Forecasting the Impacts of Climate Variability on Cotton Production in South Punjab, Pakistan

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Cotton, an important crop in Pakistan, contributes 0.8% of GDP and 4.1% of total agricultural value added. However, it faces challenges such as a reduction in area under cultivation, unfavorable weather conditions, whitefly infestation, crop stunting, bollworms, and other insect pests. The objective of this study is to identify the factors contributing to the decline in cotton production in selected districts of southern Punjab in Pakistan during the period 2004-2020. The second objective of this study was an over-time analysis of secondary data to calculate compound growth and forecast area production and average yield in Punjab, Pakistan. Data was collected from secondary sources and analyzed using SPSS and Microsoft Excel. The results showed that Rahim Yar Khan and Khanewal had no impact on production, while Lodhran had a significant impact due to the minimum temperature. A decrease in minimum temperature by one unit led to a decrease in cotton production by 21947. Pearson's correlation showed a weak relationship between humidity and cotton yield in the study area. The time series analysis revealed that cotton production in Khanewal and Multan districts will increase in the future, while in Jhang, Sahiwal, Pakpattan, Vehari, and Rahim Yar Khan districts will experience a declining trend. Previous studies suggest that Pakistan's crop production could be significantly affected by a reduction of rainfall, a 0.5-degree rise in temperature over the last three decades, and changes in the frequency of droughts and floods. This study aims to develop a policy framework involving suitable cotton varieties to improve cotton production and raise the country's GDP.

Keywords: Forecasting; Climate Variability; Impacts; Cotton Production; South Punjab

Introduction:

Pakistan is the fourth largest cotton producer in the world, the second largest exporter and the third largest exporter (USA, ICAC), and the third largest fabric producer in the world. Cotton products account for around 60% of Pakistan's foreign revenue [1]. However, cotton and its derivatives account for at least 2% of Pakistan's gross domestic product, and agriculture contributes to about 10% of the country's value-added [2][3][1][4]. Cotton is grown by 1.3 million farmers (out of a total of 5 million) on 3 million hectares, which represents 15% of the country's cultivated area [5]. Pakistan's cotton production is the largest industrial sector and includes 400 textile mills, 7 million spindles, 27,000 looms, over 250,000 other looms, 700 knitting units, 4,000 garment units, 650 dyeing and finishing units, and 650 kohls units. This sector is the most important economic sector in Pakistan, with a processing capacity of 1,150 million square meters per year [6].

Cotton faces challenges such as low per-acre yields, increased insect and pest attacks, high agricultural input prices, irrigated water shortage, lack of research and pest-resistant seeds, and unexpected rain, drought, and floods. To increase production, grow crop area, per-acre yield, or both. [7]. Due to a shortage of irrigation water in other provinces, increasing the area under cultivation is difficult to achieve, as major cotton-producing provinces are already working at full capacity [7]. Pakistan's cotton belt extends for 1200 kilometres along the Indus River, between 27- and 33-degrees north latitude and altitudes of 27 to 153 meters [8]. Cotton has a vertical taproot system and is more tolerant of higher temperatures and droughts than other crops. It is made in the hot and dry regions of Punjab and Sindh, as well as along the Indus River [7]. It is primarily grown in the districts of Bahawalnagar, Bahawalpur, Rahim Yar Khan, Multan, Vehari, D.G. Khan, Khanewal, Rajanpur, Muzaffargarh, and Lodhran in Punjab [8].

Total cotton production grew more than elevenfold between independence and the peak year of 1991–92, from 0.2 to 2.2 million metric tons. The most drastic expansion occurred during the 1980s, when production tripled from a four-year average of slightly more than 0.7 million metric tons in 1979–82 to 2.2 million in 1991–92 [6]Banuri, 1998). Yields increased dramatically in the 1980s, increasing from 364 kilograms per hectare in 1982–83 to 769 kilograms in 1991–92. This was also the period with the greatest increase in pesticide use [6]. The peak reached in 1991–92 was followed by another extreme and persistent pest attack, this time by the leaf curl virus and its disease vector, the whitefly, as it had been 20 years before. Yields decreased from 769 kilograms per hectare to between 500 and 600 kilograms per hectare [6]. After a time of increasing pesticide use and consequent yield expansion, the cotton crop experienced a period of crisis, which was associated with pest attacks and the rise of pest resistance [6].

