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RESEARCH ARTICLE

Climate Changes on the Amount of Rain and Temperature from 1990-2018 in Madaba, Jordan using Geographical Information Systems

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Abstract. Climate change is an important topic requiring thorough study due to the importance and increasing impact on the various environmental and human systems. Therefore, this study aimed to clarify the changes observed in the minimum and maximum temperatures, as well as the calculation of rainfall rates during the period spanning 1990 to 2018 in the governorate of Madaba. The amount of rain as well as the average minimum and maximum temperatures were examined through annual, seasonal, and monthly analyses. The comparison results from 2018, 2010, 2000, and 1990 showed that there was an increase in the seasonal, annual, and maximum temperatures for the month of June reaching about 1.51 °C. The month of July and Shahrab reported an elevation of 1.06 °C and 1.26 °C with an annual increase in maximum temperatures of 1.44 °C. Similarly, rainfall rates decreased by 0.05 mm between 1990 and 2018, hence legislative laws were enacted against individuals contributing to climate change. This started with individuals practicing waste and garbage burning, as well as developing unified programs and plans to address the consequences.

1. Introduction

Climate change is an undeniable phenomenon all over the world and has become a pressing issue confronting humanity. In this context, numerous bodies, organizations, and institutions are focused on tackling the problem. However, the interest is not limited to analyzing the predicted outcomes of climate elements, but the effects on the majority of the natural, economic, social, and political factors increasing the concept. Climate change refers to an imbalance in the usual climatic conditions that characterize every region on Earth as reflected in people's lifestyles and national economies. Additionally, it stimulates national and international efforts, as well as the ability to overcome the negative effects associated with the phenomenon.

Many parts of the world have seen a steady and increasing rise in temperature, as well as a decrease in rainfall and a rise in the frequency of unusual weather events such as hurricanes, heat waves, and floods. The rapid increase in surface temperatures over the last few years has been one of the most important indicators and evidence monitored on climate change in the world. According to NASA findings, frost or drought wave temperature increases are widespread but the rate ranges from 2 to 3.6 °C (Cramer et al., 2022).

United Nations Convention (UNFCC) states that climate change is directly or indirectly related to human activities contributing to the change in the composition of the atmosphere. The change in the general cycle of the atmosphere and the associated weather phenomena, such as hurricanes and droughts is due to global warming increasing the percentage of greenhouse gases in the atmosphere. The gases prevent a large part of the terrestrial radiation from escaping to the top and contribute to the rising temperature of the earth (Baias et al., 2020).

The melting of sea ice thickness caused the average level to rise by 0.3 mm due to the increase in temperature. In the fourth report in 2007, the Intergovernmental Panel on Climate Change predicted that sea levels increased by at least 0.6 mm, posing threats to coastal areas since the lives of inhabitants were exposed to the risk of flooding and increased salinity of groundwater and estuaries (IPCC, 2007). Therefore, the region experienced extreme climatic conditions, including an increase in drought due to decreased precipitation and a 15–25 % decrease in freshwater resources in the areas of the Fertile Crescent.

Several previous studies, as well as international bodies and organizations, have discussed climate change. The International Panel on Climate Change (IPCC) is known to regularly issue scientific reports on climate change and the global and regional dimensions. In the fourth report for 2007, IPCC states that climate change has become a reality, as evidenced by monitoring the increase in average air and ocean temperature in different parts of the world. Due to temperature increase, the past fifty years have seen a decrease in the number of cold days and nights, as well as the percentage of frost appearance in most land areas, while the number of hot days and nights has increased. The dimensions and adaptation of climate change in different regions have been studied, where global warming is the primary cause of the phenomenon due to the release of a large group of gases after the industrial revolution to trap heat near the earth's surface and prevent escape to outer space. This results in an increase in the earth's temperature and the consequent negative environmental manifestations in various regions (IPCC, 2007).

