Impact of Climatic Variables and Management Practices on Cotton Crop Yield of Multan District

By

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DEDICATION

To

My Loving and Caring Father and My Late Mother

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All praises, obedience, and submission to ALMIGHTY ALLAH, the propitious, the benevolent and sovereign whose blessings and glory flourish my thoughts and thrive my ambitions. I have the only pearls of my eyes to admire the blessings of the compassionate and the omnipotent because the words are bound, knowledge is limited, and time is short to express His dignity. My special praise for Holy Prophet Muhammad (PBUH) who is forever a torch of knowledge for humanity.

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ABSTRACT

The complex relationship between environmental changes and agricultural management practices has become more important considering the growing challenges posed by climate change. Thorough research is required to examine how climate change and current management techniques affect cotton crop resilience and production. The objective of this research was to investigate the decadal trends and impact of climatic variables on the cotton crop yield and to analyze the effect of current Management practices on cotton crop yield. The climate change was analyzed through Mann-Kendall trend test. The results highlighted that temperature was significantly (probability at 0.05) increasing in all three stages i.e. 304 – 319k, 309 – 314k and 305 – 311k respectively. The Rainfall trend was significantly decreasing in sowing stage (0.002-0.0003 mm day^{-1}) and maturity-picking stage (0.008-0.0007 mm $day^{-1)}$ whereas it was significantly increasing (0.001-0.01 mm day^{-1}) in emergence-flowering stage. Soil moisture displayed an overall decrease i.e. 63 – 41 m^3 m^{-3}. Survey results demonstrated that weather anomalies were affecting the cotton yield only 43.4%, pest infestations were 27%, seed quality (hybrid seeds) was 8.2%, Lack of awareness was 6.2%, High maintenance cost was 5.1%, poor soil quality was 4.3%, Sugarcane promotion was 4.1% and water scarcity was only 1.7%. All these factors were significant (Co-relation) and contributed 46% of all factors in cotton yield. In 1990 the cotton cultivation was carried out on an area of 337.9 hectares in Multan, this area reduced to 105.22 hectares in 2020. Per hectare yield was also decreased from 4.88 bales (1.05 tons) per hectare in 1990 to 2.82 bales (0.61 tons) per hectare in 2020. A decrease of 2.06 bales (0.44 tons) per hectare can be seen in these 30 years. The temporal change in climatic variables and management practices affected the cotton crop and played a vital role in this yield reduction. The findings will provide valuable insights for farmers and policy makers to enhance crop yield and adapt to changing environmental conditions.

Chapter 1

INTRODUCTION

1.1. Background Information

Climate change is one of the most important global issues now affecting economies, societies, and ecosystems worldwide. Climate change has a particularly big effect on agriculture because it can threaten food security and livelihoods through changes in temperature, precipitation patterns, and extreme weather events. Over the past century, human activities like deforestation, burning of fossil fuels and industrial processes have significantly altered the Earth's climate. As a result, greenhouse gas emissions have increased, which has caused global warming, changed weather patterns, and increased the frequency and intensity of climate events.

Climate change seriously threatens agricultural systems because it can alter precipitation and temperature, impacting crop quality, yield, and growth. Droughts, floods, and heat waves are examples of extreme weather events that can cause crop failures, and directly endanger livelihoods and food production. It is critical to comprehend and mitigate the effects of climate change when it comes to cash crops like cotton, which are vital to the economies of many regions.

Global Climate Change is one serious issue and its effects on Pakistan are drastic. Crops are vulnerable to the effects of climate change and with the prediction that temperature will increase by 2.9 to 5.5°C through 2060. (Adnan Arshad, 2021), it is now more important to investigate its impact on cotton yield. Globally, cotton is a highly significant crop due to its versatility and indispensability, which has far-reaching effects on economies, industries, and daily life. International trade in cotton promotes economic interdependence and trade between nations. Furthermore, when cotton farming is conducted using environmentally friendly methods, it can support long-term environmental sustainability. Cotton's importance goes beyond its tangible qualities; it impacts trade, industry, and agriculture, thereby serving as a fundamental component of the global economy.

Pakistan being an agrarian economy depends on the yield of crops as it contributes about 24% in Pakistan’s GDP and employs about half of the labor force. (Pakistan, 2023). A significant contributor to Pakistan's economy and employment, cotton is a major cash crop and Pakistan's industrial sector largely depends on the cotton-based textile industry.

Cotton is a staple fiber that envelops the seeds of cotton plants to provide protection. Gossypium herbaceum is its botanical name and the family it belongs to is Malvaceae. The Malvaceae family of plants produces almost entirely cellulose fiber, with trace amounts of waxes, fats, pectins, and water. Cotton can be grown in latitudes ranging from 30° N to 30° S, and weather conditions significantly impact both yield and fiber quality.

Cotton is one of the most important cash crops in the world. It is grown for its fiber and utilized in textiles and other industries. Climate parameters, which include temperature, rainfall, and humidity, are important in determining cotton output. Seed variety, soil conditions, pests and diseases, and climatic factors are factors impacting cotton crop yield.

Cotton is a major cash crop of Pakistan which has played a vital role in the GDP for ages, making it the third major exporter of the world in 2017 and fourth major exporter of cotton in 2019. Cotton is a crucial cash crop and an essential part of the textile industry. The nation's largest agro-industrial textile industry employs 17% of the workforce, generates 60% of foreign exchange earnings, and contributes 8.5 percent of GDP. Cotton production accounts for 4.5 percent of the value added in AgGDP and 0.8 percent of GDP.

Pakistan rated fourth among the countries that produce cotton. The nearly three million acres of cotton farmland situated along the Indus River irrigation system form the foundation of the nation's economy. Although cotton is primarily grown for its fiber, cotton seed oil is also widely used as edible vegetable oil and substantially contributes to the nation's oil industry. The nation is estimated to use 15 kg of edible oil per person annually, which is significantly more than other countries with comparable levels of economic development. It is estimated that 5.30 million tons will be required overall for this purpose in 2028–2030, of which 1.99 million tons may come from domestic sources. (Fan Shuli, 2018)

Gossypium herbaceum (Cotton) is experiencing a decline in cultivation. Many factors contribute to this decline such as weather adversities, ineffective pesticides, expensive fertilizers, limited seed variety, and crop switching. The nation's economy depends on the nearly three million acres of cotton farming along the Indus River irrigation system. Annual weather variations seriously threaten global agriculture, especially in underdeveloped and developing nations like Pakistan. Crop yield is highly vulnerable to trends in global warming; through 2060, increases in global temperature are expected to range from 2.9 to 5.5 C. (Adnan Arshad, 2021)

District Multan's agricultural landscape, rich soil and ideal climate for cotton growing, makes it a perfect place to research the complex relationship between cotton production, Management strategies, and climate change. In District Multan, cotton is grown using standard agricultural techniques such as crop rotation, pest control, and irrigation. In the past, farmers in the area maximized yields by relying on their expertise and experience. These methods must be re-evaluated to guarantee resilient and sustainable cotton farming.

Cotton requires different amounts of rainfall at different growth stages. From emergence to first square 0.1 inch per day, from first square to first bloom 0.1- 0.25 inch per day, from first bloom to peak bloom it requires 0.25 – 0.40 inch per day. The optimum ph. for cotton is 5.8 – 8.0 or 6.0 – 6.5. The temperature requirements for cotton are hot dry conditions to achieve maximum, below 12^{o}C it undergoes little growth and sowing begins when maximum temperature at 10cm depth is 14^{o}C for at least three days.

A yield gap is basically the Ratio of Potential yield and current yield. Global temperatures have increased because of climate change, which has noticeable implications for cotton farming. The highest yield gap in 1974 can be seen in the United States which is at 2.91tons per hectare annually. Egypt is at 1.99tons, Pakistan is at 0.93tons and India is at 0.62tons. Pakistan's yield gap in 1976 it was at 0.70tons. It decreased to zero in 1980, increased again and decreased to zero in 2000. After 2000 it continuously increased; in 2018 it was at 0.2tons per hectare annually.

Many factors are causing this yield gap. Fig.1.2. displays the graphical representation of the factors causing this yield gap. There were many other causing factors but the focus here was to highlight the factors addressed in this study. These factors include the climatic variables (i.e. temperature (average, maximum, minimum), rainfall, wind speed), soil moisture and management practices.

Increased temperatures may have a negative impact on the growth and development of cotton. Elevated temperatures hasten the growth cycle of cotton plants, resulting in shorter times for crucial stages like flowering and boll formation. Reduced fiber quality and yield can be a consequence of shorter growth cycles. Severe heat stress can also lead to heat-related illnesses, which impact plant health and potential yield. Like Many other places in the world, District Multan has seen changes in its temperature trends. The length of the growing season, the degree of heat stress experienced by the crop, and the general health of the cotton crop can all be impacted by rising temperatures. Developing adaptive strategies requires understanding the unique temperature-related challenges that cotton farmers in the region face.

Changes in precipitation patterns are another effect of climate change that has a big influence on cotton harvests. Variations in the distribution of rainfall impact cotton plant water stress, planting dates, and water availability. On the other hand, heavy rainfall and an increase in the frequency of extreme weather events may cause flooding, which can harm cotton crops, impede growth, and increase disease incidence. Droughts and water scarcity can significantly impact cotton production, particularly in areas that rely on rain-fed agriculture. Cotton farming is directly impacted by changes in precipitation patterns, including shifts in the frequency and intensity of rainfall. While protracted droughts can cause water scarcity and lower yields, excessive rainfall can cause waterlogging and increase susceptibility to pests and diseases. Understanding the historical and current precipitation patterns in District Multan can help one better understand the difficulties cotton farmers confront.

The dynamics of diseases and pests are also impacted by climate change, which influences cotton productivity. Aphids, bollworms, and whiteflies benefit from the changing patterns of precipitation and rising temperatures. Prolonged warm weather can quicken the life cycles of pests, increasing infestation and damage. Similarly, shifting climate conditions can encourage the growth and severity of diseases like Verticillium wilt and Fusarium wilt, which affect the health and productivity of cotton.

Cyclones and storms, two extreme weather events that are becoming more frequent and intense, can have disastrous effects on agriculture. These occurrences have the potential to destroy crops, sabotage supply lines, and increase already-existing weaknesses in the cotton farming industry. An analysis of the frequency and consequences of extreme weather events in District Multan provides insight into the area's vulnerability to risks associated with climate change.

Traditionally, District Multan farmers have depended on age-old farming methods handed down through the generations. These methods cover a variety of procedures, such as crop rotation, pest Management, and seed selection. Understanding historical context is a basis for assessing these practices' efficacy when considering shifting climatic conditions. Technological developments in agriculture may provide answers to problems brought on by climate change. Modern methods that can improve the resilience of cotton crops include genetically modified (GM) crops, drip irrigation, and precision farming. However, elements like affordability, accessibility, and cultural considerations might have an impact on how widely these technologies are adopted. To find areas for improvement, it is essential to evaluate how District Multan's traditional farming systems have incorporated modern technologies.

1.2. Literature Review

A significant study has previously been conducted on the yield estimation of cotton in Pakistan. Scattered work can also be found on the effect of climate change on crop yield, regionally (Pakistan) and globally. Several studies were conducted all over the world emphasizing the significance of threats imposed by climate change (Olivier BroenniMann, M. C.-J. (2011), Herring, D. (2012), Fan Shuli, A. H. (2018), M.M.A.Mahgoub, A. (2021), RehMan, S. (2021))

Climate change and its effect on cotton have been investigated vigorously, globally, and regionally. However, in chronological order only some important studies carried out in recent years are added below.

Anirup, et, al. (2023), undertook research demonstrating the evidence related to climate change and its impressions on cotton crop yield in Maharashtra. A GIS-based model was developed using vector data and associated raster data. Regression and statistical data describe the relationship between independent and dependent variables. The results were weak but acceptable for complex natural environments. The outcome demonstrated that climate change was causing a significantly negative impact on yield. (Anirup Sengupta, 2023)

Sharma, et, al. (2022) worked on evaluating the effects of climatic variables (temperature and rainfall) on cotton and soybean yields from 1980 to 2020 Southeastern region of the United States. The study used the fixed-effect model (panel data approach) for climate and yield studies. After averaging the data from 11 states for each growing season, the findings showed notable variations in rainfall and temperature over the previous 40 years. Rainfall had no discernible impact on yields of soybeans or cotton. A 1°C increase in Tmin resulted in a 20.8% increase in cotton yield and a 31.6% decrease in soybean yield. On the other hand, a 1 °C increase in Tmax resulted in a 10.3% and 25.6% decrease in cotton and soybean yield, respectively. (Ramandeep Kumar Sharma, 2022)

In his study Shujaat Abbas (2022) examines the relationship between Pakistan's cotton production, the amount of land under cultivation, fertilizer consumption, and climate change from 1980 to 2018. Model bounds testing with autoregressive distributed lag (ARDL) is used to investigate the existence and type of relationships. The outcome demonstrated that the dependent and explanatory variables are co-related. According to the findings, temperature and cotton yield were somewhat dependent on each other. The results negate the concept that cotton yield increases with a rise in temperature. The area under cultivation and fertilizer consumption data have shown both short- and long-term significant effects. (Abbas, 2022)

Han, et, al. (2022), conducted research to quantitatively analyze the effects of climate variation on cotton yield variability in China's main cotton-growing regions using combined historical climate and yield data. The variability in cotton yield in the Yangtze River basin, the Yellow River basin, and the northwest inland was explained by climate variation. The YER saw a decrease in solar radiation and an increase in average temperature, which led to an increase in cotton yield. The primary factor influencing cotton yield was rainfall, increased rainfall and increased solar radiation decreased cotton yield. Intricate models produced the main source of yield variation at the provincial level. Furthermore, many provinces had nonlinear changes in cotton yields, and the yield fluctuated significantly. (Wanrui Han, 2022)

Welsh t, al. (2022), reviewed time-series yield and crop production techniques that take climate into account. The study used temperature and rainfall data to conduct a time series analysis of cotton yield and climate. The results demonstrated that while irrigated lint yields have improved during more frequent average rain/hot growing seasons, dryland lint yields have increased during average-to-moderate rain/temperature years (1997–2018). The findings also showed that the different phases of ENSO and the El Niño Modoki and Niño4 indices affect the climate in central cotton growing areas. The findings represent a significant advancement in the accounting of yield-related inputs like fertilizer and water resources, and climate variability. (J.M.Welsh, 2022)

Arshad, et, al. (2021), ran out model projections for 15 agrometeorology sites in Pakistan and China. The results revealed decreased growth time for the sowing-harvesting and sowing-boll opening stages. The duration of the warming effect of the sowing-to-harvest duration was also delayed. Temperature was found to be adversely linked with the stages of sowing, emergence, blooming, and maturity. By enhancing agrotechnological services, this study shed light on adapting smarter and better cotton. (Adnan Arshad M. A.,2021)

Naveed, et, al. (2021) identified the climate change effect on cotton crops by exploring the changes in crop yield and their relationship to climate change in the Indus River basin. For this purpose, spatial analysis was conducted, trends were analyzed through Mann- Kendall nonparametric test, correlation and regression was performed to determine the relationship between dependent and independent factors. The results indicated that sunshine hours positively whereas average temperature, minimum temperature, and air relative humidity negatively affected the cotton crop yield. (Naveed M, 2021)

Jans, et, al. (2021), studied the impacts of climate change on the productivity of cotton in various regions across the globe. Two models ISIMIP and LPJml were used in this research. The LPJml model results were in complete alignment with the statistics and numbers on the published reports. The ISIMIP model was then used for future prediction by using the general circulation models for the concentrated pathways. The results demonstrated a significant relationship between cotton yield and climate change. They concluded that the hour needs to assess its implication on the yield while keeping in mind a complete profile of its requirements. (Yvonne Jans, 2021)