According to [9], Pakistan cotton production for the year 2007–08, production is expected to be 11.7 million bales, down 9.3 percent from the previous year's 12.9 million bales. From 2008 to 2013, the value of Pakistan's and the world's cotton exports increased but then began to decline until 2018 [5]. Pakistan fell short of its goal of 10.671 million bales of cotton in 2016–17 [10]. Pest infestations, a slow marketing system, and a major reduction in sowing area all contributed to the reduced volume [11]. During 2017–2018, the total area under cotton cultivation was 2,700,000 ha, which decreased to 2,373,000 ha in 2018–2019. Cotton production decreased from 11,946,000 bales in 2017–2018 to 9,861,000 bales in 2018–2019, and per-hectare yields shifted from 753 kg in 2017–2018 to 707 kg in 2018–2019 [12].

Cotton fibre is a single-celled system that aids in cell expansion and cellulose biosynthesis, unlike the evolution of seeds' dermatogens. Each cotton seed kernel contains over 1.5 million fibres, with connected genes aiding in genetic understanding. These fibres differ from dermatogens and are unbranched and unicellular. [1]. Fiber length, or staple length, is a crucial factor in cotton fiber quality. It influences yarn fineness, strength, and spinning efficiency. Longer fibres can be processed more efficiently, resulting in finer and stronger yarns, while shorter fibres require more twisting, leading to low-strength, poor-quality yarns. Therefore, fibre length is essential for achieving high-quality cotton fibres. [13]. The strength of cotton fibre is determined by the average length of cellulose molecules, with longer chains resulting in stronger fibres. Fiber quality traits are quantitative and heavily influenced by the environment [13].

Fiber length is a standard dimension along the length of a thread, the quantity of more than 50% of the load in a sample. The extent of fibre: 25% of the fibres by weight are lengthy, and 75% less than the length gained [14]. The cotton varieties that are grown in southern Punjab are MNH-786a, CIM-448a, FDH-170b, FH-628b, FDH-170b, CIM-496c, Neelam-121c, CIM-465c, CRSM-38d, NIBGE-2d, NIBGE-1e, NIAB-846e, IR-1524, VH-305, NIAB-78, B-821, NIAB-26, FH-113, AGC 999, CIM 109, TS-103, CYTO-177, FH-87, FH-657, MNH-516, IR 3701, B 820, BH 118, AA 703, AC 134, MM 58, B 803, FVH 49, 149-F, S 12, FH 629, MVH 518, VS-13, Tarzan-1, FH-113, TSR-2375, NIAB 846, FH Lalazar, CIM 240, CIM 1100, [15].

Previous studies suggest that Pakistan's crop production could be significantly affected by reduced rainfall, a 0.5-degree rise in temperature over the last three decades, and changes in the frequency of droughts and floods. [16]. Agriculture relies on the Indus River for irrigation, but water reserves from glaciers such as the Karakoram, Himalayan, and Tibetan glaciers are depleting due to decreasing snowfall and rising temperatures, leading to flooding and crop failures in southern Punjab and Sindh. [7]. The growth and production of cotton would be favoured by rising temperatures as long as it does not reach 32 °C due to its vertical taproot. 28.5 °C is the optimum temperature for maximum cotton yields [8]. [7] points out that the annual temperature in Pakistan rises during flowering and boll formation in cotton cultivation, which is exacerbated by the increase in pathogens and insect pests, the use of fertilizers and pesticides, and declining human health.

The contraction in the cultivated field, severe weather conditions, whitefly attacks, crop stunting, bollworms, and other pest insects are all threatening the cotton crop's production and productivity development [7]. This research investigates the impact of climate change on cotton production in southern Punjab, Pakistan. It examines the area, production, and yield of cotton over time and forecasts the crop's production for the study area districts. The aim is to understand how different climatic impacts influence cotton productivity and provide useful information for policies aimed at increasing cotton output.

Data and Methodology:

Study Area:

Punjab, Pakistan's second-largest province, contains 25.8% of the country's landmass. South Punjab, also known as the cotton belt, is the study area for this study. The districts with a percentage change in production and area of over 40% from 2004-2020 are selected from the data sets of Southern Punjab districts. These districts are known for their high cotton production. The selected districts with a percentage change in Production and Area of greater than 40% are Khanewal, Lodhran, Multan, Sahiwal, Rahim Yar Khan, Vehari, Pakpattan, and Jhang. Punjab, Pakistan's most populated province, is situated in the semiarid lowlands zone, 27°-34° north latitude and 69°-75° east longitude. It is situated on the northwestern edge of the Indian plate in South Asia. The province is known for its fertile land suitable for cotton, wheat, and other crops, with about 50 years of historical evidence of pesticide use. Punjab has three major seasons: hot (April to June), rainy (July to September), and cooler/mild (October to March). The heat can reach 110 ˚F, the rainy season can reach 96 cm in the sub-mountain region and 46 cm in the plains, and the cooler weather can reach 40 ˚F. Punjab receives 7 to 8 hours of sunlight daily, with the longest period (8 to over 10 hours) from April to June and the smallest from December to March. This favourable climate allows for the growth of tropical, subtropical, and temperate crops [17].