Ferrelli, et al (2024) examined the trends in daily temperature and rainfall indices in South Australia spanning the last fifty years to ascertain the presence of warming signals. The analysis focused on extreme cold, hot, and rainfall events using climatic data from 37 weather stations. Meanwhile, trend analysis was conducted using the Mann–Kendall test with Sen's estimator. The results reported an increase in maximum and minimum temperatures by 1.1 and 0.7 °C during the 1970–2021 period, with a negative trend in precipitation, showing a decrease of 52.2 mm per period. Statistical significance was observed in the analysis of extreme cold and hot events to show the impact of warming signals on South Australia.

Yesuph, et al. (2023) investigated the impact of climate change on multidimensional poverty and the contributing factors in Ethiopia. Analytical methods including the multidimensional poverty index, probit model, and parametric tests were used to analyze the data with descriptive statistics. The results showed statistically significant differences between poor and non-poor households across eleven variables. Moreover, a trend of increasing temperatures and decreasing rainfall was reported over time in the study area. These changes affected the livelihoods of smallholder farmers, whose dependence on rain-fed agriculture increased vulnerability. The study found that 82% of sampled households experienced multidimensional poverty using a multidimensional approach to poverty assessment. Among the villages studied, Abala Gefeta showed the highest poverty incidence of 89%, followed by Bossa Wanche and Abala Shoya at 80% and 84%, respectively.

Albadry (2021) examined spatial and temporal assessments of temperature trends and rainfall in Iraq from 1979 to 2018, using data from the Iraqi Meteorological Authority. The lowest temperatures were recorded during all seasons of the year, with the summer presenting faster trends toward warmth that exceeded 3 °C during the study period in some monitoring stations, such as the Kha'if and Najaf stations. In contrast, the results of the rain trend analysis reported clear spatial and temporal variations since most of the stations were characterized by a decrease in the amounts of rain. This was achieved during the spring and autumn seasons, recording an increase in the amounts of rain in most of the stations. Future changes in temperature and rainfall amounts were evaluated based on data from the coordinated regional scale reduction project. In this context, the minimum temperatures for the Mandel scenario are expected to increase by (1.1-1.7) m over the next four decades. Even though maximum temperatures rise by 12.7% from current levels, the amount of rain is expected to fall in most parts of Iraq, particularly in the southern regions. Therefore, future climatic changes will increase the environmental and economic pressures on agricultural production sectors, water resources, and energy consumption. The study suggested developing appropriate future policies and strategies for climate change adaptation.

(Hussein, 2017) used the time-series method to predict rainfall rates based on the time series data from 2006 to 2016, and weakly stationary stability is reported since the data are not affected by time and space. The results showed that the roots of the time series are outside the circle of a correct radius on average. Due to the differences in rainfall amounts between governorates, the study recommended conducting similar analyses for each governorate separately, as well as the use of other statistical and scientific methods to predict the amount of rainfall, due to the significance in planning and development.

(Abdul Hafez and Al-Asadi, 2019) showed the climatic changes in the days of stay of depressions and highlands at the level of 500 millibars due to climate change over Iraq for 1950–2016 and not climatic cycles. The amount of seasonal change in the days of low cut-off stays in Iraq during the two observations is decreasing since the lowest number is recorded in the fifth cycle with the survival rate in the northern region at 0.85 and 0.92 per day. The percentage change amount was negative at 40.64% and 45.55% for day and night observations, respectively.

(Yehia, 2021) identified the respondents' level of knowledge about climatic changes in Siwa Oasis and the negative consequences in Egypt. The relationship between some variables and the level of knowledge about the negative consequences were also identified to show the most significant problems. The issues include heat, humidity, ecosystem disruption, and deterioration in vegetable and fruit crop productivity.

Ahmed (2018) developed a mathematical model to predict the average amount of rainfall for each month of the year in the Arab Republic of Egypt, based on data from January 2000 to December 2014. Therefore, a statistical mathematical model is constructed to predict the average amount of rain in the Arab Republic of Egypt for each month of the year. This model aims to account for potential periodic patterns in the average amount of rain and the quality is verified by applying an independent period. Future values of the monthly averages of the average amount of rain for the entire 12-month period in 2015 are predicted based on the model. The temporal behavior of average rainfall amounts in the Arab Republic of Egypt follows a semi-periodic and semi-regular pattern. However, the detection of this pattern is difficult except through the use of harmonic regression. The study recommended that officials and policymakers in various fields use scientific methods in forecasting to plan scientifically.