Li, et, al. (2021) established a meta-database of changes in future cotton yield by using 27 published research (containing 1353 samples) at the global scale to thoroughly evaluate the possible effects of climate change and adaptation on yield and analyze the related uncertainties. Using local polynomial (Loess) regression on the entire dataset, the responses of cotton relative yield change to variations in mean temperature, minimum temperature, maximum temperature, precipitation, and CO_2 concentration were investigated. A linear mixed-effect model was employed to investigate the quantitative relationship between them. The results demonstrated that the simulated cotton production dropped when the average temperature went by 4.3 °C or when the average precipitation changed too much (>200%). Temperature, precipitation, changes in CO_2 concentration, adaptation strategies, research area, climate models, and climate scenarios were found to substantially affect changes in cotton yield change by establishing a linear mixed-effect model. When the average temperature increased by 1 °C, the cotton production fell by 1.64%. The cotton yield increased by 0.09% and 0.05% for every 1% increase in precipitation and 1 ppm rise in CO_2 concentration. Compared to no adaptation, the yield of cotton produced under adaptation procedures increased by 8.97%. (Na li, 2021)

Vyankatrao (2020) investigated the effect of climate change on cotton production by using various models to predict climate impact and mitigation measures at the global scale. The results demonstrated that cotton production was affected by projected changes in precipitation. Though the effect on temperature is relatively minor, it clearly demonstrates that any further increase in global temperature would significantly reduce cotton yield. Mitigation measures can mitigate the negative effects of climate change. (Vyankatrao, 2020)

Haseeb,et,al. (2020) researched the temporal and spatial changes in climatic parameters for two distinguished (Baseline, Projected) periods in southeast Punjab. Mann-Kendall test analysis and ArcGIS were used to identify the impact on climatic parameters with spatial variation. The results depicted that precipitation trends were inconsistent but both precipitation and temperature were significantly affecting the crop yield and for the predicted future the scenario seems to exist with the indication of reduced yield with temperature change. (Haseeb Akbar, 2020)

Sajjad, et, al. (2019), carried out research in district of Multan. The study's main purpose was to highlight the changes in land use and land cover by classifying the Landsat images in ERDAS IMAGINE. The accuracy of the results and Kappa coefficients indicated that from the past three decades the built-up area is increasing and the area for vegetation is continuously declining. The results for LST indicated an increase in temperature in Multan which was related to crop yield. (Sajjad Hussain, 2019)

Chen, et, al. (2019), worked on the Qira oasis in China to assess water requirements and cotton yield under various future climate scenarios. The climate for the near (2041–2060) and far future (2061–2080) periods was projected using six general circulation models. The Root Zone Water Quality Model (RZWQM2) was used to simulate the effects of climate change on cotton yield and water requirement under current Management practices. The model was calibrated using a prior study's experimental data from 2007 to 2014. The results showed that stress from low temperatures marginally increased cotton yield. The values of water requirements represent a 7.5% and 10.3% decrease from the current baseline (786mm). The reduction was ascribed to reduced growing seasons and elevated CO_2 levels. The findings implied that the agricultural water crisis in the area might be resolved in the future. (Xiaoping Chen, 2019)

Sajjad, et, al. (2017), worked on various climate factors i.e. Rainfall, Temperature (minimum, maximum), Sunshine and Relative humidity in Multan. The effect of these factors was studied for major crops of Pakistan. The results showed that rainfall is inversely linked with crop yield, minimum temperature is significant, and maximum temperature adversely affects crop yield over the years. (Sajjad Ali, 2017)

Chen et, al. (2015), grabbed the provincial data to understand the effects of climate change on cotton output in three key cotton-producing regions of China between 1961 and 2010 to create scientific countermeasures. According to the findings, most provinces saw an increase in cotton yield when the average temperature rose, but the Yangtze River basin undergoes a decline in cotton yield. In certain areas, a drop in the diurnal temperature range (DTR) decreased cotton output; however, in other provinces, a positive effect was noted. The variation in precipitation resulted in a 1.1% reduction in average production. They concluded that favorable effects of temperature and precipitation existed in the cotton-growing regions of Northwest China during 1961–2010, changes in these variables reduced cotton yields in China. (Chao Chen, December 2015)

In his report Peter Ton (2011) discussed cotton both as a contributor to climate change and as a vulnerable target of climate change in all cotton-producing centers. The evidence collected through the literature review implied that the cotton crop shows high resilience to high temperatures till 32oC but after, it affects the cotton yield negatively. To sum up his study he concluded that the climate change is negatively affecting the cotton yield in some countries which includes western US, Pakistan, China, and Australia. In some countries up to a certain level cotton responds positively to high temperature, but continuous high temperature produced stressed crops. (Ton, 2011)

Imran, et, al. (2009), analyzed factors affecting the cotton crop production in Multan district. For the study, the primary data was used by collecting random samples i.e. 15 large, 25 medium and 60 small farmers. The Cobb-Douglas Production Function assessed the effects of cultivation, seed, sowing, irrigation, fertilizer, plant protection, inter-culturing / hoeing, and labor cost on cotton output. The findings showed that all farmer categories in Multan area had shortages of seed, fertilizer, and irrigation supplies. The coefficients for cultivation (0.113) and seed (0.103) were found to be statistically significant at the 1 percent level, according to the Cobb-Douglas Production Function results. Large farmers were shown to have a greater cost-benefit ratio (1.41) than small (1.22) and medium (1.24) producers. Given that these limited inputs were crucial components of the cotton harvest, it is imperative that the public and private sectors guarantee their supply. (Imran Sharif Chaudhry, 2009)

1.3. Rationale

The issue of global climate change has the potential to have a big impact on crop output everywhere, particularly in Pakistan. Annual weather changes seriously threaten regional agriculture, contributing adversely to developing countries and even globally. Crop productivity is very vulnerable to trends in global warming, with an increase in world temperature expected to range from 2.9C to 5.5 C by the year 2060. Extreme heat drastically reduces crop yields because it negatively impacts agricultural phenology. In agro-economic regions like Pakistan, crop yield estimation is critical to future food security, particularly in the coming decades to meet ultimate needs of the nation. Given that Pakistan is one of the few nations in the world, most affected by climate change. There is a risk that the biological niche may shift dramatically to the poles, which could provide serious risks to jeopardize economy in the future.

1.4. Scope of the study

This study aims to conduct a thorough research scope that investigates how different management techniques and climate change affect the output of cotton in this area, particularly in the Multan region. We will examine Multan's historical climate data to spot patterns and shifts in temperature, rainfall, wind speed and soil moisture. It will also focus on how climate change affects cotton in the growing season by considering harsh weather and shifting climatic trends. By analyzing Multan's cotton farming history and current agriculture Management techniques it will determine and evaluate the effects on cotton yield of different agronomic techniques, irrigation methods, approaches to Managing pests and diseases, and soil Management techniques. We will compile empirical data on cotton crop production across multiple growing seasons by conducting field surveys and considering climatic and Management practice differences. This work will also analyze the gathered information using statistical techniques to find relationships between Management techniques, climate variables, and cotton yield. By discussing the results, we will make suggestions for agricultural practices which will help to formulate strategies/ policies that could increase the yield and resilience of cotton crops in the future face of climate change. This research can greatly benefit farmers in Multan district by helping them make informed decisions and improve their crop productivity. This knowledge can be used to develop strategies to optimize cotton yield and adapt to climate change. It could contribute to sustainable agricultural practices. The study can offer significant perspectives on the intricate relationship among climate change, agricultural practices, and cotton crop productivity within the Multan setting by examining these facets.

1.5. Objectives

This study focuses on two main objectives.

1. To investigate the decadal trends and impact of climatic variables on cotton crop yield.
2. To Analyze the effect of current Management practices on cotton crop yield.

Chapter 2

MATERIALS AND METHODS

2.1 STUDY AREA

Pakistan's most significant cash crop is cotton. In addition to being a significant source of foreign exchange earnings, it supports millions of people in Pakistan. A significant-producing region in Punjab is found in the southern region (Multan, Rahim Yar Khan, Bahawalpur, and D.G. Khan Divisions), with a cotton-wheat-cotton cropping pattern. The research was carried out for the district of Multan which is situated in between 30.1575° N to 71.5249° E. It is a major-growing region in Pakistan, and millions of people in Pakistan rely on it for their living on one end and serve as a significant source of foreign exchange revenues on the other. This study area holds the historical significance of Multan in the cotton field. The first ever and the oldest cotton research facility in Southern Punjab was built in Multan. The primary goal of this research facility is to develop cotton varieties specifically for this cotton belt. It is the center of cotton research activities and has produced the greatest number of cotton varieties in Punjab (16) at this research station to date. Approximately 600 million rupees is the estimated total economic contribution of Cotton Research Station Multan verities, the highest amount of any other cotton research center in Pakistan. Four tehsils fall under this study area: Jalalpur Pirwala, Shujabad, Multan Saddar and Multan City. Chenab river flows through it. When we talk about its climate, Multan is categorized as a hot desert climate. According to Koppen’s climate classification, it experiences hot summers and mild winters.

Figure 2.1. displays the study area map which contains three data frames. In one frame is the shapefile of world, other has the shapefile of Pakistan with district boundaries and the main frame

displays Multan city which is digitized according to the UC it covers. The open street basemap was clipped according to Multan's digitized shape file.

Multan's climate is ideal for growing cotton. For cotton to grow well, it needs warm weather and an extended period without frost. The area's warm summers and moderate winters make for the perfect growing conditions for cotton plants. A sizable section of the local populace in and around Multan finds work opportunities in cotton cultivation and related industries.

2.2 DATA SOURCES, QUALITY AND LIMITATION

Table.2.1. described the various data sets which were used in the study.

Cotton crop data was obtained from Multan cotton research institute. The data increases the yearly cotton yield in tons per acre and the coordinate points of the cotton farms in Multan district. ERA 5 data of temperature, rainfall, windspeed and soil moisture was acquired from Copernicus data repository. The data was gridded, and resolution of the data was 0.25^{o}. The whole study area was covered by 31 grids. The area each grid covered was 27.75km.

For land use land cover classification Landsat 7 and sentinel 2 images for the month of august were downloaded for year 2000 and 2020. The resolution of Landsat 7 image is 30meters whereas that of sentinel2 is 10meters as shown in Table.2.2.

2.3 ANALYTICAL FRAMEWORKS

The study was executed by following a set of processes in a sequence. Fig.2.2. is the graphical representation of the methodology which was followed throughout the research.

Data Processing:

The coordinates were displayed as X, Y data in ArcGIS and a shapefile of these coordinates was overlayed on the processed satellite images (Landsat7 and sentinel2).

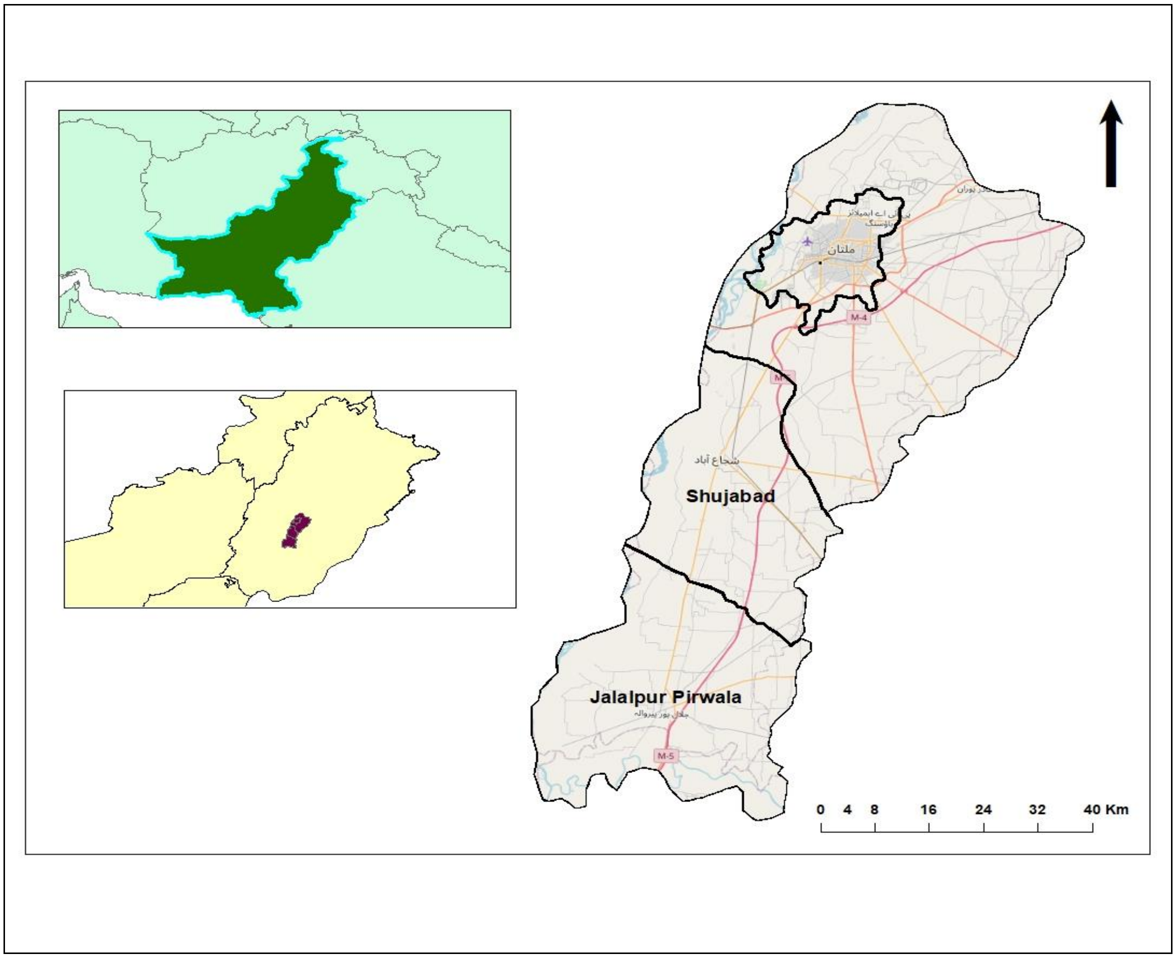


Figure 2.1. Study area map displaying the digitized Multan district with the uc boundaries (Shujabad, Jalalpur Pirwala, Saddar and Multan city).

In ArcGIS the sampling was done by using reference points and google earth. The cotton crop, water, bare land, built up, and other vegetation were identified. To check the accuracy assessment points were created and confusion matrix was generated. The classified data was then converted to polygons to calculate the area of cotton.

The raster data sets from ERA5 were in Netcdf format. To convert this format into tiff format i.e. ArcGIS acceptable format Netcdf was converted into raster layer according to the associated variables and dimensions. For this purpose, the time slice tool was installed and used. The data was then sliced into multiple time stamps (i.e. 7 months data for 30 years).

The gridded data was then resampled and extracted using Multan shapefile on which the tehsils were digitized first. The datasets were divided into the three above-mentioned stages and the average for each stage was calculated to measure and to visualize the change.

Land Use Land Cover:

Fundamental ideas such as land use and land cover offer a thorough understanding of how the Earth's surface is used and altered. The term "land use" refers to the use of a specific piece of land by humans. It covers a broad range of uses, including commercial, industrial, residential, agricultural, and recreational. It illustrates the dynamic relationship that exists between individuals and their surroundings by reflecting the interactions between human societies and the landscape. The land use patterns that are shaped by economic activities, cultural practices, and societal needs are crucial in determining the spatial organization and functionality of different regions.

Table.2.1. Datasets used in the study of cotton yield and climate change.

Dataset	**Specification**	**Data Source**
Crop Data	Yield; Variety; Acreage, Coordinate points	Cotton Research Station Multan / Central Cotton Research Institute Multan
Soil Data	Soil moisture	ERA5(Gridded Soil Data) 0.25°
Weather Data	Rainfall, Temperature (Min, Max, Mean), Wind Speed	Pakistan Meteorological Department/ERA5
Management Practices	Irrigation, Pest infestations, Weed Management, Nutrient Deficiency, Labor, Seed Quality	Online Survey (questionnaire)

Table.2.2. Datasets used for land use land cover classification.