Punjab, located in South Asia, is primarily reliant on cotton and rice for its national treasury, accounting for 76% of the country's annual food output, with nearly 80% of cotton produced using pesticides [18]. The research focuses on the eight districts of South Punjab, Pakistan, which have arid/semi-arid climates. The study, which covers 2004 to 2020, uses data from various national sources, including the Agriculture Department and the Federal Bureau of Statistics, the Government of Pakistan [19], the Pakistan Meteorological Department (PMD), and the Pakistan Economic Survey Report [19] to analyse cotton production, yield per hectare, and area under cultivation. The study also collects information on the export rate of cotton manufacturers in Pakistan.

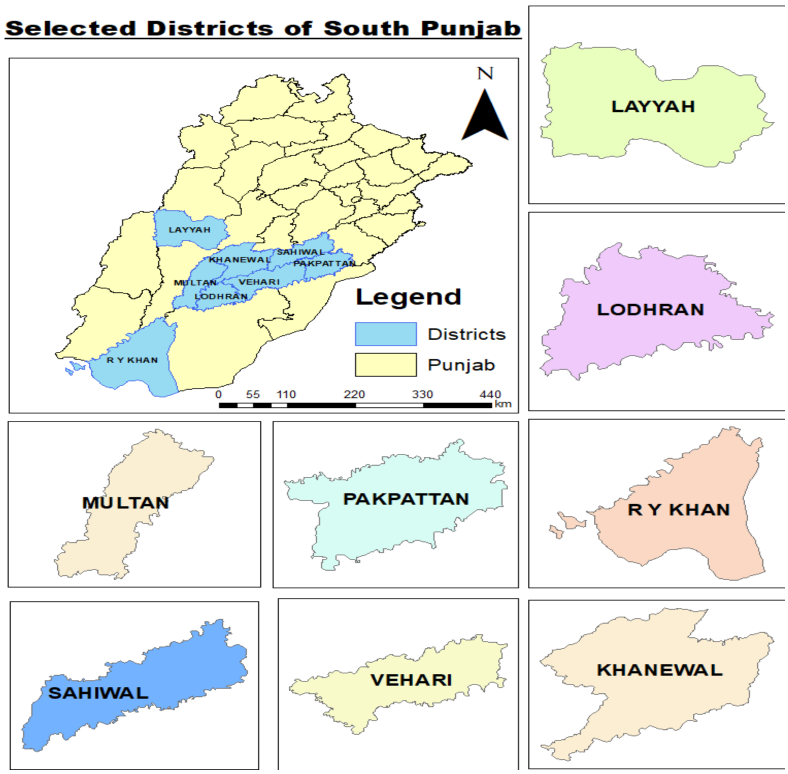


Figure 1. Selected Districts of South Punjab

Data Sources:

This research is being conducted in eight districts of South Punjab (Pak Patan, Jhang, Vehari, Lodhran, Khanewal, Multan, Sahiwal, and Rahim Yar Khan) that have an arid/semi-arid climate. As Punjab produces most of the country's cotton, the study concentrated on the districts of southern Punjab, Pakistan. The variables for this study, which spans the years 2004 to 2020, are drawn from a range of national data sources (secondary sources). **The** Agriculture Department and the Federal Bureau of Statistics, Government of Pakistan [19], provided data on cotton production, yield per hectare, and area under cultivation, while the Pakistan Meteorological Department (PMD) provided meteorological data on rainfall, precipitation, humidity, and mean minimum and mean maximum temperature. The Pakistan Economic Survey Report [19] provided statistics on Pakistan's cotton manufacturers' export rate.

Analysis:

This study used metrological data for climographs. The study by [20], [21] used the Pearson Correlation Coefficient method to check the relation of cotton growth with climatic variables in Xinjiang, China, and Southern Mali. Therefore, the Pearson Correlation Coefficient was applied in the study to check the relationship between Yield and Humidity.

Coefficient values determined the significance of the variable for cotton crop productivity. To examine the linear relationship between two variables, scatter plots were created as well. Time series analysis was applied to forecast the production of cotton crops. Time series analysis in crop output includes data evaluation compiled over time to examine the patterns, trends, and to forecast yield.

