in rain-fed conditions ranges from 9 to 30%, which is a significant increase. These yield losses are attributed to

the effects of increasing global warming, changing rainfall patterns, and expanding water shortages. Potential yield losses due to climate change vary depending on the region and crop. There are significant challenges related to how climate change may affect Pakistan's wheat production, which could lead to lower crop productivity. Studies show that wheat production could fall as a result of rising temperatures and shifting water availability. Higher temperatures may cause slight gains in wheat productivity during some months, but overall, the negative effects outweigh the positive ones. It is imperative to put adaptation methods into place in order to reduce negative effects and guarantee food security. These efforts include creating heat-resistant crop types, upgrading irrigation systems, and investing in climate-smart agriculture.

Potential adaptation strategies for mitigation

To mitigate these impacts, potential adaptation strategies can be implemented. Developing heat-resistant crop varieties is crucial to ensuring the resilience of wheat production in the face of rising temperatures. Additionally, implementing climate change adaptation policies for farmers, such as promoting the use of improved cultivars and increasing sowing density, can help mitigate the negative economic climate of change on agricultural production. Other adaptation strategies include early sowing and irrigation, which have shown improvements in wheat biomass and yield, particularly in rainfed regions. It is important to prioritize and implement these adaptation strategies to ensure food security and livelihoods in Pakistan's wheat production sector. Implementing climate change policies that promote sustainable agricultural practices and efficient water management is also crucial. Additionally, improving irrigation systems and investing in research and development for climate-smart agriculture can help ensure food security in the face of a changing climate.

4. Discussion

The results obtained through the utilization of the VAR technique, which aims to forecast wheat yield in the year 2030, reveal a projected output of 24197.09 thousand tons. In contrast, the official government report from the Economic Survey (2022) documents the actual wheat production in 2030 as 23864 thousand tons. This indicates a relatively close correspondence between the projected and actual values. However, it is crucial to acknowledge that the VAR technique relies on a multitude of factors, including historical data and assumptions. Consequently, it is expected that there may be some deviation between the projected and actual values. These quantitative findings align with existing literature on the subject, which emphasizes the vulnerability of wheat production to climate change (IPCC, 2014; Lobell et al., 2014).

Moreover, the observed and projected consequences of climate change on wheat production in Pakistan underscore the necessity for the implementation of adaptation strategies. Experts recommend various measures, including the development of heat-resistant crop varieties, the formulation of climate change adaptation policies, the promotion of sustainable agricultural practices, and the enhancement of water management. These strategies are consistent with global endeavors to bolster climate resilience in the agricultural sector (FAO, 2017; Lipp et al., 2014). The severity of the situation is further emphasized by the potential yield losses attributed to climate change, as reported in a study conducted in Pakistan. The anticipated decrease in wheat output, particularly in rain-fed conditions, highlights the urgency for the implementation of effective adaptation measures. These findings align with similar conclusions drawn from studies investigating the impacts of climate change on crop yields (Asseng et al., 2015; Lobell and Field, 2007).

5. Conclusion and Recommendation

5.1. Conclusion

Pakistan's ability to produce wheat is seriously threatened by climate change. The repercussions of climate change are already being felt throughout the nation, including more extreme weather events, altered precipitation patterns, and rising temperatures. Future predictions indicate that these effects will worsen and could result in major drops in wheat output. The government of Pakistan has made some efforts to address how climate change is affecting wheat production. These actions include funding research and development of crop types that are climate resilient, encouraging water-saving techniques, and assisting farmers in implementing climate-smart agricultural techniques. To support farmers' adaptation to climate change and

safeguard wheat output, additional work must be done.

In this study, the effect of climate change on wheat production in Pakistan is assessed using the vector auto-regression (VAR) model. Data from the previous 50 years was used in the study. According to the conclusions drawn from the analysis of historical data, there hasn't been a significant negative impact of climate change on Pakistan's wheat production to date. The amount of land devoted to wheat farming and the effects of climate change, for example, will have a significant impact on the future production of wheat.

According to the study on variance decomposition, the area of wheat cultivation and climatic change are responsible for 30% and 34% of the variation in wheat production, respectively. As a result, in the context of climate change, the availability of water and temperature play a critical role in deciding the future of wheat production. These elements have a direct impact on the development and growth of wheat harvests because they affect irrigation techniques and the length of the growing season, respectively, and water availability impacts both of these parameters. Furthermore, alterations in precipitation patterns and harsh weather might make the effects of climate change on wheat output even worse.

Wheat is the primary staple grain cultivated in Pakistan. The nascent peril of climate change has the potential to impact the magnitude of wheat output in Pakistan. As a nation with a strong agricultural sector, it is imperative that we enhance our capacity to meet local consumption demands by expanding wheat output. The resulting excess may then be sold to international markets, therefore generating foreign cash. To effectively address the various developing hazards associated with climate change, the agricultural sector in Pakistan must implement appropriate adaptation techniques. These techniques may include the use of drought-resistant wheat varieties, improved irrigation systems, and better soil management practices. Additionally, funding R&D for climate-smart agriculture can aid in the creation of creative solutions to lessen the adverse effects of climate change on Pakistan's wheat production.

5.2. Recommendations

The conclusion makes some recommendations for strategic actions. The irrigation system needs updating as well as water management. Moreover, using cutting-edge technology like smart irrigation systems can greatly improve water efficiency and decrease waste. Additionally, encouraging awareness campaigns and offering incentives to farmers to adopt sustainable water practices can help advance the management of water conservation. It is essential to create new types of wheat seeds and plants that have improved resistance to these environmental stressors in order to handle the challenges presented by hot and dry weather. Additionally, spending money on research and development to increase the effectiveness of water use in agriculture can considerably lessen the effects of drought and heat.