Satellite	**Date**	**Resolution**
Landsat 7	2000 (25th July – 25th august)	30 meters
Sentinel 2	2020 (25th July – 25th august)	10 meters

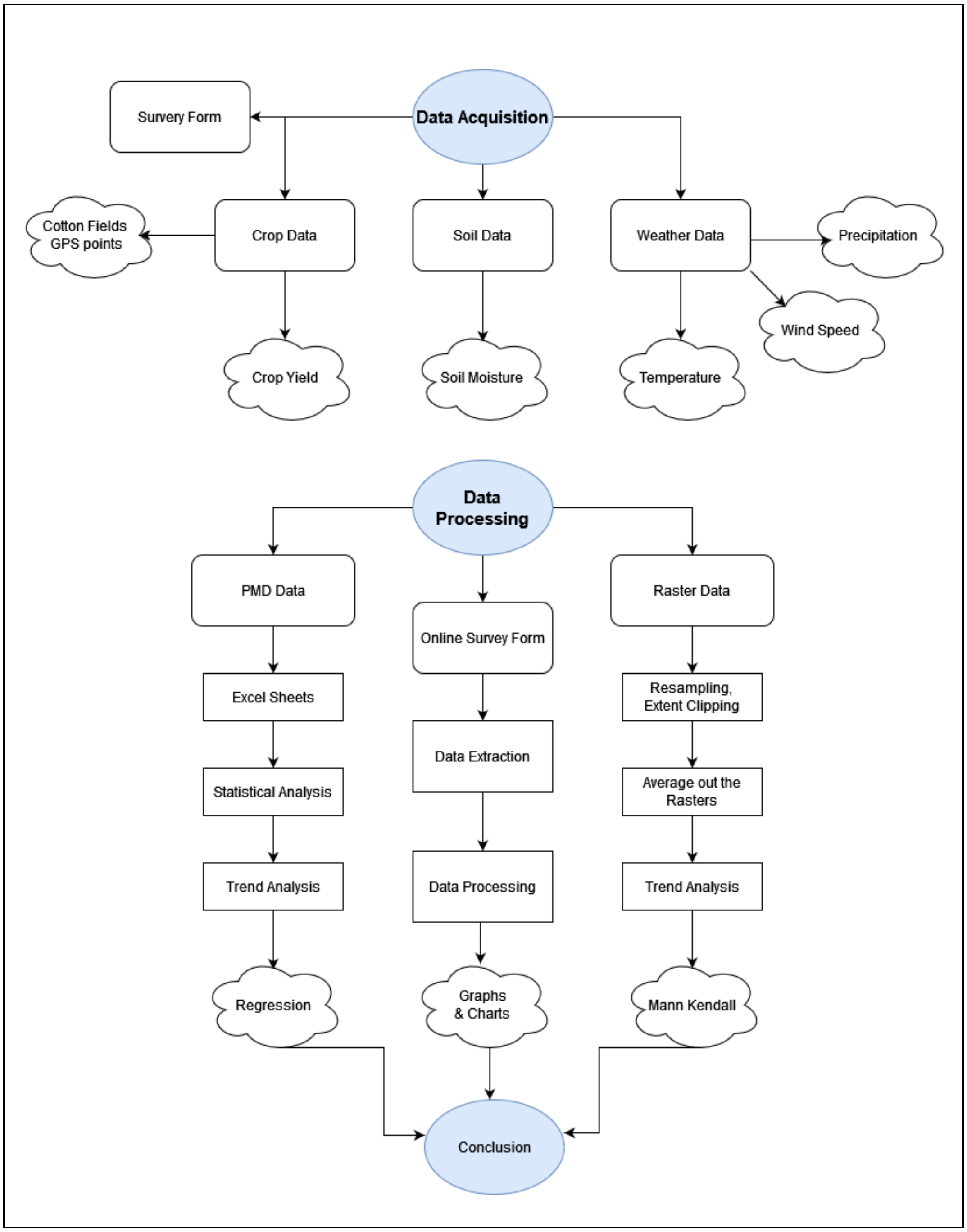


Figure 2.2. Methodological framework showing processing stages from data acquisition to conclusion.

On the other hand, land cover refers to the physical attributes and natural features found on Earth's surface, such as water bodies, bare soil, vegetation, and man-made structures. It illustrates the physical distribution of various elements within a given area. Based on their spectral, textural, and spatial properties, surface features can be identified and categorized with the aid of land cover classification. Differentiating between different types of land cover allows researchers to observe changes, understand ecosystems, and evaluate the effects of human activity on the environment over time. Analyzing land use and land cover together offers a thorough understanding of the intricate interactions between human activity and the environmental systems that shape the surface of our planet.

Validation:

The data was validated using the ground truth data obtained from the Pakistan Meteorological Department (PMD).

R and R Studio:

Within the field of data analysis and statistical computing, R and RStudio are a formidable pair. Specifically created for graphics and statistical computing, R is an open-source programming language. With R's extensive library and package selection, advanced statistical modeling, visualization, and data manipulation are easier. An Integrated Development Environment (IDE) that complements R, RStudio offers code editing, visualization tools, and an intuitive interface that further improves the user experience. By providing tools for managing scripts, displaying data, and interactive programming, RStudio helps R users work more efficiently.

The average raster for each year was then processed into R and R-Studio and the Mann-Kendall trend was applied to determine the areas with significant change and the areas with non-significant change. The areas with significant change were more closely observed to highlight the fact that the change was positively or negatively significant.

Mann-Kendall Test:

A non-parametric statistical test called the Mann-Kendall test determines whether trends exist in time-series data. This test is especially useful for identifying monotonous trends, regardless of how linear they may be. It is widely used to study temporal patterns in variables like temperature and precipitation. The Mann-Kendall test is strong in the presence of outliers and variations from normality because it does not assume a particular distribution for the data.

The test assesses the probability that a time series' values will show a steady downward or upward trend over the course of the series. The alternative hypothesis proposes the existence of a monotonic trend, whereas the null hypothesis asserts the non-existence of any trend. The test statistic measures how well or poorly the sets agree or disagree within the time series. A positive value indicates an increasing trend, while a decreasing trend is implied by a negative value. A normal approximation or, in the case of small sample sizes, a table of previously calculated critical values are used to determine significance.

Correlation and Regression:

The dependent and independent variables were processed through a proper statistical procedure to analyze the summary statistics, correlation, and regression and whether these independent variables contribute to determining the dependent factor.

Survey Form:

The online survey form was developed to analyze further the effect of Management practices on cotton crop yield.

Local farmers were encouraged to participate in this activity to better and more accurately understand the issues and problems.

Visual Representation:

The results were further processed to maintain a standard scale and shape throughout the procedure. The graphs and gifs were prepared.

Fig.2.3. is a graphical representation of the process each factor (data obtained from ERA5) went through.

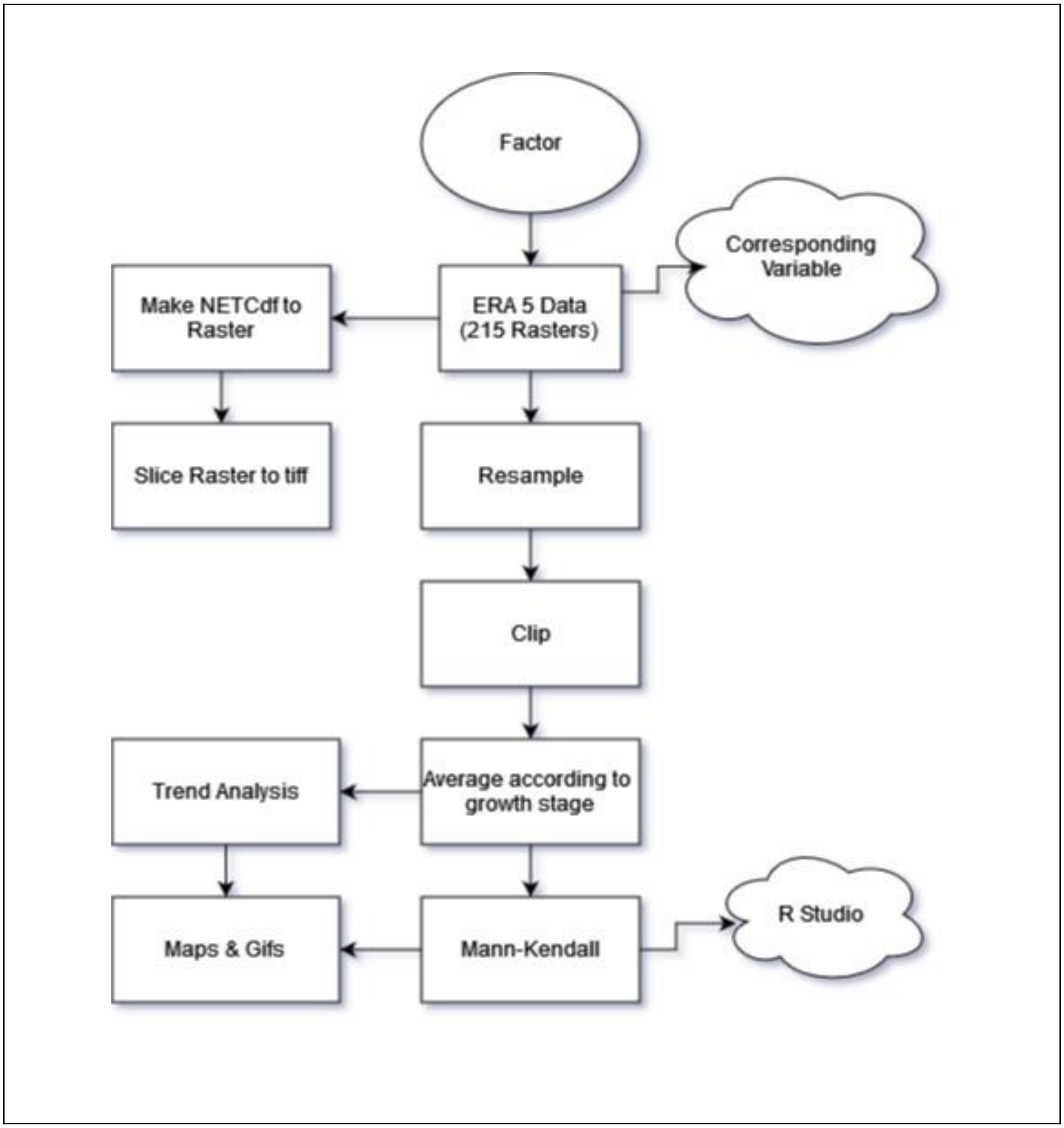


Fig.2.3. Displaying the procedure of era5 data processing.

Chapter 3

RESULTS AND DISCUSSIONS

This section shed light on the interpretation and analysis of the results that were obtained from this study. A foundation for critical analysis and investigation is provided by the data gathered via meticulous experimentation and a thorough review of the literature. The discussion that follows explores the implications of these results in the context of the research goals, covering both the expected results and any unexpected trends or patterns.

3.1. Land use Land Cover:

Land use land cover classification was done for two years 2000 and 2020 to identify the cotton growing areas of Multan and to detect the change in cotton production over a time span of 20 years.

The results in figure 3.1(a) displayed 5 classified classes (water, bareland, builtup, cotton and other vegetation) in 2000 and figure 3.1(b) highlighted the classified classes in 2020. The area under cotton cultivation in 2000 was 146683.98sqkm, but it was reduced to 79489.06sq km in 2020. A decrease of almost sq km can be observed in these 20 years.

Table 3.1. showed the accuracy of all classified classes for the year 2000. The producer accuracy of cotton in 2000 classified image was 80.9% and user accuracy of cotton was 85%. Table 3.2. displayed the accuracy of all the classified classes for the year 2020. The producer accuracy of cotton in 2020 classified image was 94.1% and user accuracy of cotton was 80%.

Figure 3.2 (a) highlighted the extracted cotton class in 2000 and figure 3.2 (b) displayed the extracted cotton class in 2020. Visible change can be seen in both classified images.

Table 3.3 revealed that the cotton area in 2000 was 146683.98 sq km, it reduced to 79489.06sq km in 2020. A decrease of almost 67194.92 sq km can be observed in these 20 years.

3.2. Climatic Factors:

All selected significant Climatic Factors (Temperature, Rainfall, Wind Speed) and soil moisture were divided into three cotton growth stages and analyzed through various processes. The three stages are as

Sowing Stage (April and May)

Emergence to Flowering Stage (June, July and August)

Maturity and Picking Stage (September and October)

For Average Temperature, Maximum Temperature and Minimum Temperature were taken into consideration.

In figure 3.3. (a) the results displayed the average temperature data (yearly) for the sowing stage i.e. April to May from 1990 to 2020. Two images represented the average temperature. One from 1992 and another from 2020 to visually analyze the temperature change trend. The average temperature seemed to increase. In 1992 the highest temperature was 304k whereas in 2020 the highest temperature reached 309k. The change was not drastic but gradual.

To determine the trend direction (Positive or Negative) Mann-Kendall Test was run on average 30 years sowing Stage data. The results displayed that the overall trend was increasing. In Jalalpur Pirwala and some areas of Shujabad the trend was severely increasing while other areas experienced a mild increasing trend. It was shown in figure 3.3. (b).

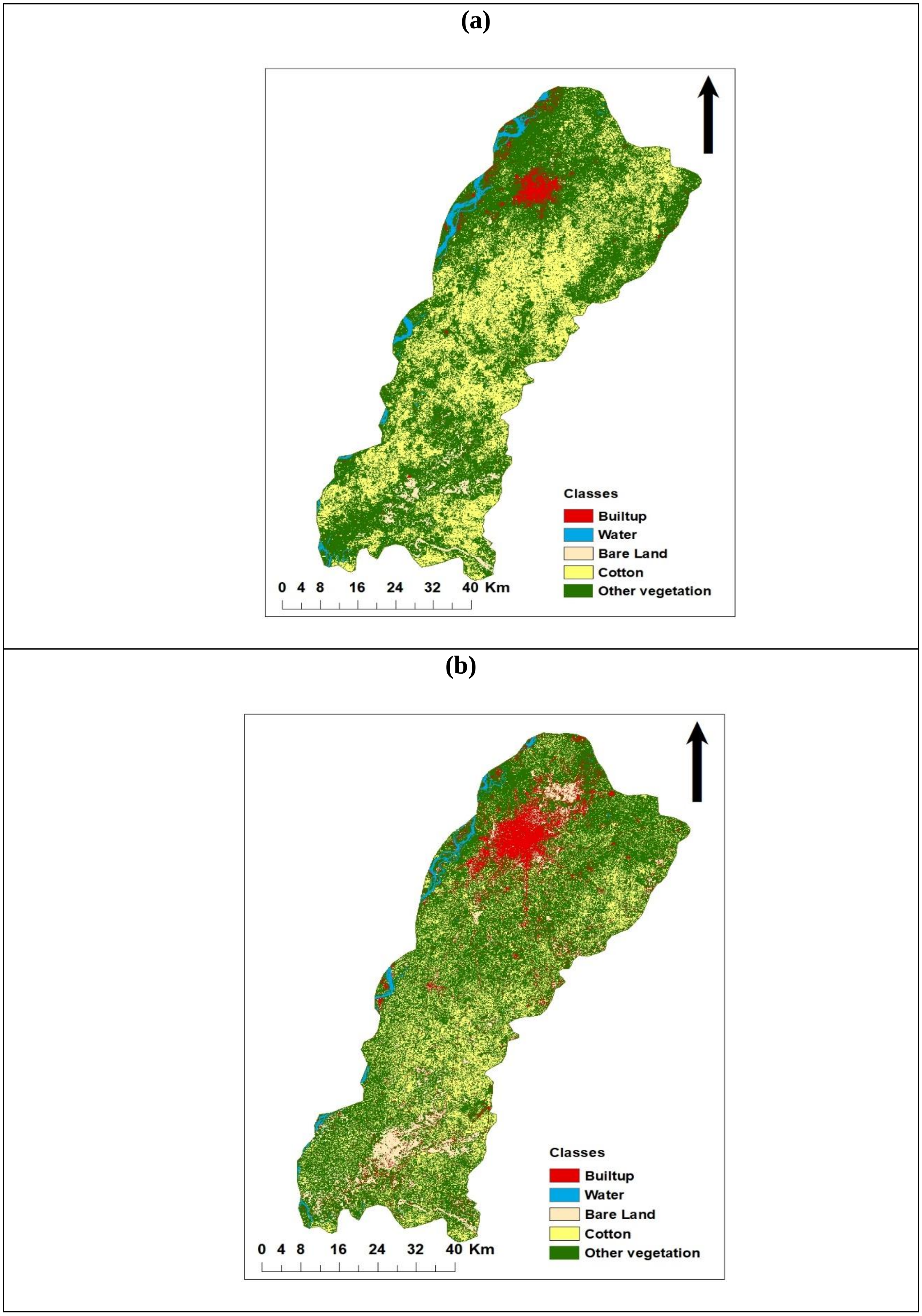
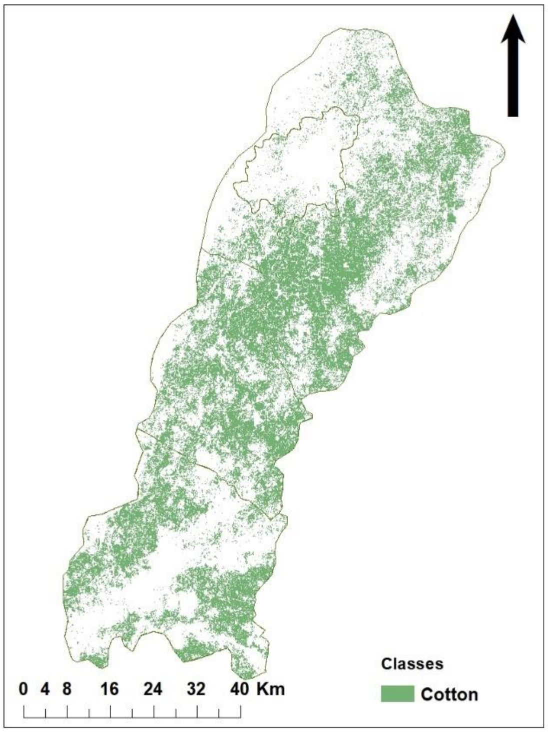


Figure 3.1. Displaying the classified map of different classes (built up, water, bare land, cotton, other vegetation) of year (a) 2000 (b) 2020.