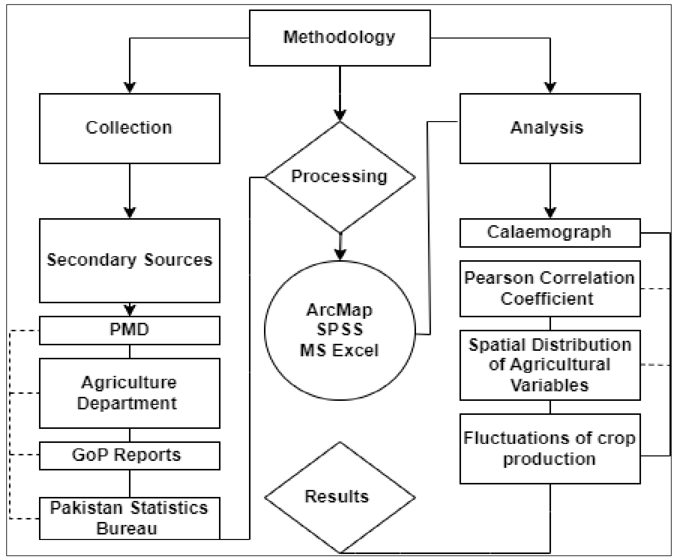
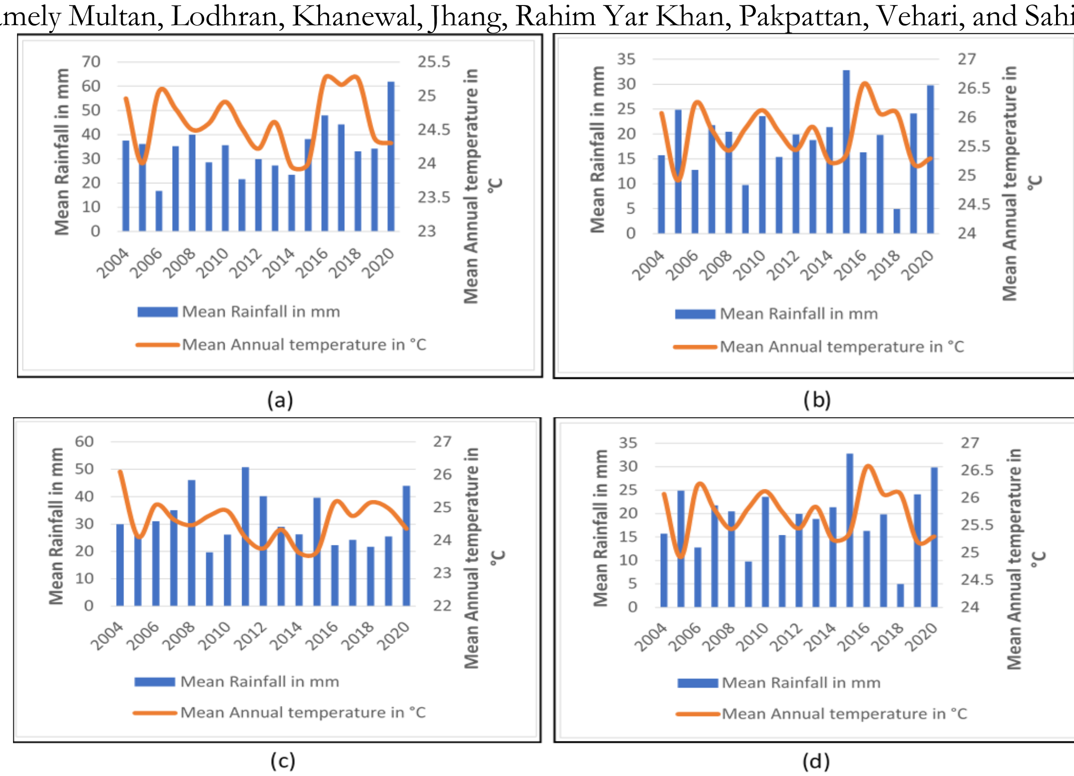


Figure 2. Methodology Framework

Results:

Impacts of Changing Trends on Local Climate:

This study used metrological data for climographs in the current study area districts, namely Multan, Lodhran, Khanewal, Jhang, Rahim Yar Khan, Pakpattan, Vehari, and Sahiwal.