(Al-Wakeel and Hadi, 2017) presented a statistical study on an appropriate distribution of the amount of rainfall for the governorates of Iraq using two types of distributions for the period (2005-2015). The logarithmic normal distribution and the mixed exponential distribution were suggested, and each governorate was tested with the distributions to determine the optimal distribution of rain in Iraq. The specific distribution was determined using the minimum standards produced by some good conformity and testing standards (Consistent Akaike (CAIC), Bayesian Akaike (BIC), Akaike) (AIC). The distributions were used to ascertain the suitable distribution for rainfall data across the governorates. The maximum likelihood and the method of least squares were used to estimate the distribution parameters. The optimal probability distribution for rainfall data in most Iraqi provinces is the logarithmic normal distribution or the mixed exponential distribution. Specifically, ten out of twelve provinces show a probabilistic distribution of mixed exponential distribution.

The significance lies in the focused examination of the predicted effects of climate change on minimum and maximum temperatures, as well as rainfall patterns in the Madaba governorate. By selecting the region, which is influenced by cold and warm air masses as well as Mediterranean depressions during the winter season, valuable insights are provided into the local manifestations of global climate shifts. Moreover, this study extends beyond analysis, stating the potential implications for various sectors including agriculture, water resources, and energy consumption. By investigating the projected changes in temperature and precipitation, crucial information is offered for policymakers and stakeholders to develop targeted adaptation strategies. Furthermore, the study contributes to the broader discourse on climate change impacts in the Middle East region, adding to informed decision-making and sustainable development initiatives. Through the meticulous examination of climatic trends and implications for the Madaba governorate, this study serves as a valuable resource for understanding and addressing the complex challenges posed by climate change in the region.

The Madaba Governorate is included in the study area and divided into two (Kasbah of Madaba, the District of Theban) and five districts (Greena, Ma'in, Al-Faisaliah, Al-Areed, and Malih), as well as seven municipalities. The Madaba Governorate is located south of Amman and is far from the Jordanian capital (Amman). The area is (939.70) km^2, which accounts for approximately (0.014) percent of the total area of the Kingdom. Additionally, it has a Mediterranean climate, which is mild in the summer and cold in the winter, with an average temperature of 25 °C in the summer and below zero °C in the winter, rising to about 774 meters above sea level. Madaba was selected because the location is in the central region, which includes four governorates (the capital, Al-Balqa, Zarqa, and Madaba), with a dry and semi-arid climate. Even though climate varies, desert and semi-desert nature dominate large parts of the Mediterranean climate, which is more vulnerable to cold polar air masses causing frost during the winter season, as well as warm and hot air masses resulting in increased temperature.

2. Methods

There are numerous analytical methods for detecting, monitoring, evaluating, and interpreting the state of climate change. Given the study's focus on determining the value of change, the following approaches were used to achieve the objectives. The descriptive approach was used to show the natural characteristics of Madaba Governorate, including geography, topography, land uses, climate, and soil types. This was conducted to report the natural, human, or climatic origin of the developmental changes during the study period of 1990–2018. The aim was to analyze the changes, state the attributes, characterize the nature, and assess the quality of the relationship between the variables. The analytical approach was used in analyzing remote sensing data from the World Club and represented in climate visuals to evaluate and interpret the state of change, derive values, and analyze the data. The comparative approach was used to compare the evolution of climate change using the results from digital analysis of climate visuals from 1990 to 2018. The stages of the study can be divided into methodological and data collection, data preparation, as well as processing and analysis.