(a)



(b)

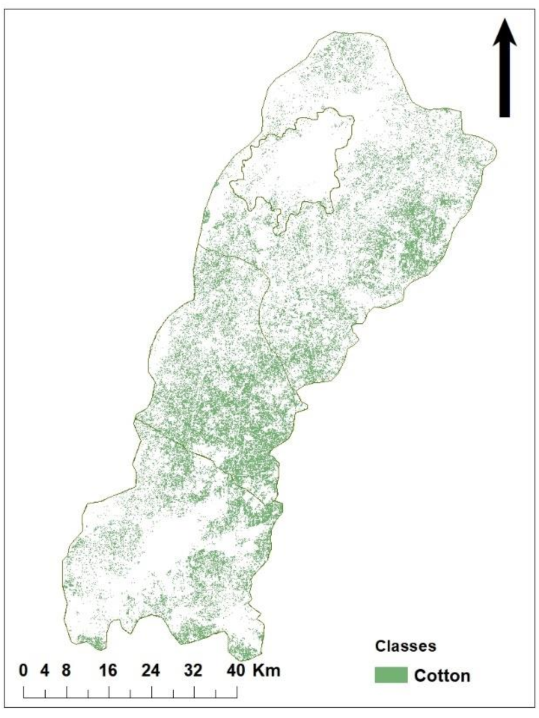


Figure 3.2. Displaying the extracted cotton class for year (a) 2000 (b) 2020.

Table.3.1. Accuracy assessment of classified image for year 2000.

Class	Built up	Water	Bare land	Cotton	Other Vegetation	Total	User Accuracy	Kappa
Built up	11	0	5	3	1	20	0.55	0
Water	0	20	0	0	0	20	1	0
Bare land	0	0	17	0	3	20	0.85	0
Cotton	0	0	3	17	0	20	0.85	0
Other Vegetation	0	0	4	1	15	20	0.75	0
Total	11	20	29	21	19	100	0	0
Producer Accuracy	1	1	0.586207	0.8095	0.789474	0	0.8	0
Kappa	0	0	0	0	0	0	0	0.75

Table.3.2. Accuracy assessment for classified image of 2020.

Class	Built up	Water	Bare land	Cotton	Other Vegetation	Total	User Accuracy	Kappa
Built up	14	0	6	0	0	20	0.7	0
Water	0	20	0	0	0	20	1	0
Bare land	2	0	17	0	1	20	0.85	0
Cotton	0	0	0	16	4	20	0.8	0
Other Vegetation	0	0	2	1	17	20	0.85	0
Total	16	20	25	17	22	100	0	0
Producer Accuracy	0.875	1	0.68	0.941176	0.772727	0	0.84	0
Kappa	0	0	0	0	0	0	0	0.8

Table 3.3. Cotton area in hectares according to the extracted cotton class.

Year	Cotton Area (hectares)
2000	146683.98
2020	79489.06

Mann-Kendall trend was run on the averaged 30 years sowing stage data to analyze whether the trend was significant or non-significant. The probability value at 0.05 was written as significant and all other values were placed under the heading of non-significant. The areas with green color demonstrated that the trend was significant. Jalalpur Pirwala and Shujabad displayed a more significant trend than Multan City and Multan Saddar as shown in figure 3.3(c).

In figure 3.4 (a) the results displayed the average data (yearly) for the emergence - Flowering stage i.e. June, July, August from 1990 to 2020. The average temperature was represented by two images. One from 1992 and another from 2020 to visually analyze the temperature change trend. The average temperature seemed to increase. In 1992 the highest temperature was 309k whereas in 2020 the highest temperature reached 314k. The change was not drastic but gradual.

To determine the trend direction (Positive or Negative) Mann-Kendall Test was run on average 30 years emergence to flowering Stage data. The results displayed that the overall trend was stable. It was decreasing in some areas and some areas highlighted the increasing trend direction as displayed in figure 3.4 (b).

To analyze whether the trend was significant or non-significant, the Man-Kendall trend was run on the averaged 30 years emergence-flowering stage data. The probability value at 0.05 was written as significant and all other values were placed under the heading of non-significant. The areas with green color demonstrated that the trend was significant. The Significant trend here was very less because of Monsoon Rains as presented in figure 3.4(c).

The results displayed the average data (yearly) for the Maturity and Picking stage i.e. September and October from 1990 to 2020.

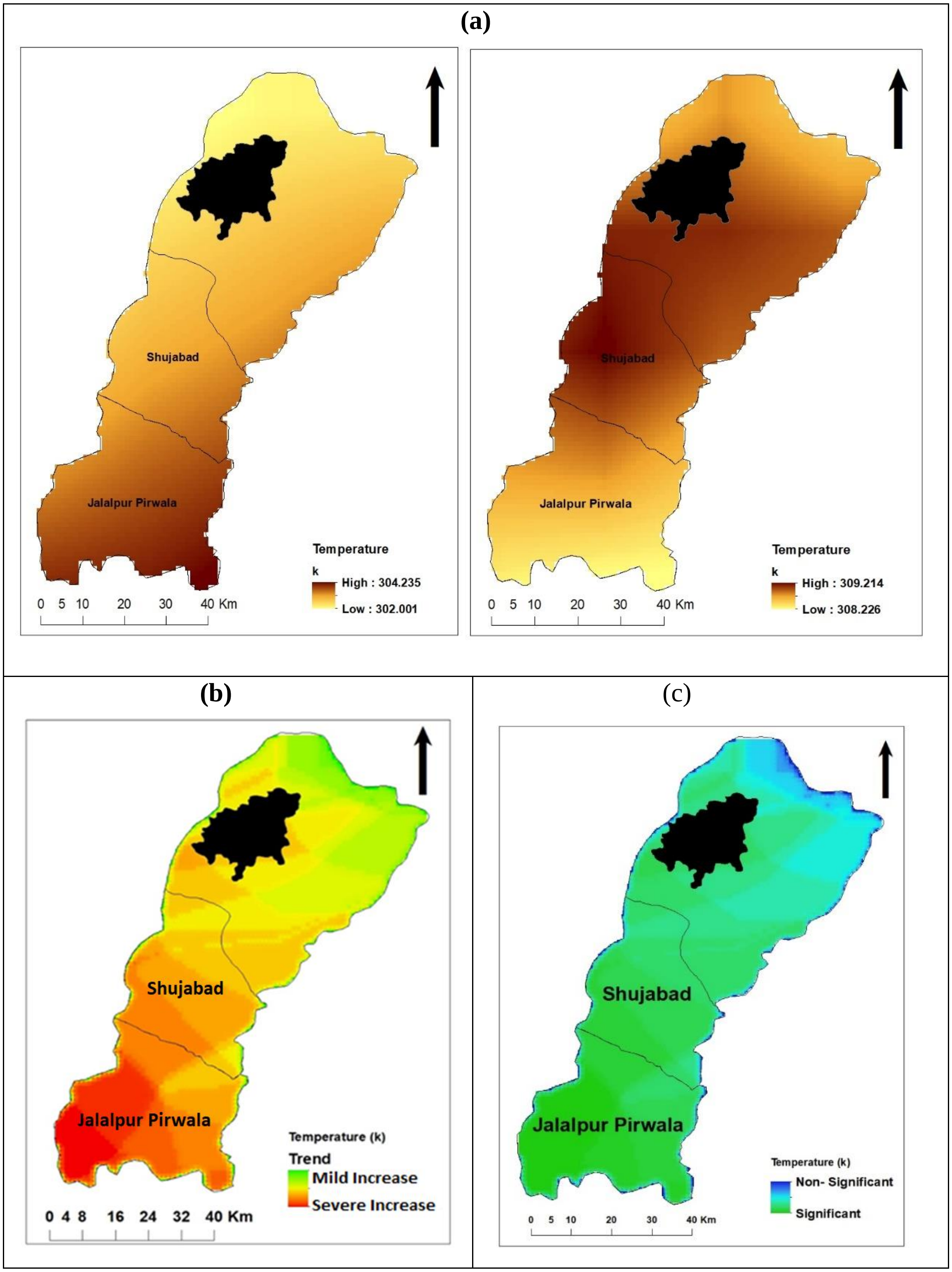


Figure 3.3. Presenting sowing stage average temperature (a) 30 years difference (b) trend map (c) probability map**.**

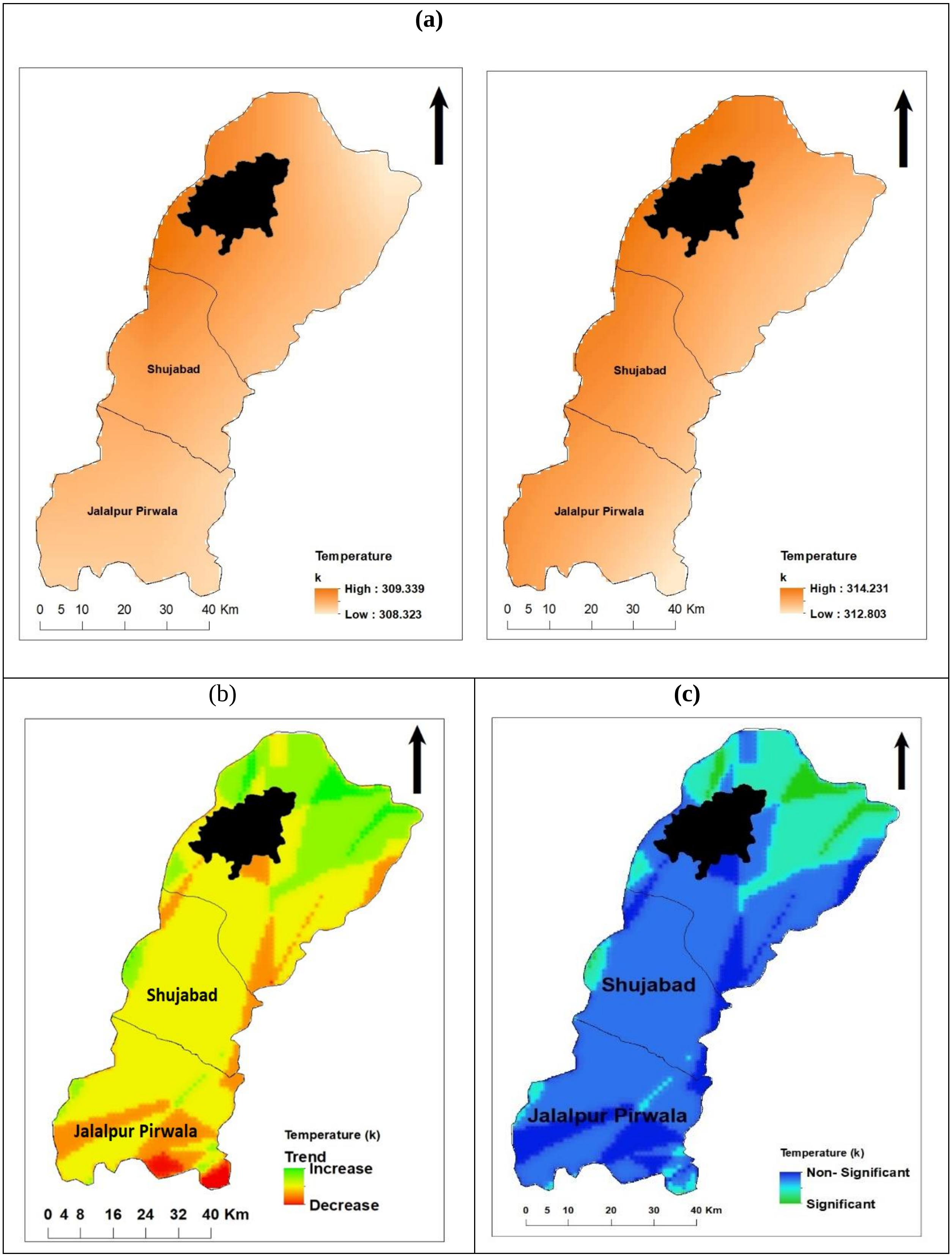


Figure 3.4. Displaying emergence-flowering stage average temperature (a) 30 years difference (b) trend map (c) probability map**.**

Two images represented the average temperature. One from 1992 and another from 2020 to visually analyze the temperature change trend. The average temperature seemed to increase. In 1992 the highest temperature was 305k whereas in 2020 the highest temperature reached 311k. The change was not drastic but gradual as displayed in figure 3.5(a).

To determine the trend direction (Positive or Negative) Mann-Kendall Test was run on averaged 30 years maturity and Picking Stage data. The results displayed that the overall trend was severely increasing. In Jalalpur Pirwala, Shujabad and some areas of Multan city the trend was severely increasing while a very small area at the north-west of Multan city experienced a mild increasing trend as shown in figure 3.5 (b).

To analyze whether the trend was significant or non-significant, the Mann-Kendall trend was run on the averaged 30 years maturity and picking stage data. The probability value at 0.05 was written as significant and all other values were placed under the heading of non-significant. The areas with green color demonstrated that the trend was significant. Jalalpur Pirwala, Shujabad and Multan displayed a more significant trend. A significant trend can be seen in this stage in figure 3.5 (c).

The results showed the average data (yearly) for the sowing stage i.e. April and May from 1990 to 2020. The average temperature was represented by two images. One from 1992 and another from 2020 to visually analyze the temperature change trend. The average maximum temperature seemed to increase. In 1992 the highest temperature was 305k whereas in 2020 the highest temperature reached 310k. The change was not drastic but gradual as presented in figure 3.6 (a). The results in figure 3.6 (b) highlighted the average data (yearly) for the emergence - Flowering stage i.e. June, July, August from 1990 to 2020. Two images represented the average maximum temperature.