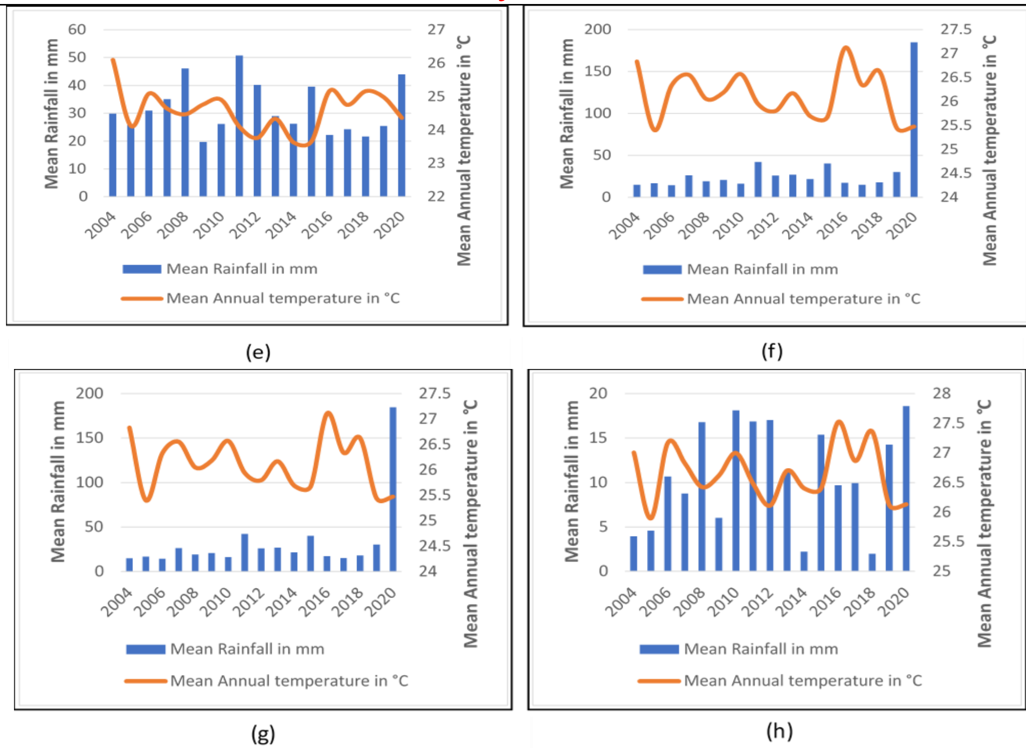


Figure 3. Chirographs of Metrological Data

Figure 3 represents the average annual temperature and average annual rainfall for the past 16 years (2004-2020) of the districts (a) Jhang, (b) Multan, (c) Sahiwal, (d) Lodhran, (e) Khanewal, (f) Pakpattan, (g) Vehari, and (h) Rahim Yar Khan. The line represents the mean annual temperature of district Jhang. Temperature is gradually increasing and decreasing throughout 16 years. In district Jhang, the lowest rainfall (16.75mm) occurred in 2006, and the highest rainfall (61.88mm) occurred in 2020. In the district of Multan, the lowest rainfall (4.95mm) occurred in 2008, and the highest rainfall (32.8mm) occurred in 2015. In district Sahiwal, the lowest rainfall (19.65mm) occurred in 2009, and the highest rainfall (50.75mm) occurred in 2011. In the district of Lodhran, the lowest rainfall (4.95mm) occurred in 2018, and the highest rainfall (32.8mm) occurred in 2015. In the district of Khanewal, the lowest rainfall (19.65mm) occurred in 2009, and the highest rainfall (50.7mm) occurred in 2011. In the district of Pakpattan, the lowest rainfall (14.48mm) occurred in 2006, and the highest rainfall (184.61mm) occurred in 2020. In district Vehari, the lowest rainfall (14.48mm) occurred in 2006, and the highest rainfall (184.61mm) occurred in 2020. In the district of Rahim Yar Khan, the lowest rainfall (1.95mm) occurred in 2018, and the highest rainfall (18.6mm) occurred in 2020.

Impacts of Climate variability on cotton yield:

Pearson Correlation Coefficient analysis is used to investigate the relationship between humidity and cotton crop yield. The tail correlation is significant at a 0.05 confidence level. From 2004 to 2017, in this study, Pearson correlation was performed between cotton yield in mnds/acres and cumulative average humidity at 5 a.m., 5 p.m., and 8 a.m.

Figure 4. Pearson Correlation Coefficient Scatter plot of the districts (a) Jhang, (b) Multan, (c) Sahiwal, (d) Lodhran, (e) Khanewal, (f) Pakpattan, (g) Vehari, (h) Rahim Yar Khan, depicts the relationship between humidity and yield. Scatter plots are useful for determining the relationships between two variables, which affirms the finding of the Pearson correlation Coefficient.