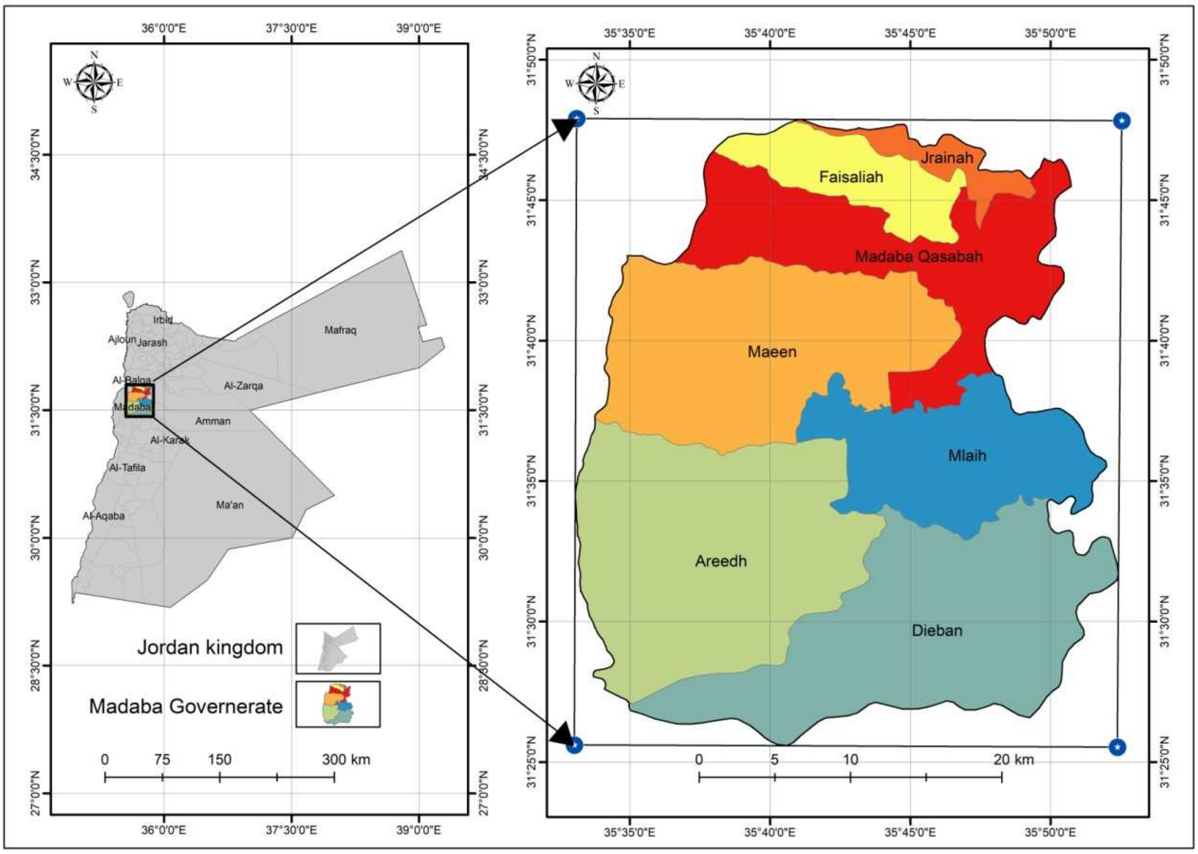

Figure 1. Study Area (Source: Prepared by using GIS)

Data collection

Spatial and descriptive data were collected from a variety of specialized institutions, and a digital elevation model with a discriminatory accuracy of 30 m was obtained from the US Geological Survey website. In addition, the Natural Resources Authority provided geological data, and the Madaba municipality provided borders, administrative divisions, streets, and land uses. The climatic data was obtained from the global website (WorldClub), with the largest archive of remote sensing data as well as climatic visuals of minimum and maximum temperatures for previous years. This website allowed downloading of climate graphics for free and the data were obtained for the years 1990–2018. Some data were gathered through fieldwork to compensate for the information gaps and to ensure accuracy.

Data preparation and processing stage

The collected data was used to generate the necessary maps for the analysis process. The data was converted in the form of images representing global climate to cut the study area's boundaries using GIS program's tools (10.8). The images contained temperatures and monthly rainfall rates for the time series of 1990-2018, as well as the errors were corrected using the Topology technique.

The images were also converted into vector data, with climate information stored at each point. Meanwhile, the points were converted into a raster with climate values in each pixel using the Geostatistical Analyst program. In this context, the information was signed and matched on maps using the Palestinian square coordinate system. The necessary maps were created using the satellite images provided by the American company Azri with a resolution of 1m.