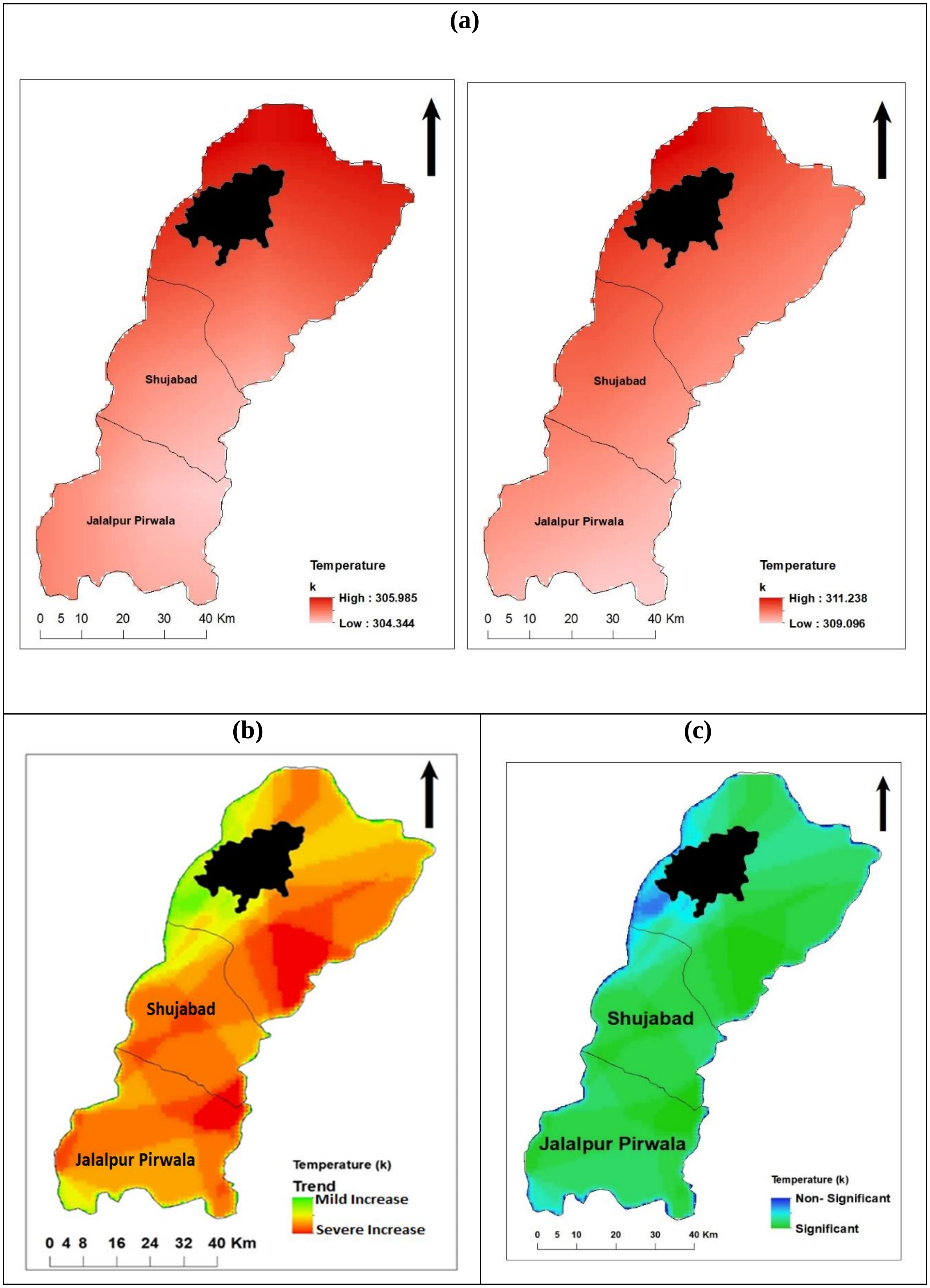


Figure 3.5. Displaying maturity and picking stage average temperature (a) 30 years difference (b) trend map (c) probability map**.**

One from 1992 and another from 2020 to visually analyze the temperature change trend. The average maximum temperature seemed to increase. In 1992 the highest temperature was 312k whereas in 2020 the highest temperature reached 318k. The average maximum temperature seemed to increase throughout the years. The change was not drastic but gradual as highlighted in figure 3.6 (b)

The results displayed the average data (yearly) for the Maturity and Picking stage i.e. September and October from 1990 to 2020. Two images represented the average maximum temperature. One from 1992 and another from 2020 to visually analyze the temperature change trend. The average maximum temperature seemed to increase. In 1992 the highest temperature was 308k whereas in 2020 the highest temperature reached 313k. The average maximum temperature seemed to increase throughout the years. The change was not drastic but gradual as shown in figure 3.6 (c)

The results highlighted the average data (yearly) for the sowing stage i.e. April and May from 1990 to 2020. Two images represented the average minimum temperature. One from 1992 and another from 2020 to visually analyze the temperature change trend. The average minimum temperature seemed to increase. In 1992 the highest temperature was 302k whereas in 2020 the highest temperature reached 310k. The average minimum temperature seemed to increase throughout the years. The change was not drastic but gradual as displayed in figure 3.7 (a).

The results showed the average data (yearly) for the emergence - Flowering stage i.e. June, July, August from 1990 to 2020. Two images represented the average minimum temperature. One from 1992 and another from 2020 to visually analyze the temperature change trend. The average minimum temperature seemed to increase.

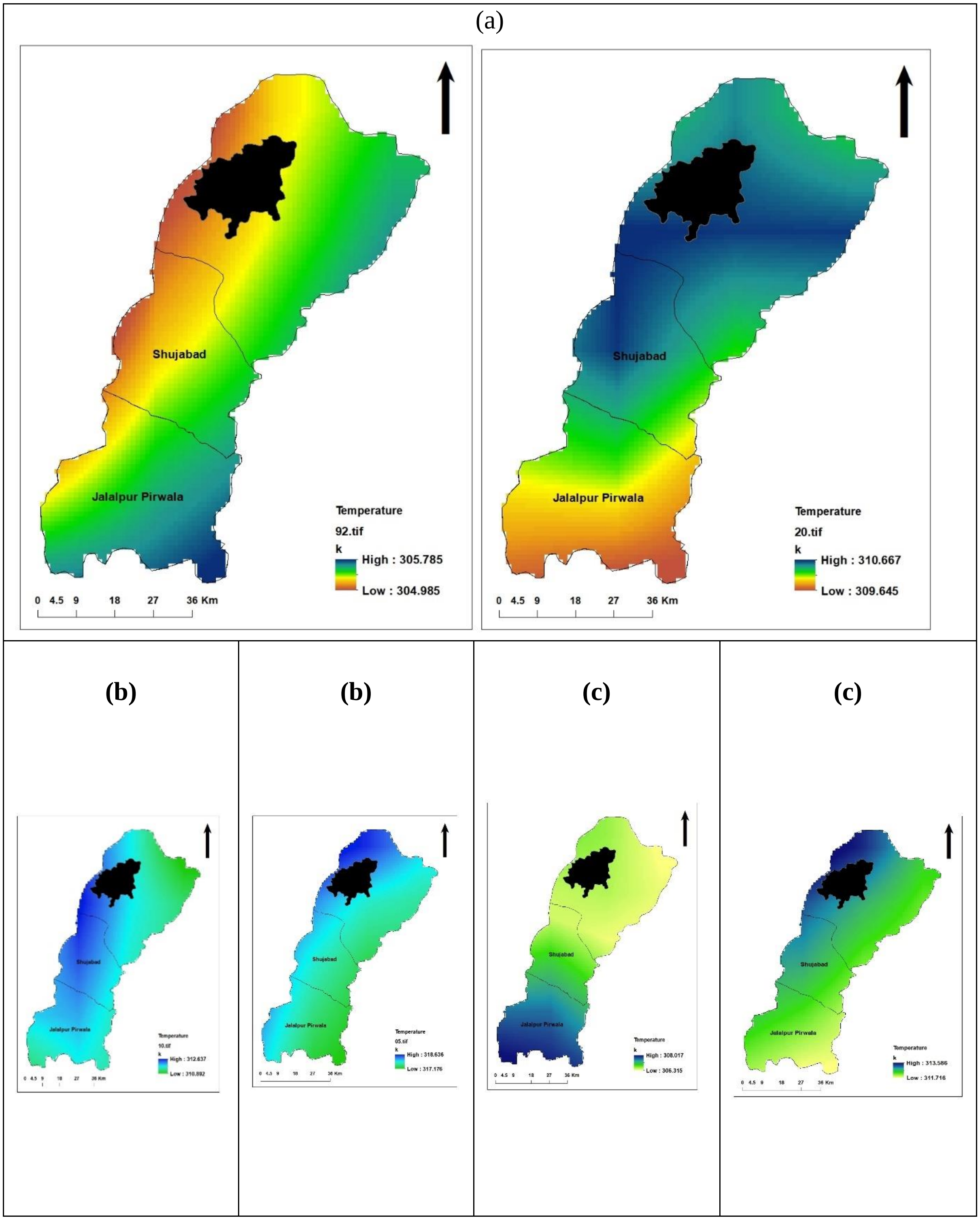


Figure 3.6 Showing the average maximum temperature (a) for the sowing stage (b) for the emergence-flowering stage (c) for the maturity and picking stage.

In 1992 the highest temperature was 308k whereas in 2020 the highest temperature reached 312k. The change was not drastic but gradual as exhibited in figure 3.7 (b).

The results highlighted the average data (yearly) for the Maturity and Picking stage i.e. September and October from 1990 to 2020. Two images represented the average minimum temperature. One from 1992 and another from 2020 to visually analyze the temperature change trend. The average minimum temperature seemed to increase. In 1992 the highest temperature was 304k whereas in 2020 the highest temperature reached 309k. The change was not drastic but gradual as highlighted in figure 3.7 (c).

Zafar (2023) in his bulletin report proved with evidence that the temperature in Pakistan has been increased over the past few decades. He described that from 1901 to 2021 an annual increase of 1.68 degrees Celsius can be observed in Pakistan which was greater than the world average temperature increases i.e. 1. 1 degree Celsius. (Z. Imran, 2023)

Argueso,et,al.(2014) predicted the future temperature changes due to climate change in Sydney. He concluded through future simulations that the temperature will continue to increase due to urbanization and global warming. (Argueso, 2014)

These studies justified the results of the ongoing study i.e. an increase in average temperature, maximum temperature, and minimum temperature for three cotton growing stages. From 1990 to 2020 Pakistan has experienced more intense and frequent heatwaves, moreover, the human activities accelerated the entrapping of heatwaves resulted in greenhouse effect. All these factors contributed to the overall increase in temperature for the Multan district as observed in this study.

The next climatic factor was rainfall. The results displayed the average data (yearly) for the sowing stage i.e. April and May from 1990 to 2020.

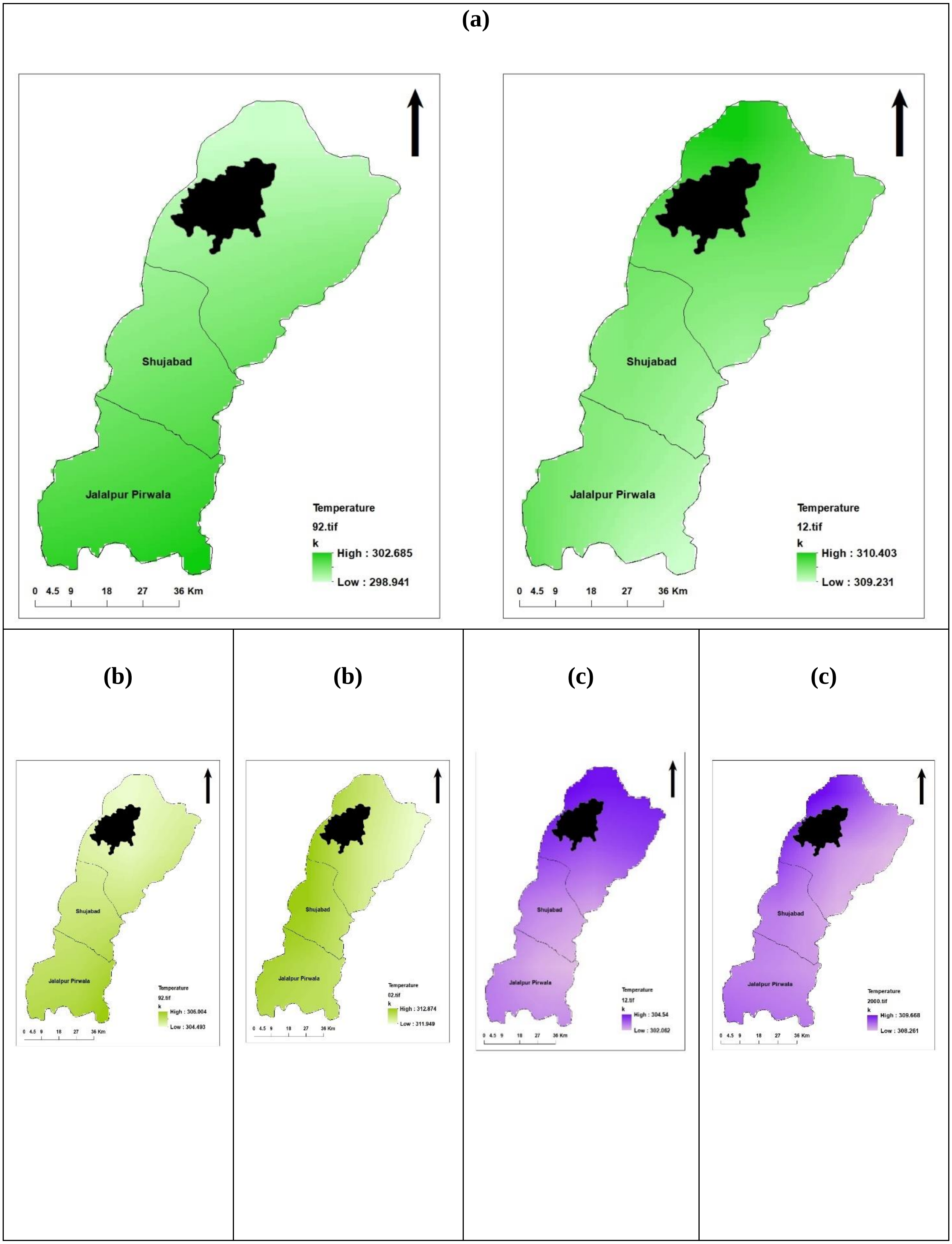


Figure 3.7. Presenting average minimum temperature (a) for sowing stage (b) for emergence-flowering stage (c) for maturity and picking stage.

Two images represented the average rainfall. One from 1992 and another from 2020 to visually analyze the rainfall change trend which seemed to decrease. In 1992 the highest average rainfall was 0.002 mm day^{-1} whereas in 2020 the highest average rainfall reached 0.0003 mm day^{-1}. The change was not drastic but gradual as presented in figure 3.8 (a).

To determine the trend direction (Positive or Negative) Mann-Kendall Test was run on average 30 years sowing Stage data. The results showed that the overall trend was both decreasing and increasing. In Jalalpur Pirwala, Shujabad and some areas of Multan city the trend was decreasing; in Multan city most of the area experienced an increasing trend as exhibited in figure 3.8 (b).

To analyze whether the trend is significant or non-significant, the Man-Kendall trend was run on the averaged 30 years sowing stage data. The probability value at 0.05 was written as significant and all other values were placed under the heading of non-significant. The areas with light purple demonstrated that the trend was significant, and dark purple suggests that the trend was not significant. A mixture of significant and non-significant trend can be seen throughout the study area as presented in figure 3.8 (c).

The results displayed the average data (yearly) for the emergence - Flowering stage i.e. June, July, August from 1990 to 2020. Two images represented the average rainfall. One from 1992 and another from 2020 to visually analyze the rainfall change trend which seemed to increase. In 1992 the highest average rainfall was 0.0018 mm day^{-1} whereas in 2020 the highest average rainfall reached 0.012 mm day^{-1}. The change was not drastic but gradual as highlighted in figure 3.9 (a).