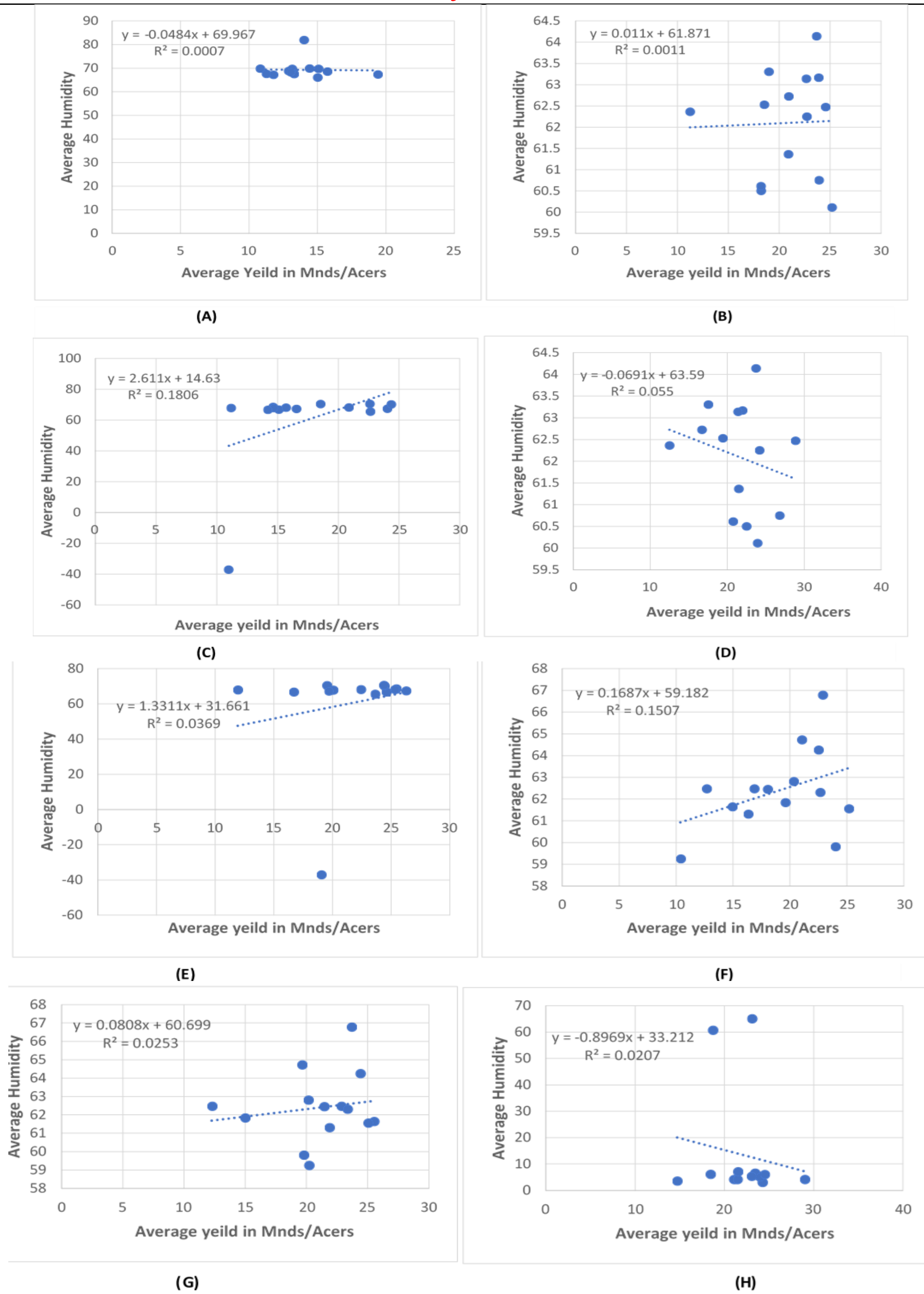


Figure 4. Pearson Correlation Coefficient Scatter plot of the districts

The significance two-tailed value for Jhang district is 0.926, which is insignificant because it is more than the α 0.05 value. The Pearson Correlation value is -0.27, indicating a low negative correlation between mean humidity and yield in mnds/acres. The significance two-tailed value for the Multan district is 0.91, which is insignificant because it is more than the α 0.05 value. The Pearson Correlation value is 0.33, indicating a low positive correlation between mean humidity and yield in mnds/acres. The significance two-tailed value for the Sahiwal district is 0.916, which is insignificant because it is more than the α 0.05 value. The Pearson Correlation value is -0.31, indicating a low negative correlation between mean humidity and yield in mnds/acres. A single value can be identified as an outlier. The significance of the tailed value for the Lodhran district is 0.420, which is insignificant because it is more than the α 0.05 value. The Pearson Correlation value is -0.23, indicating a low negative correlation between mean humidity and yield in mnds/acres. The significance two-tailed value for Khanewal district is 0.510, which is insignificant because it is more than the α 0.05 value. The Pearson Correlation value is 0.19, indicating a low positive correlation between mean humidity and yield in mnds/acres. The significance of the tailed value for the Pakpattan district is 0.170, which is insignificant because it is more than the α 0.05 value. The Pearson Correlation value is 0.38, indicating a low positive correlation between mean humidity and yield in mnds/acres. The significance two-tailed value for the Vehari district is 0.58, which is insignificant because it is more than the α 0.05 value. The Pearson Correlation value is 0.15, indicating a low positive correlation between mean humidity and yield in mnds/acres. Since the two-tailed significance value for Rahim Yar Khan district is 0.62, it is insignificant because it is more than the α 0.05 value. The Pearson Correlation value is -0.14, indicating a low negative correlation between mean humidity and yield in mnds/acres.