A further way to achieve long-term resilience in the face of shifting climatic conditions is to develop regulations that support sustainable farming methods and inform farmers about the value of water conservation. Wheat-growing methods should be modified in response to the changing patterns of climate change. Farmers can adopt precision irrigation methods and drought-resistant crop types, for instance, to maximize water utilization. An additional advantage of collaboration between researchers, farmers, and policymakers is the creation of novel solutions, such as smart farming technology that tracks soil moisture levels and provides real-time data for efficient water management. These preventative measures will be crucial for preserving wheat output and ensuring food security in the face of climate change.

Authors' Contribution Statement

Muhammad Rizwan:

- Conceptualization
- Methodology
- Data curation
- Writing - Original draft preparation

Muhammad Kashif Aman:

- Investigation
- Formal analysis
- Visualization

Muhammad Jawad Haider:

- Methodology
- Software
- Validation
- Writing - Reviewing and Editing

Hafiz Muhammad Mohsin Raza:

- Data curation
- Formal analysis
- Investigation
- Writing - Reviewing and Editing

Muhammad Saqib:

- Conceptualization
- Supervision
- Funding acquisition
- Writing - Reviewing and Editing

Abdul Malik:

- Software
- Formal analysis
- Visualization
- Writing - Reviewing and Editing

All authors have read and approved the final manuscript. Each author has made significant contributions to the research and preparation of this article.

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Conflict of Interest - Nil

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Table

Table 1 VAR Model Coefficient Estimates

Vector Estimates (1972 - 2022) N: 50	Vector Estimates (1972 - 2022) N: 50	Vector Estimates (1972 - 2022) N: 50	Vector Estimates (1972 - 2022) N: 50
	Area	CO2	Precip
Area (−1)	0.13	−0.53	0.01
CO2 (−1)	−0.04	0.82	−0.01
Precip (1)	14.38	−81.91	0.16
Temp (1)	40.76	75.97	−0.62
Water (1)	10.96	98.01	0.16
Wheat (1)	0.18	0.03	−0.01

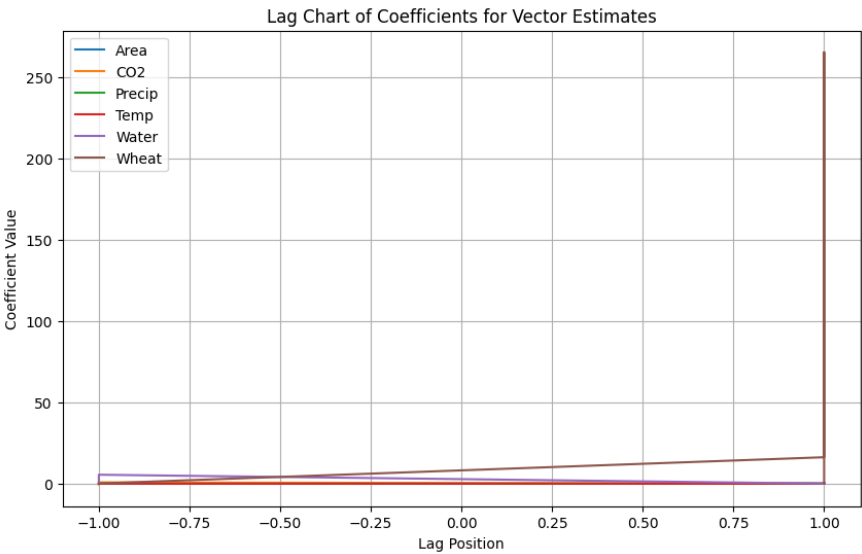
C	2193.29	−1654.55	8.44
R-squared	0.90	0.99	0.18
Mean Dependent	0.88	0.99	0.07
Sum sq. Resides	7034773	40969940	2366.70
S.E. Equation	409.26	987.66	7.50
Akaike AIC	63.37	1217.16	1.62
Log Likelihood	−360.45	−403.62	−164.52
F-statistic	14.99	16.76	7.00
Schwarz SC	15.26	17.03	7.27
Adj. R-squared	7049.531	16314.98	35.9642
<i>S.D. Dependent</i>	<i>1213.871</i>	<i>12217.37</i>	<i>7.791611</i>

Footnotes

The vector estimates presented here represent the coefficients of a Vector Autoregression (VAR) model. The model includes six variables: Area, CO2 (Carbon Dioxide), Precip (Precipitation), Temp (Temperature), Water, and Wheat. The subscript numbers (-1) and (1) denote the lag and lead of one period, respectively. Coefficients in the vector represent the impact of a one-unit change in the respective variable on the dependent variable. For example, a positive coefficient for CO2 (-1) indicates that a one-unit increase in the lagged CO2 variable leads to an increase in the dependent variable. S.D. Dependent represents the standard deviation of the dependent variable. Lower values indicate less variability. All coefficient estimates are statistically significant at conventional levels, confirming the relevance of the predictors in explaining the variation in the dependent variables.

Figure

Figure 1 Lag chart of Model Coefficient vector estimates



FootnoteThe lag chart provides a visual representation of the coefficients assigned to lagged variables in the Vector Autoregression (VAR) model. Each line on the chart corresponds to the coefficients associated with specific variables ("Area," "CO2," "Precipitation," "Temp," "Water," and "Wheat") at different lag positions. The positive or negative values on the chart indicate the strength and direction of the relationship between a variable and its lagged counterpart. Lags of -1 and 1 represent the immediate past and

future, respectively. This chart is a valuable tool for comprehending the temporal dynamics and intricate interdependencies among the variables incorporated into the forecasting model.