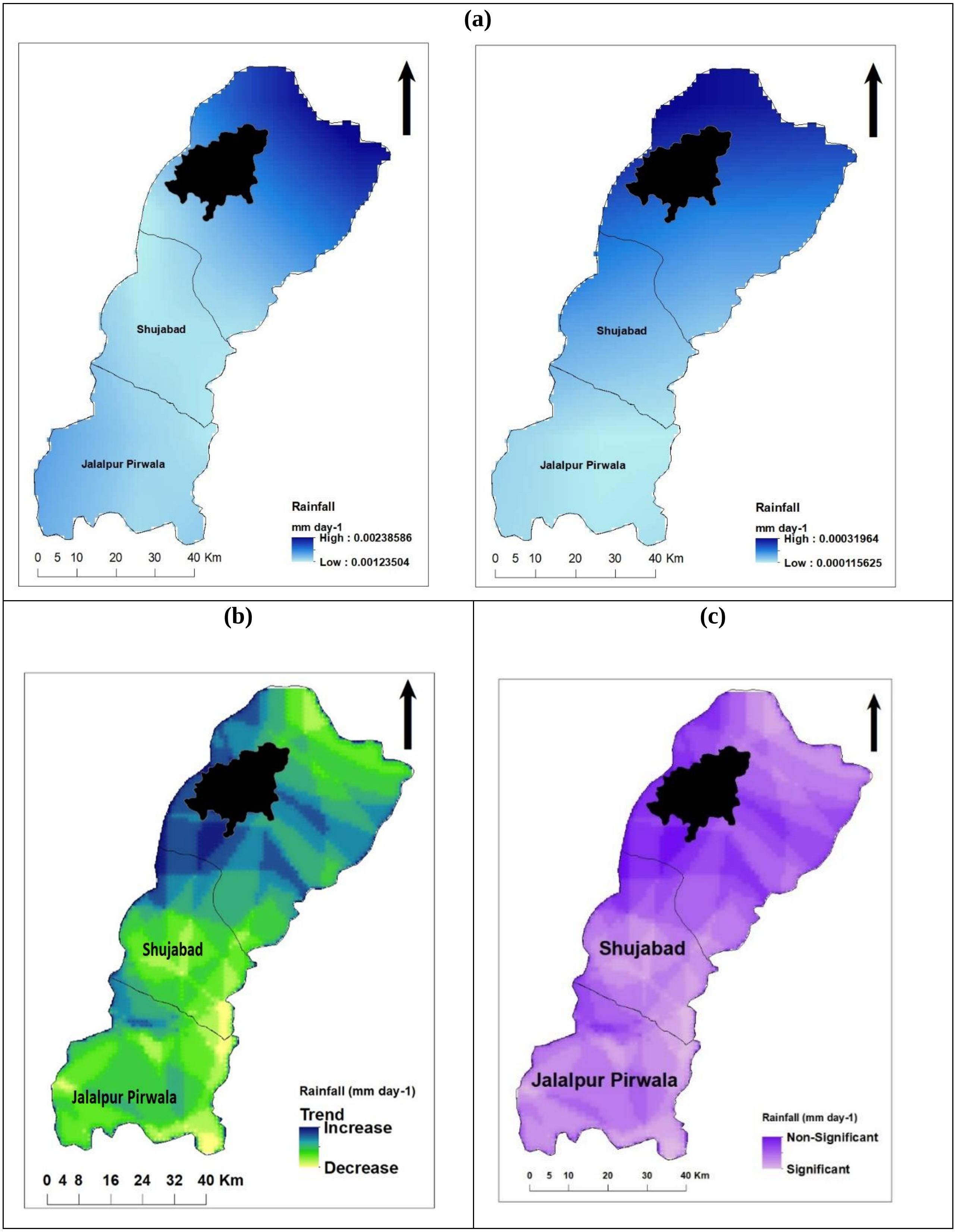


Figure 3.8. Displaying sowing stage average rainfall (a) 30 years difference (b) trend map (c) probability map**.**

To determine the trend direction (Positive or Negative) Mann-Kendall Test was run on average 30 years emergence to flowering Stage data. The results displayed that the overall trend was decreasing in nature. In Jalalpur Pirwala and Shujabad the trend was increasing while Multan city experienced a decreasing trend as shown in figure 3.9 (b).

To analyze whether the trend is significant or non-significant, the Man-Kendall trend was run on the averaged 30 years emergence-flowering stage data. The probability value at 0.05 was written as significant and all other values were placed under the heading of non-significant. The areas with light purple showed that the trend was significant, and the dark purple area displayed not-significant trend areas. A discrete and demarcated trend highlighted the areas with significant and non-significant trends. Jalalpur Pirwala and Shujabad displayed more significant trends than Multan City and Multan Saddar as highlighted in figure 3.9 (c).

The results displayed the average data (yearly) for the Maturity and Picking stage i.e. September and October from 1990 to 2020. Two images represented the average rainfall. One from 1992 and another from 2020 to visually analyze the rainfall change trend which seemed to decrease. In 1992 the highest average rainfall was 0.008 mm day^{-1} whereas in 2020 the highest average rainfall reached 0.0007 mm day^{-1}. The change was not drastic but gradual as presented in figure 3.10 (a).

To determine the trend direction (Positive or Negative) Mann-Kendall Test was run on averaged 30 years of maturity and Picking Stage data. The results displayed that the overall trend was increasing in nature. In Jalalpur Pirwala, Shujabad and some areas of Multan city the trend was increasing overall but a very small area of Jalalpur Pirwala, Shujabad and Multan city experienced an increasing trend as displayed in figure 3.10 (b).

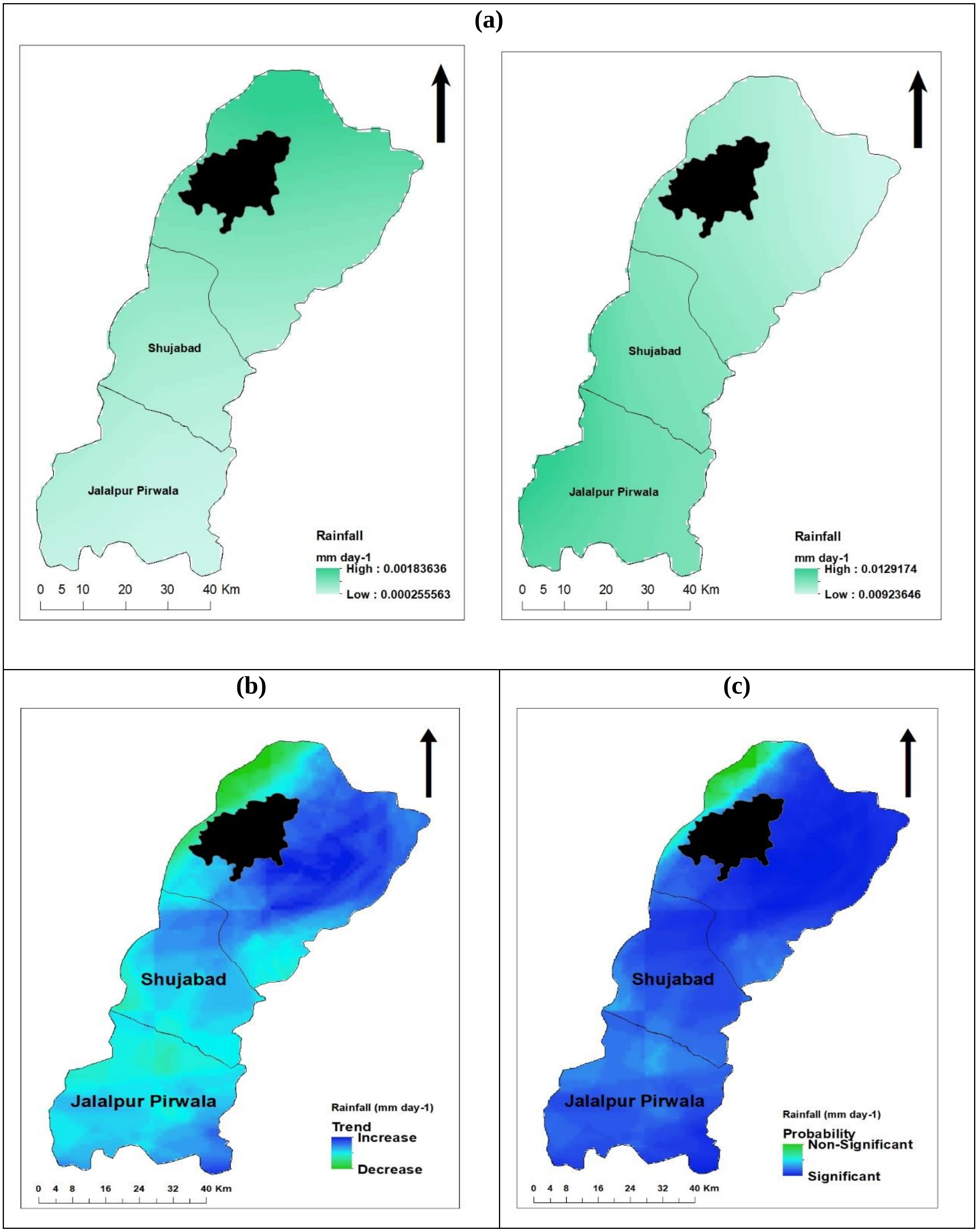


Figure 3.9. Showing emergence to flowering stage average rainfall (a) 30 years difference (b) trend map (c) probability map**.**

To analyze whether the trend was significant or non-significant, Man-Kendall trend was run on the averaged 30 years sowing stage data. The probability value at 0.05 was written as significant and all other values were placed under the heading of non-significant. The light purple color displayed the areas where the trend was significant and dark purple color highlighted non-significant trend areas. A mixture of significant and non-significant trend areas can be seen in figure 3.10 (c).

The graph displayed that the rainfall and cotton yield were highly co-related. The relation was significant but negative in nature. The years where rainfall was high crop yield was less, and the areas where rainfall was less cotton yield was high which displayed the inverse relationship between rain and cotton yield as shown in figure 3.10 (d).

Salma et al., 2012 conducted a study to analyze the rainfall trend patterns in different climatic zones of Pakistan by acquiring thirty meteorological observatories datasets spanning thirty years, from 1976 to 2005. T3 test and ANOVA were used to assess the entire set of data. The findings indicate a nationwide declining tendency (-1.18mm/decade), which might be related to the drought that existed from 1998 to 2001. (Salma, 2012) This study justified the results of sowing stage and maturity – picking stage results where the areas in Multan district highlighted an overall decreasing trend from 1990-2020.

Mahmood et al., (2019) worked on evaluating the trends of rainfall due to climate change in the Potohar region of Pakistan. The data from the four districts was processed using Mann-kendall test and the results demonstrated the rainfall increase in some months and some months experienced a decrease in rainfall. (Mahmood, 2019). Another study by Farooqi et al., (2005) predicted that Pakistan will experience more extreme, intense, and frequent events in the future.

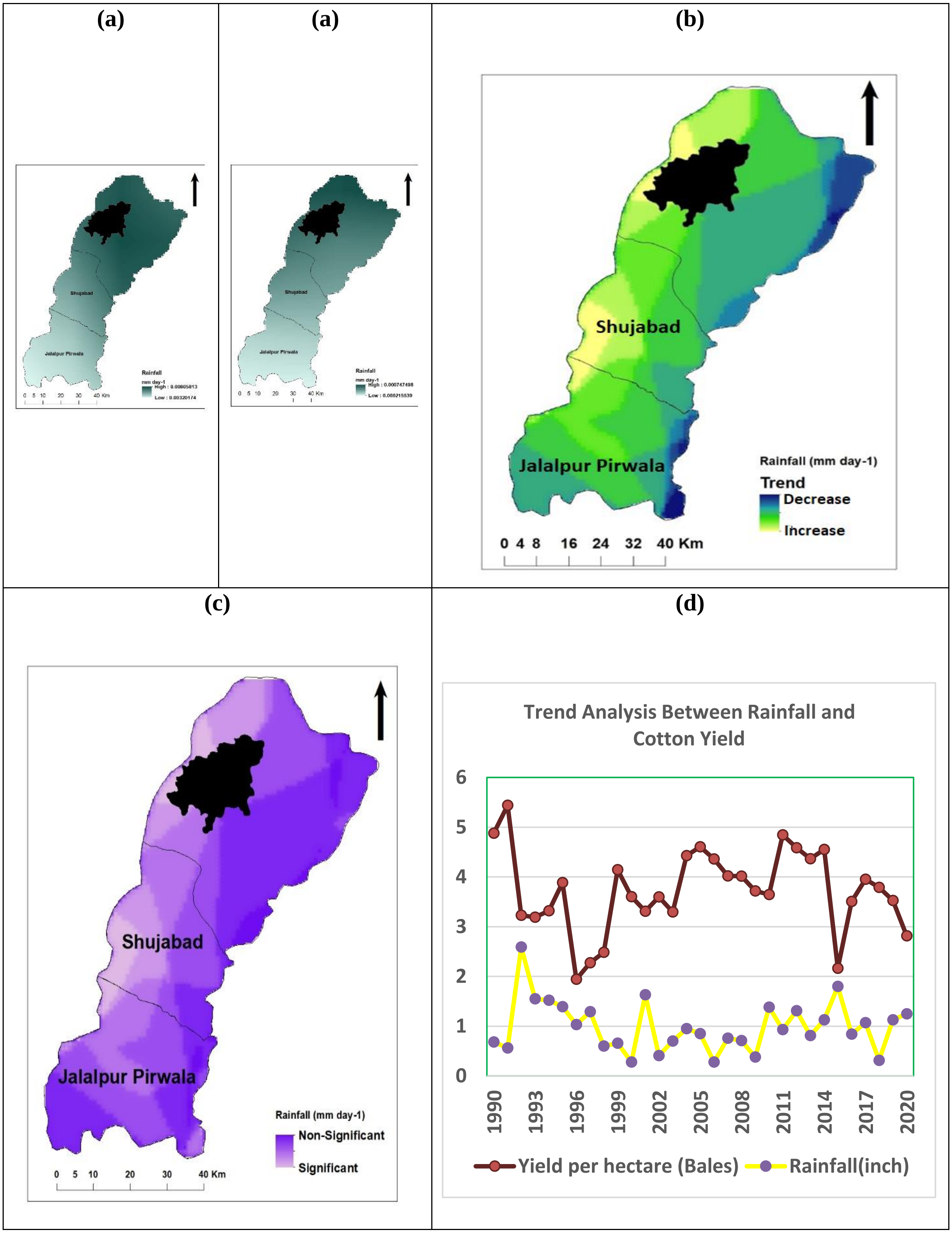


Figure 3.10. Displaying maturityand picking stage average rainfall (a) 30 years difference (b) trend map (c) probability map (d) rainfall and cotton yield trend analysis.

It justified the results of increase rainfall in the emergence-flowering stage. This is because during monsoon season the area experiences more drastic events.

Another climatic factor was windspeed. The results displayed the average data (yearly) for the sowing stage i.e. April and May from 1990 to 2020. The average wind speed was represented by two images to analyze the wind speed change visually. The average wind speed seemed to increase throughout the years. The change was not drastic but gradual as highlighted in figure 3.11 (a).

To determine the trend direction (Positive or Negative) Mann-Kendall Test was run on average 30 years sowing Stage data. The results displayed that the overall trend was increasing. In Jalalpur Pirwala, Shujabad and some areas of Multan city the trend was increasing while a very small area at the north of Multan city experienced a decreasing trend as displayed in figure 3.11 (b).

To analyze whether the trend was significant or non-significant, Man-Kendall trend was run on the averaged 30 years sowing stage data. The probability value at 0.05 was written as significant and all other values were placed under the heading of non-significant. The areas with green color demonstrated that the trend was not significant whereas the red color highlighted the areas with significant trend. Multan City and Multan Saddar displayed a more significant trend than Jalalpur Pirwala and Shujabad as presented in figure 3.11 (c).

The results displayed the average data (yearly) for the emergence - Flowering stage i.e. June, July, August from 1990 to 2020. The average wind speed was represented by two images to analyze the wind speed change visually. The average wind speed seemed to increase throughout the years. The change was not drastic but gradual as shown in figure 3.12 (a).