Data analysis

After verifying the integrity of the geographical databases containing climate information, the data were analyzed to obtain the results. The monthly average of rain in millimeters and the monthly average of minimum and maximum temperatures in Celsius were calculated using the data. The collected data were exported to the program (Arcgis10.8) to determine the amount of climate change. Subsequently, heat and rain data, minimum and maximum temperatures, as well as monthly rainfall rates, were represented in the form of maps over the time series of 1990–2018. Based on the results, the values of the change are recognized through the creation of maps.

3. Results and Discussions

Digital Elevation Model

Figure 2 shows that the lowest and highest elevations in the study area are 437 and 862, respectively. The slope ranges from 0-5 degrees, with a decrease and increase in regression observed in the eastern regions and western regions, respectively.

Geological structure

The geological structures in the study area play a significant and primary role in the distribution of population and economic activities. These structures are affected by soil erosion, slips, landslides, rock composition, soil types, and faults. The economic factor is represented by natural resources such as mineral wealth and quarries.

Main buildings and streets

According to Figure 4, the area of licensed buildings in the governorate was approximately 1.4% of the total area of licensed buildings in the Kingdom, and the length of the streets was approximately 2033582.18 m.

Land uses

The organized lands covered approximately 191.46 km^2 and included the Mujib Reserve, which covered 152.27 km^2 as shown in Figure 5.

Average monthly minimum temperatures for the years (1990-2018)

According to Figure 6, the lowest and highest minimum temperatures were 5.1 and 20.04 °C in January and August, respectively. Meanwhile, the minimum temperature was constantly rising when the annual average reached 13.52 °C.

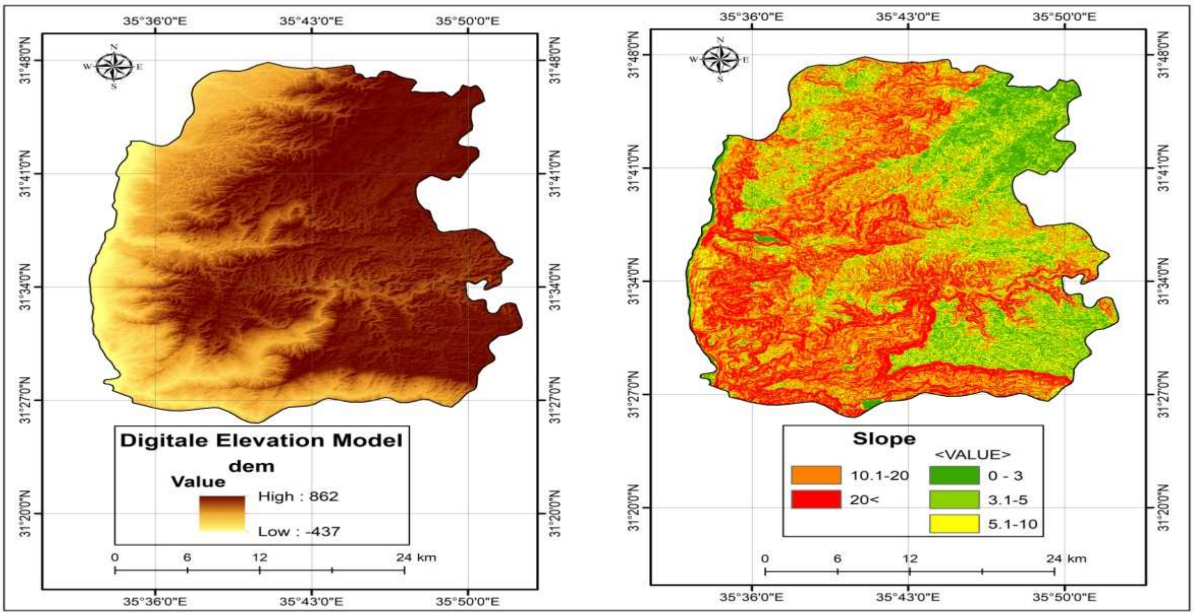

Figure 2. Digital elevation model and slope map for the study area.