According to the results of the Pearson Correlation Coefficient and the scatter plots, it is indicated clearly that the districts of South Punjab, districts of Jhang, Lodhran, and Rahim Yar Khan indicate a decreasing trend, while the districts of Multan, Sahiwal, Khanewal, Pakpattan, and Vehari indicate an increasing trend. The overall findings depict a weak relationship between humidity and cotton yield.

Spatial distribution of Cotton production:

The figure below demonstrates the spatial distribution of agricultural variables: The spatial distribution of agricultural variables is depicted in Figure 4.9 by pie charts of area in 000 acres, production in 000 bales, and yield in mnds/acres. The boundaries of the study area, consisting of districts of Pakistan's southern Punjab, are highlighted in red. Pakpattan and Jhang have a high yield, according to this data. The lowest-yielding areas are Rahim Yar Khan, Khanewal, Lodhran, and Multan. Rahim Yar Khan and Lodhran are the highest cotton-producing districts, while Jhang is the least cotton-producing district. The yellow colour in the pie chart shows the area that is under the cultivation of cotton crops, with Jhang district having the most cultivated area.

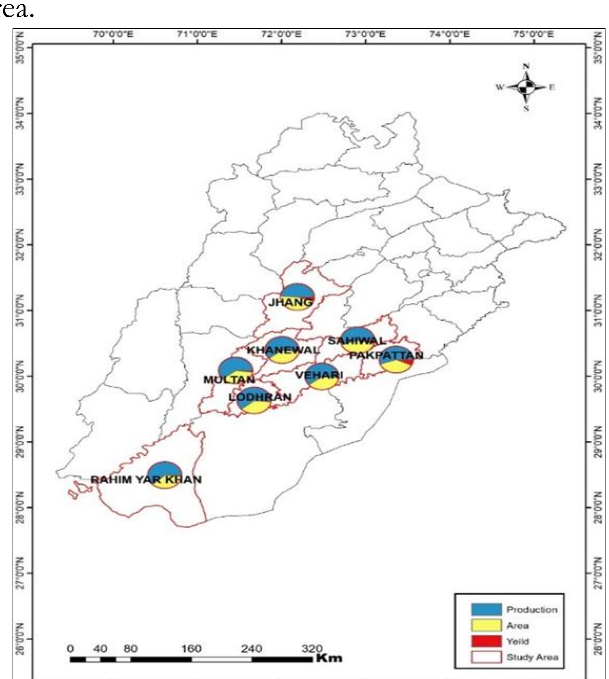


Figure 5. Spatial Distribution of Agricultural Variables

Fluctuations in cotton crop production:

For identifying fluctuations of cotton crop production, Time Series analysis is performed. The study period was narrowed down for this research to 2004-2020. Production is taken on the X-axis, and years are taken on the Y-axis.

Figure 6. Spatial Distribution of Agricultural Variables

Figure 06 demonstrates the forecasting of cotton crop production for districts (a) Jhang, (b) Multan, (c) Sahiwal, (d) Lodhran, (e) Khanewal, (f) Pakpattan, (g) Vehari, and (h) Rahim Yar Khan.

In Jhang, cotton crop production declined significantly in the years 1994, 1998, 2004, and 2020. However, the cotton crop production in 1992, 1996, 2006, 2009, and 2012 was abnormally high. As the predicted forecast shows, by 2030, the production is going to decrease slightly, so much so that 2030, it is postulated that the production might only be 54.54 bales. In Multan, cotton crop production declined significantly in the years 1994, 1998, 2004, 2010, and 2016. However, cotton crop production in 1992, 1996, 2000, 2006, 2009, 2016, and 2018 was abnormally high. As the predicted forecast shows, by 2030, the production is going to increase slightly, so much so that it is postulated that the production might only be 505.47 bales.

In Sahiwal, cotton crop production declined significantly in the years 1994, 1998, 2002, 2004, 2008, 2010, 2014, and 2016. However, the cotton crop production in 1992, 1996, 2000, 2006, 2009, 2012, and 2016 was abnormally high. As the predicted forecast shows, by 2030, the production is going to decrease so much that it is postulated that the production might only be 136.64 bales. In Lodhran, cotton crop production declined significantly in the years 1992, 1995, 1997, 1998, 2000, 2002, 2004, 2009, 2012, 2014, 2016, and 2020. However, the cotton crop production in 1994, 1996, 1998, 2001, 2006, 2010, 2012, 2015, and 2018 was abnormally high. As the predicted forecast shows, by 2030, the production is going to get so stable that it is postulated that the production might only be 536.61 bales.