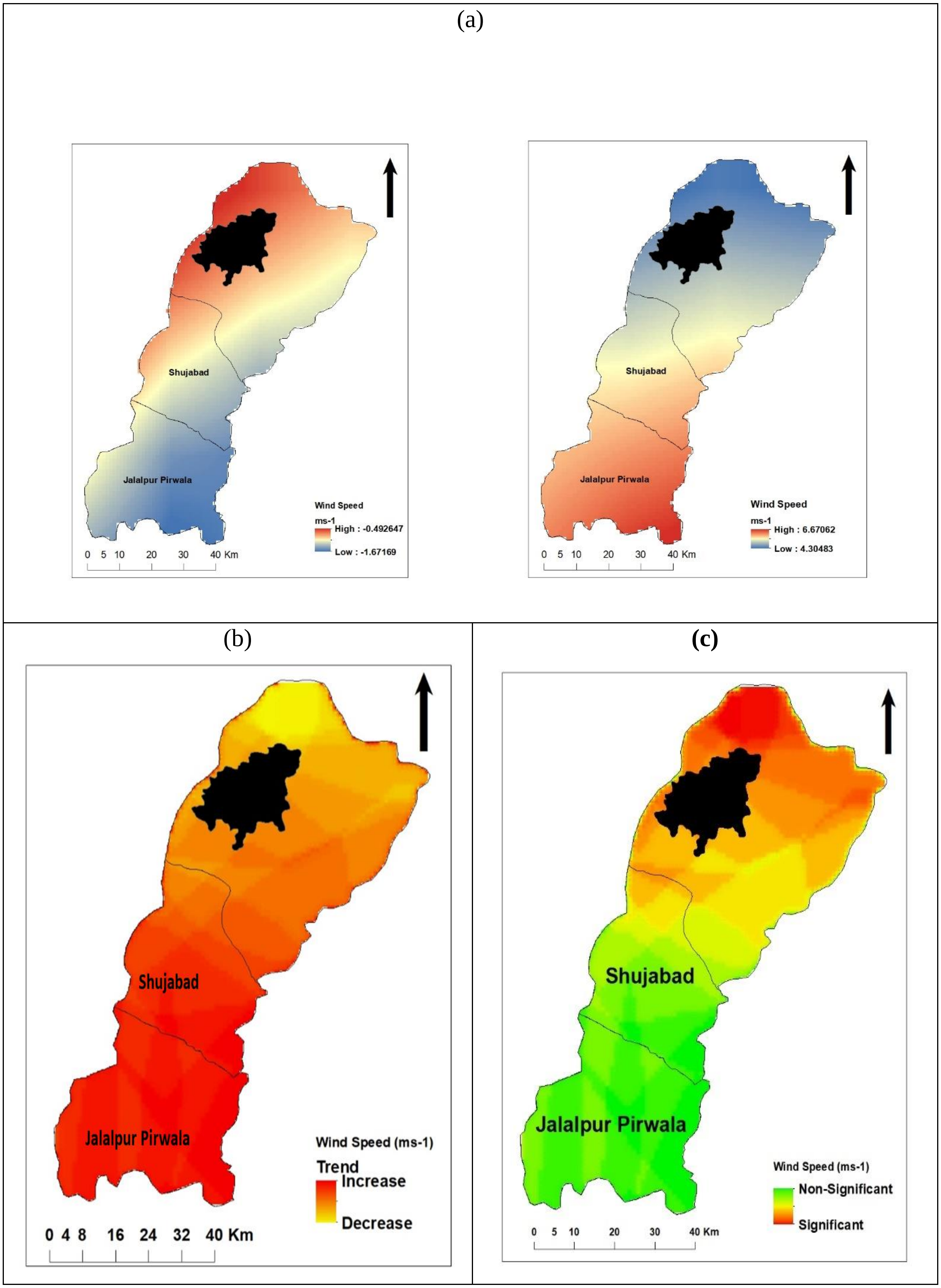


Figure3.11. Sowing stage average wind speed (a) 30 years difference (b) trend map (c) probability map**.**

To determine the trend direction (Positive or Negative) Mann-Kendall Test was run on average 30 years emergence - flowering Stage data. The results displayed that the overall trend was decreasing. In Jalalpur Pirwala, Shujabad and some areas of Multan city the trend was decreasing while a very small area at the north of Multan city experienced an increasing trend as presented in figure 3.12 (b).

To analyze whether the trend was significant or non-significant, the Man-Kendall trend was run on the averaged 30 years sowing stage data. The probability value at 0.05 was written as significant and all other values were placed under the heading of non-significant. The areas with green color demonstrated that the trend was not significant and red areas highlighted the areas where trend was significant. Clearly demarcated significant and non-significant trends can be seen throughout the research area as highlighted in figure 3.12 (c).

The results displayed the average data (yearly) for the Maturity and Picking stage i.e. September and October from 1990 to 2020. The average wind speed was represented by two images to analyze the change in the wind speed visually. The average wind speed seemed to increase throughout the years. The change was not drastic but gradual as exhibited in figure 3.13 (a).

To determine the trend direction (Positive or Negative) Mann-Kendall Test was run on averaged 30 years of maturity and Picking Stage data. The results displayed that the overall trend was both increasing in nature. In some areas of Jalalpur Pirwala, Shujabad and Multan city the trend was decreasing while an increasing trend can be seen otherwise as displayed in figure 3.13 (b).

To analyze whether the trend was significant or non-significant, Man-Kendall trend was run on the averaged 30 years sowing stage data. The probability value at 0.05 was written as significant and all other values were placed under the heading of non-significant.

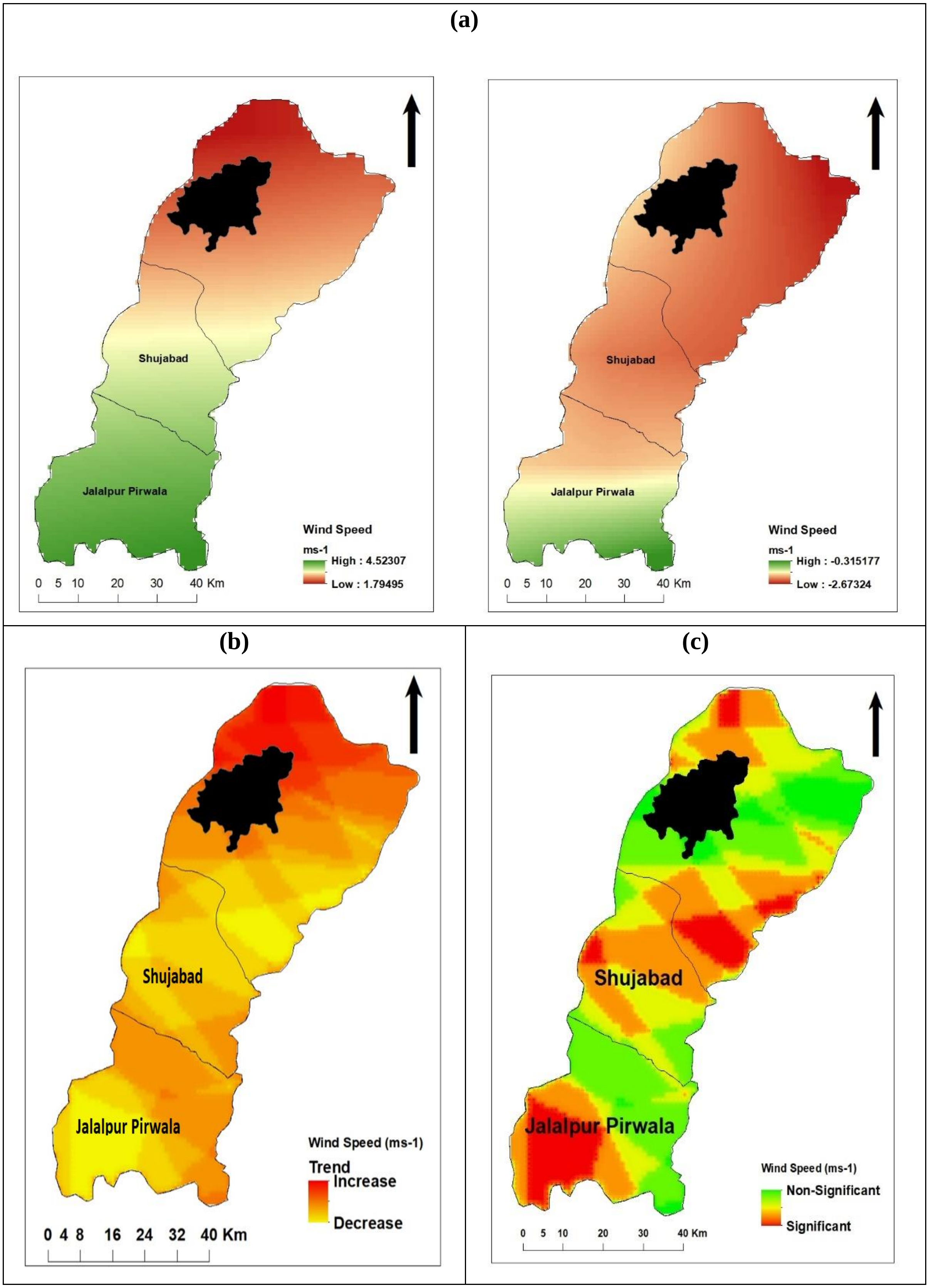


Figure 3.12. Showing emergence-flowering stage average wind speed (a) 30 years difference (b) trend map (c) probability map**.**

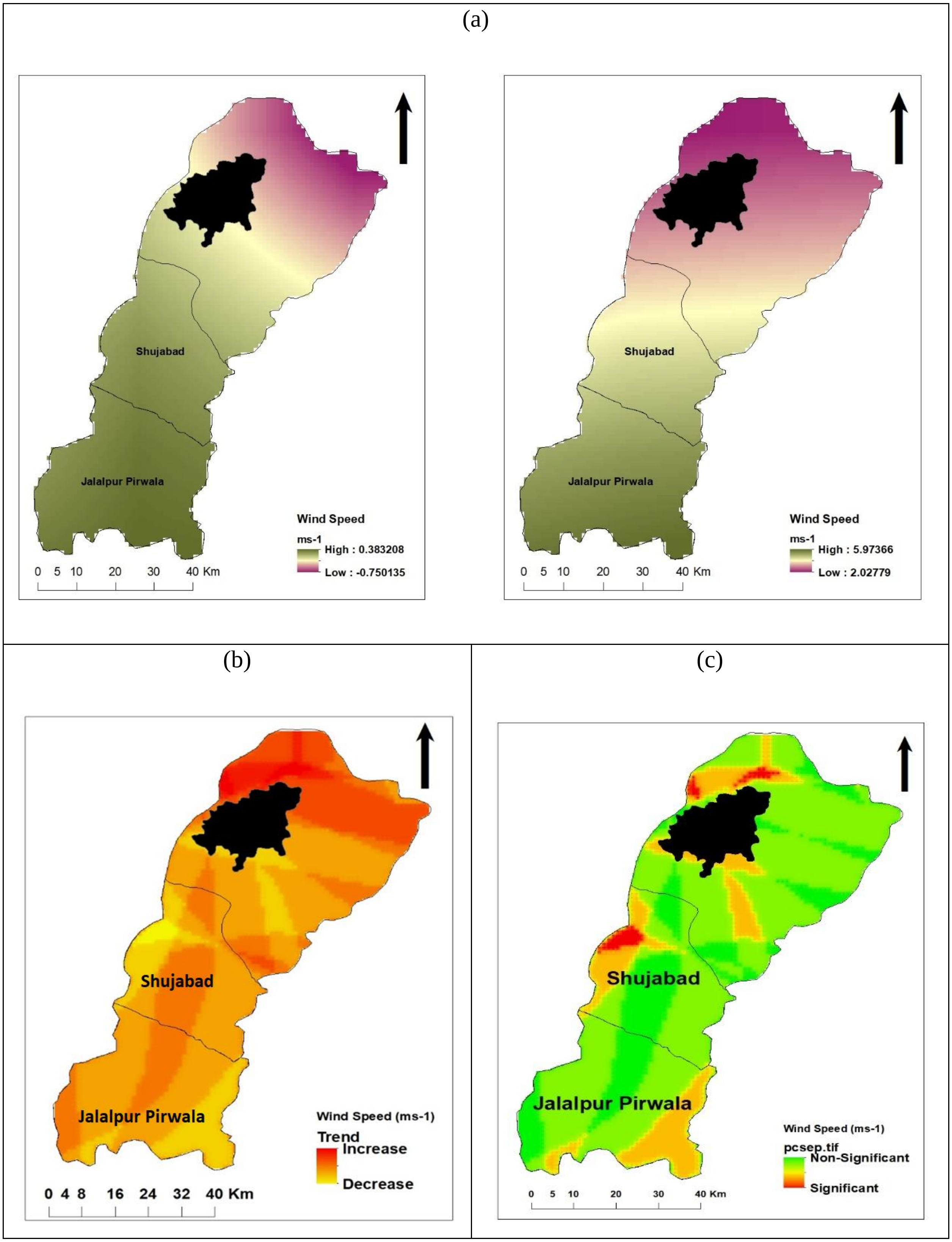


Figure 3.13. Displaying maturity and picking stage average wind speed (a) 30 years difference (b) trend map (c) probability map**.**

The areas with green color demonstrated that the trend was not significant whereas the red color highlighted the areas with significant trend. Jalalpur Pirwala and Shujabad displayed more non-significant trends than Multan City and Multan Saddar as shown in figure 3.13 (c).

Back and Bretherton, (2005) proved that high wind speed increased the amount of evaporation, resulting in high rainfall. This supported the results of windspeed where rainfall and windspeed show similar patterns. (Back and Bretherton, 2005)

The results displayed the average data (yearly) for the cotton growth season i.e. April and October from 1990 to 2020. The average soil moisture was represented by two images to analyze the soil moisture change visually. The average soil moisture seemed to decrease throughout the years. The change was not drastic but gradual as highlighted in figure 3.14 (a).

To determine the trend direction (Positive or Negative) Mann-Kendall Test was run on averaged 30 years Cotton Growing season (April-October) data. The results displayed that the overall trend was decreasing. In some areas of Jalalpur Pirwala, Shujabad and Multan city the trend was increasing while most of the study area highlighted the decreasing trend as displayed in figure 3.14 (b).

Man-Kendall trend was run on the averaged 30 years sowing stage data to analyze whether the trend was significant or non-significant. The probability value at 0.05 was written as significant and all other values were placed under the heading of non-significant. The areas with light blue demonstrated that the trend was significant and dark blue highlighted the non-significant trend areas. Jalalpur Pirwala, Shujabad and almost all of the Multan city displayed significant trend as shown in figure 3.14 (c).

Varikoden and Revadekar, (2017) in their research proved that rainfall and soil moisture are directly related to each other in a linear manner. (Varikoden and Revadekar, 2017)

The rainfall showed an overall decreasing trend which justified the decrease in soil moisture.

Correlation Matrix and Regression

To investigate the relationship between dependent variables (i.e. Cotton Yield) and the independent variables (i.e. Climatic Factors (Temperature, Rainfall, Wind Speed), correlation was calculated. For every variable the probability value at 0.05 was calculated by keeping in mind the number of observations.

In table 3.4 the results displayed that all three climatic factors were significant. Rainfall and wind speed negatively affected the cotton yield, whereas temperature positively affected the cotton yield.

To clearly analyze the percentage of relationship between dependent variable and independent variable, regression analysis was performed on the 30 years data. In table 3.5 the results demonstrated that the independent variables were affecting the dependent variable only 46%. It highlighted the fact that climatic factors were not the only aspects affecting the cotton yield.

3.3. Management Practices:

To understand what other factors were affecting the cotton yield, a survey was conducted. The survey form was circulated among farmers to approach a more related group of people. The survey form included questions related to former and modern farming techniques and how lack of guidance, poor and outdated Management practices were continuously affecting the cotton yield.