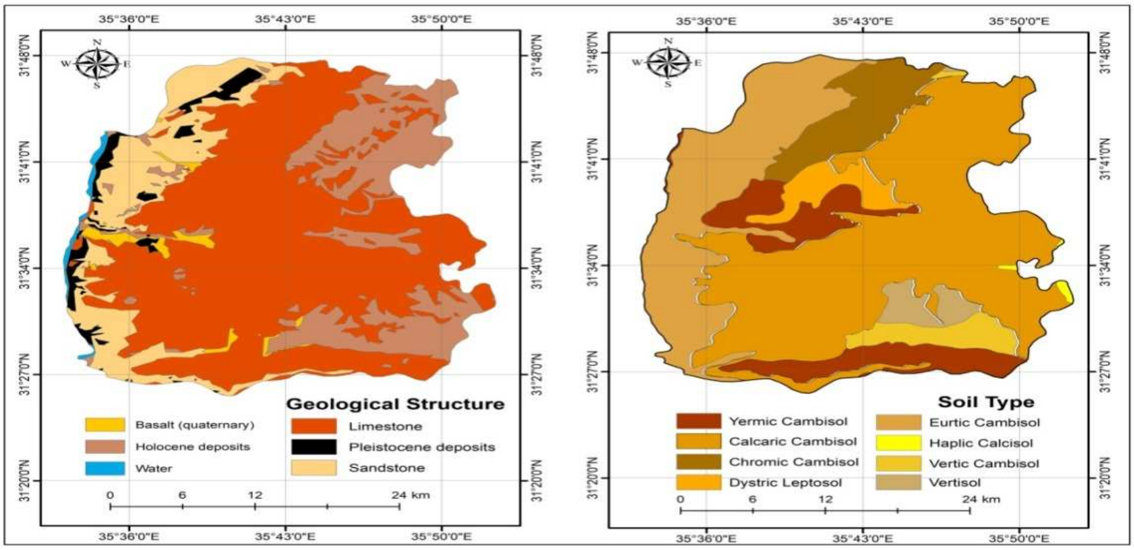

Figure 3. Geological Structure and soil type map for the study area.