In Khanewal, crop production declined significantly in the years 1992, 1994, 1998, 2002, 2004, 2008, 2010, 2016, and 2020. However, cotton crop production in 1996, 2000, 2006, 2012, and 2018 was abnormally high. As the predicted forecast shows, by 2030, the production is going to slightly increase, so much so that 2030, it is postulated that the production might only be 579.41 bales. In Pakpattan, cotton crop production declined significantly in the years 1994, 1998, 2000, 2004, 2006, 2010, 2013, 2014, 2016, and 2020. However, the cotton crop production in 1992, 1996, 1998, 2002, 2005, 2008, 2012, 2015, and 2018 was abnormally high. As the predicted forecast shows, by 2030, the production is going to slightly decrease, so much so that in 2030 it is postulated that the production might only be -16.99 bales.

In Vehari, cotton crop production declined significantly in the years 1994, 1998, 2004, 2008, 2011, 2016, and 2020. However, the cotton crop production in 1992, 1996, 2000, 2006, 2012, 2014, and 2018 was abnormally high. As the predicted forecast shows, by 2030, the production is going to decrease so much that it is postulated that the production might only be 296.32 bales. In Rahim Yar Khan, cotton crop production declined significantly in the years 1994, 1998, 2002, 2008, 20011, 2016, and 2018. However, the cotton crop production in 1992, 1996, 1997, 2000, 2006, 2012, 2015, and 2020 was abnormally high. As the predicted forecast shows, by 2030, the production is going to decrease so much that it is postulated that the production might only be -691.77 bales. Therefore, this forecast helps this study to conclude that Khanewal and Multan districts will be experiencing a slightly rising trend in the production of cotton crops by the year 2030. And Jhang, Sahiwal, Pakpattan, Vehari, and Rahim Yar Khan districts will be experiencing a slight declining trend, and the district of Lodhran will experience stability in production by 2030.

Discussion:

Cotton is a major cash crop in Pakistan and is considered the backbone of the economy. The foreign exchange market is dominated by it. Many factors affect cotton productivity, namely, socio-economic, biological, managerial, and physical. In this study, some important factors were considered to determine their effect on cotton productivity. These vital factors were minimum and maximum temperature, humidity, and rainfall. Climate change could have a significant negative impact on the production of cotton crops due to minimum and maximum temperatures, humidity, and rainfall. Any or all of these adverse factors would directly affect the income and livelihood security of cotton farmers. In past studies, we identified a strong positive correlation between severe temperature indexes and crop yield; however, other potential factors, such as the use of cutting-edge technology plant food, may lead to improved net production. Keeping this in mind, the present study was conducted to observe the impact of climate change on cotton crop production in various districts of southern Punjab, Pakistan, over the period 2004–2020. For this study, secondary data were collected from the Agriculture Department and the Pakistan Meteorological Department for analysis. The Pearson Correlation Model was applied to check the significance of this study. Scatterplots present relationships between humidity and yield. The results were highly insignificant but showed a relationship with each other. This study explains the gradually increasing and decreasing trends between the production of cotton and three weather variables, i.e., minimum and maximum temperature, rainfall, and humidity, in eight districts of Punjab, i.e., Jhang, Multan, Sahiwal, Lodhran, Khanewal, Pakpattan, Vehari, and Rahim Yar Khan. Farmers will benefit from this research because they will be able to easily identify the cause of cotton crop decline in their districts, whether it is due to rainfall or temperature, and will be able to take appropriate actions to improve production.

Conclusion:

This study presents the possible impact of climate change on cotton crop production in various districts of southern Punjab, Pakistan. The statistical analysis of Pearson correlation and time series has been used. The estimated results of the Pearson correlation have revealed that for the districts of South Punjab, there is a weak relationship between humidity and cotton yield because the results are insignificant. The estimated results of the time series analysis have revealed that Khanewal and Multan districts will experience a rising trend in the future. But Jhang, Sahiwal, Pakpattan, Vehari, and Rahim Yar Khan districts will experience a declining trend in the future.

Author's Contribution:

Muhammad Nasar-u-Minallah led the conceptualization, methodology, and data analysis, conducted the overall analysis, and wrote the manuscript. Nausheen Mazhar supervised the research and provided resources, and Sohail Abbas provided technical inputs for the research and reviewed the paper. Iqra Shahzadi and Maria Kamal reviewed and edited the manuscript.

Availability of data and materials:

Data utilized in this research are available from the corresponding author upon reasonable request.

Declarations:

Ethics approval and consent to participate:

The authors declare that they followed the ethics in scientific research.

Consent for publication:

Not applicable

Competing interests:

The authors declare no competing interests

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