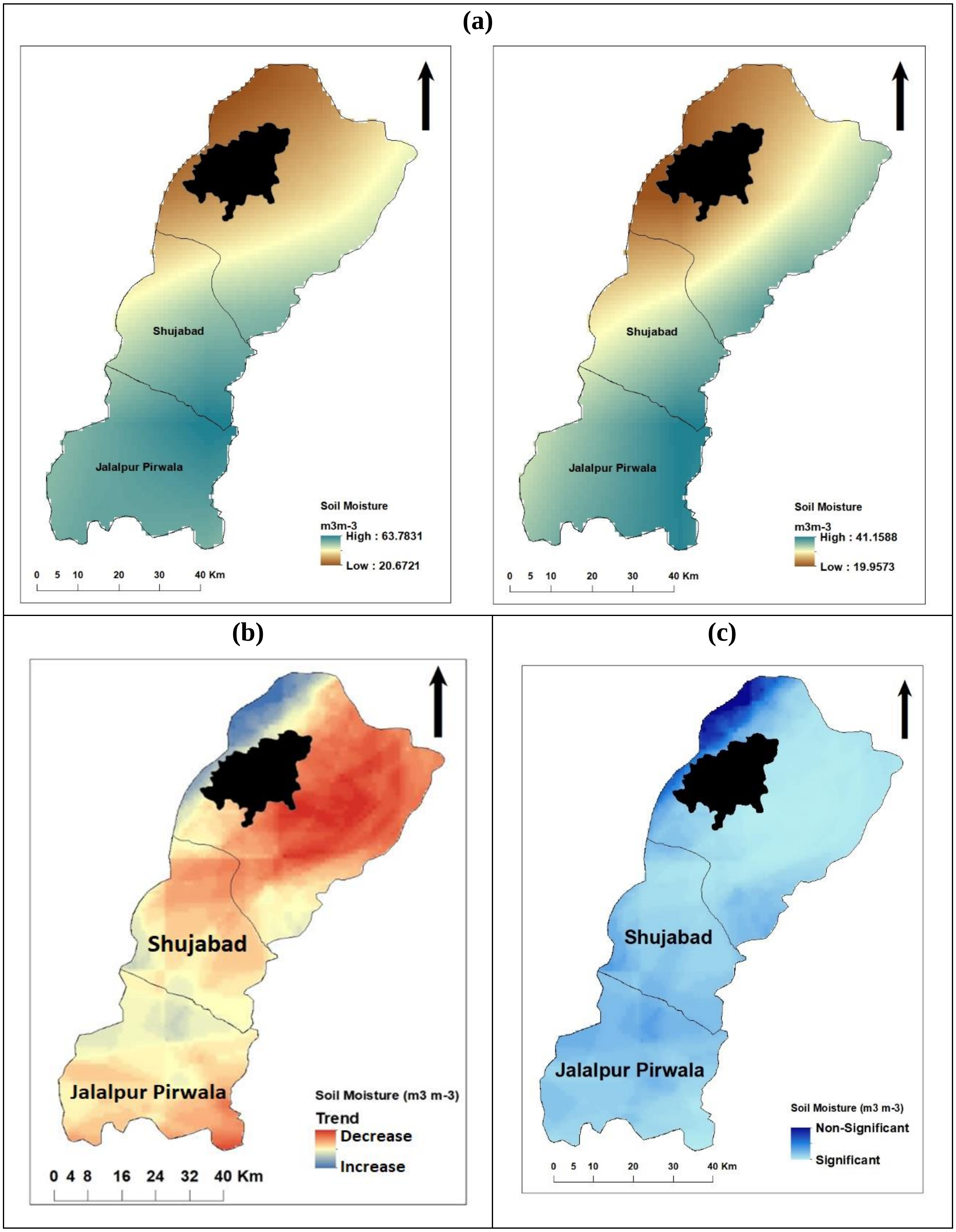


Figure 3.14. Showing average soil moisture for cotton growth stage (a) 30 years change (b) trend map (c) probability map**.**

Table. 3.4. Correlation matrix for climatic factors and cotton yield.

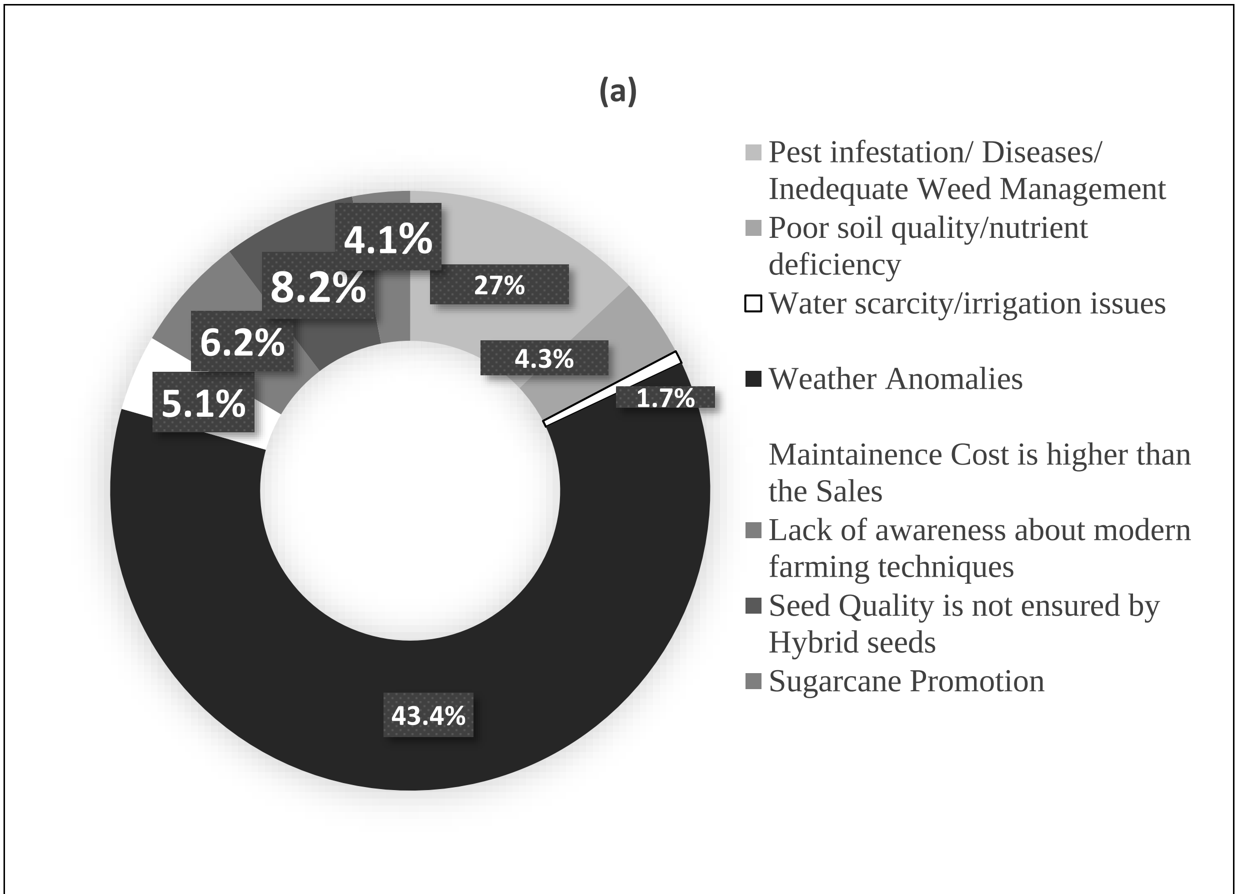
	Temperature	**Rainfall**	**Wind Speed**	**Yield per hectare**
Temperature	1			
Rainfall	-0.57	1		
Wind Speed	0.24	0.01	1	
Yield per hectare (in Bales)	0.21	-0.34	-0.10	1

Table. 3.5. Regression analysis of dependent and independent variables.

SUMMARY OUTPUT	
Regression Statistics	
Multiple R	0.46
R Square	0.54
Adjusted R Square	0.52
Standard Error	0.14
Observations	31

The results demonstrated that weather anomalies were affecting the cotton yield only 43.4%, pest infestations were 27%, seed quality (hybrid seeds) was 8.2%, Lack of awareness was 6.2%, High maintenance cost was 5.1%, poor soil quality was 4.3%, Sugarcane promotion was 4.1% and water scarcity was only 1.7% as highlighted in figure 3.15 (a). All these factors played a major role in Multan division's cotton yield reduction, causing a decline of almost one t/h average loss per year.

The results in figure 3.15 (b) displayed the further characterization of each climate Factor. The highest contribution was from rainfall which was 52%, temperature was at 41%, and the wind speed was only at 7%.



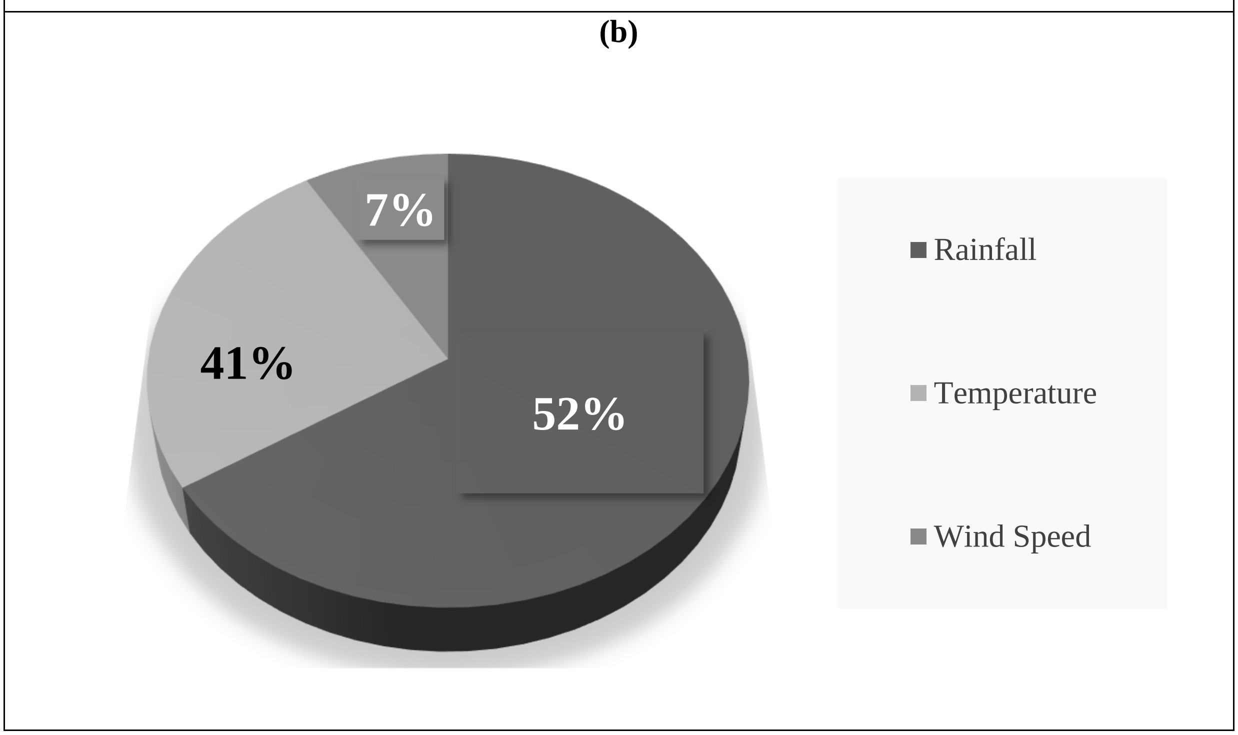


Figure 3.15 Displaying (a) factors affecting cotton yield (survey) (b) categorization of weather anomalies (survey).

Chapter 4

CONCLUSTION AND RECOMMENDATIONS

4.1 CONCLUSIONS

The yield of cotton is seriously threatened by climate change. Variations in temperature, patterns and intensity of rainfall, and the dynamics of pests and diseases impact cotton's growth, development, and productivity. The following conclusions can be made based on analysis, results, and indicators.

Temperature increase positively impacts cotton yield, but after a specific temperature, more temperature increase affects the cotton yield negatively. Cotton plants are especially sensitive to temperature changes throughout their growth stages, so ideal temperature is necessary to produce high yields. Warm temperatures generally encourage vigorous plant growth but extremes in temperature, either high or low, can interfere with vital stages of the cotton life cycle.

Cotton plants require very low rainfall. Every stage of the cotton growth cycle requires different rainfall, and disruption in any can cause harm. Sufficient and evenly distributed rainfall is necessary to encourage ideal germination, early plant growth, and development of cotton. Water stress brought on by insufficient rainfall can harm cotton plant establishment and prevent them from maturing to their full potential. On the other hand, too much rain, particularly in the stages of flowering and boll development, can cause waterlogging and raise the risk of diseases that occur in humid conditions. Consequently, rainfall distribution, amount and time are crucial factors in determining how well cotton crops are.

The influence of wind speed on cotton yield is a complex factor. A moderate wind can benefit cotton crops by improving air circulation and lowering humidity, wind speeds that are too high could be problematic. Too strong winds can physically harm cotton plants by uprooting seedlings, shattering stems, or abrading leaves and bolls. Physical stress can cause plants to struggle to recover and realize their full potential for productivity, which can result in yield loss. During the flowering stage high winds can also cause interference with pollination, which will reduce the number of cotton bolls. Furthermore, wind, particularly in arid areas, can increase evaporation, which in turn worsens water stress in cotton plants.

The impact of soil moisture on cotton yield is a critical factor in evaluating the efficacy of cotton farming. For the best germination, root development, and general growth of cotton plants, there soil must have sufficient moisture. Water stress caused by inadequate moisture, especially in critical growth stages, can negatively affect seedling establishment and make it more difficult for plants to flower and set bolls. On the other hand, too much moisture in the soil can result in soggy conditions that hinder root growth and raise the risk of diseases. A successful and high-yielding cotton harvest is ultimately facilitated by ensuring that cotton plants receive the proper amount of water in the soil to support robust growth, boll development, and fiber quality.

4.2 RECOMMENDATIONS

Considering the complexities caused by climate change, cotton farming must use adaptation and mitigation measures. Some suggestions/recommendations may be considered in this regard.

Through breeding and genetic development initiatives, cotton cultivators can create climate-resilient cultivars that show increased resistance to heat, drought, and pests.

While preserving the health of the soil, crop rotation and diversification can reduce the danger of pests and diseases.

Cotton crops can be made more resilient by implementing sustainable agricultural techniques including integrated pest Management, organic farming, and conservation agriculture.

A range of stakeholders, including legislators, researchers, farmers, and business leaders, must work together to address how climate change affects cotton crop productivity.

Policies that support climate-smart practices, encouraging sustainable agriculture, and aid in research and development can be put in place by governments.

It is recommended that research institutions and organizations prioritize the development of novel solutions to enhance crop Management techniques, remote sensing technologies, and weather forecasting models customized for cotton farming.

Public-private partnerships along the cotton value chain can promote knowledge exchange, make resources more accessible, and strengthen climate resilience.

We can lessen the negative effects of climate change on cotton cultivation by implementing sustainable practices, fostering collaboration, and adopting adaptive measures.

Prioritizing policy support, knowledge sharing, and research is essential to ensuring the cotton industry's sustainability and resilience in the face of climate change.

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APPENDICES

Appendix-1. Survey form of factors affecting cotton crop yield

1. **General Information**

Name

____

Email

____

Gender

- Male
- Female

Age

____

Location (City/Country)

____

Occupation

____

2. **Cotton Farming**

Are you involved in cotton farming?

- Yes
- No

3. **Factors Causing Yield Reduction:**

Please rate the following factors based on their contribution to cotton yield reduction.

Pest infestation:

- 10-30%
- 30-50%
- 50-70%
- 70-90%
- 90-100%

Diseases (bacterial, viral, fungal, etc.):

- 10-30%
- 30-50%

Cont..

- 50-70%
- 70-90%
- 90-100%

Poor soil quality/nutrient deficiency:

- 10-30%
- 30-50%
- 50-70%
- 70-90%
- 90-100%

Water scarcity/irrigation issues:

- 10-30%
- 30-50%
- 50-70%
- 70-90%
- 90-100%

Extreme weather events:

- 10-30%
- 30-50%
- 50-70%
- 70-90%
- 90-100%

Inadequate weed management:

- 10-30%
- 30-50%
- 50-70%
- 70-90%
- 90-100%

Lack of knowledge/awareness about modern farming techniques:

- 10-30%
- 30-50%
- 50-70%
- 70-90%
- 90-100%

Cont..

Seed Quality is ensured by using hybrid/improved seed:

- Yes
- No

If "Yes" name the seed variety.

____

4.Switching from Cotton

Please rate the following factors based on their contribution to switch from cotton to sugarcane and other crops.

Fertilizer cost is more than yield profit.

- 10-30%
- 30-50%
- 50-70%
- 70-90%
- 90-100%

Less cotton seed varieties.

- 10-30%
- 30-50%
- 50-70%
- 70-90%
- 90-100%

Farmer friendly policies on shifting to sugar cane.

- 10-30%
- 30-50%
- 50-70%
- 70-90%
- 90-100%

Labor cost is high.

- 10-30%
- 30-50%
- 50-70%

- 70-90%
- 90-100%

Labor is not available at the time of harvest.

- 10-30%
- 30-50%
- 50-70%
- 70-90%
- 90-100%

5. Mitigation Strategies:

Suggest any strategies to mitigate the impact of these factors on cotton yield reduction.

____

6. Future Perspectives:

In your opinion, what measures should be taken at a local, regional, or global level to address these factors and improve cotton yield?

____

7. Additional Comments:

Please feel free to provide any additional comments, observations, or suggestions related to factors causing cotton yield reduction.

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