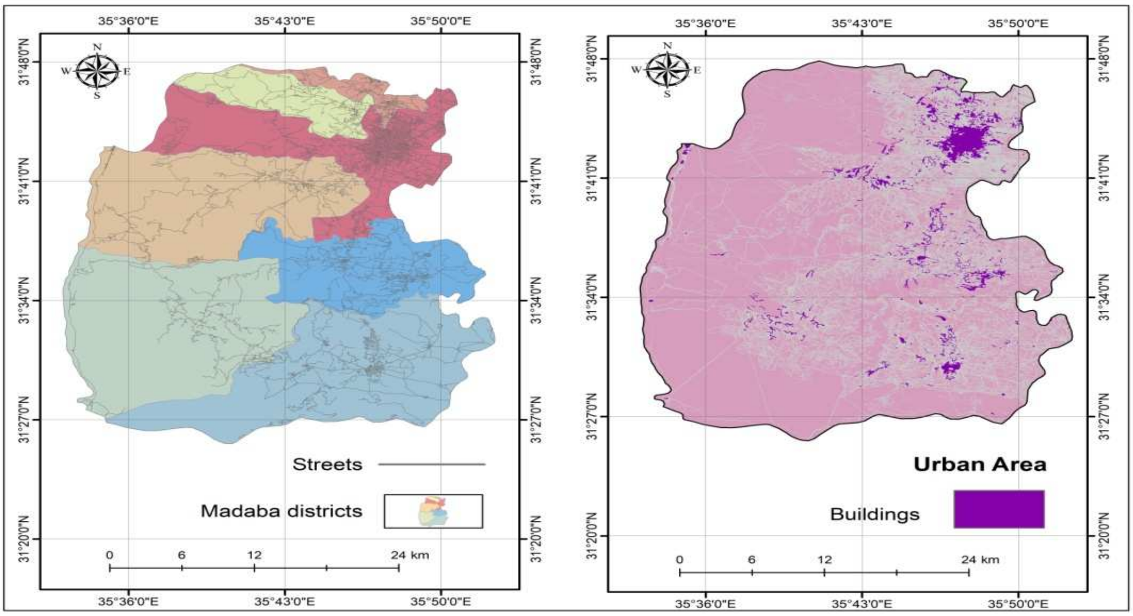

Figure 4. Buildings and main streets in the study area

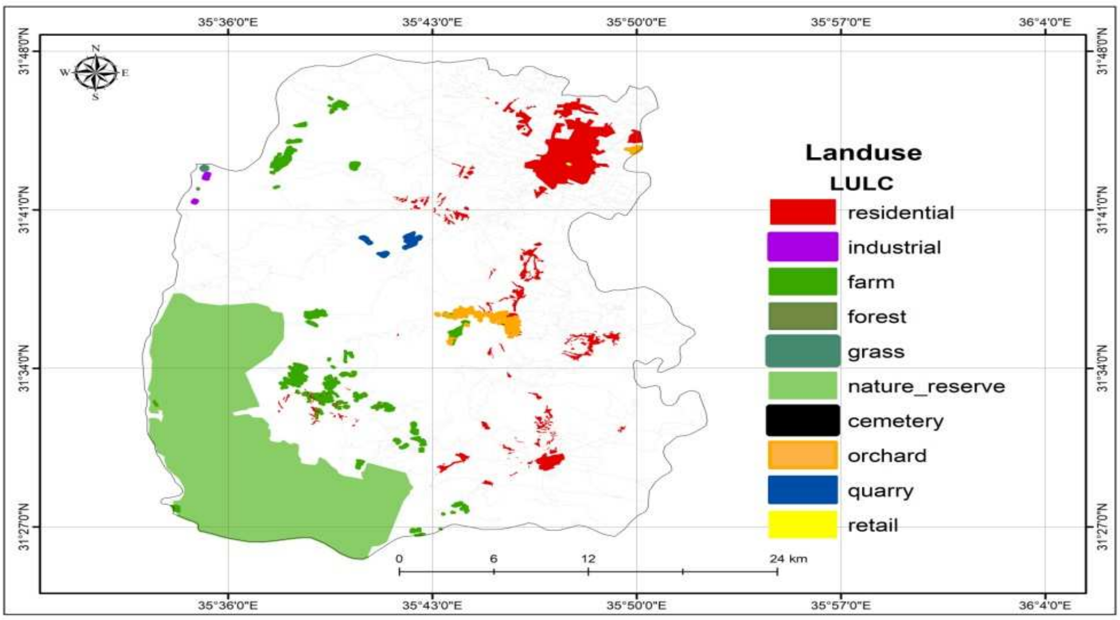

Figure 5. Land use in the study area

In 2000, the lowest and highest minimum temperatures were 5.92 and 22.44 °C in January and May, respectively. The annual average of the minimum temperature was 14.18 °C, and in 1990, the percentage increase was 0.66 °C.

In 2010, the lowest and highest minimum temperatures were 9.16 and 22.88 °C in January and August, with an annual average of 15.83 °C. As shown in Figure 8, the percentage increase in 1990 and 2000 was 2.31 and 1.65 °C, respectively.

In 2018, the lowest and highest minimum temperatures were 7.38 and 21.67 °C in January and July, with an annual average of 15.44 °C. The annual minimum temperature increased by 1.77, 2.09, and 2.40 °C in 2010, 2000, and 1990, respectively.

The maximum monthly temperature for the years (1990-2018)

According to Figure 10, the lowest and highest maximum temperatures were 14.02 and 31.97 °C in January and June, respectively. The maximum temperature was constantly rising when the annual average increased to 23.04 °C.

In 2000, the lowest and highest maximum temperatures were 13.91 and 33.88 °C in January and June, with an annual average of 23.05 °C. As reported in Figure 11, the percentage increase in 1990 was 0.01 °C.

In 2010, the lowest and highest maximum temperatures were 17.79 and 34.72 °C in January and August, with an annual average of 25.55 °C. As shown in Figure 12, the percentage increase in 1990 and 2000 were 2.51 and 2.50 °C, respectively.

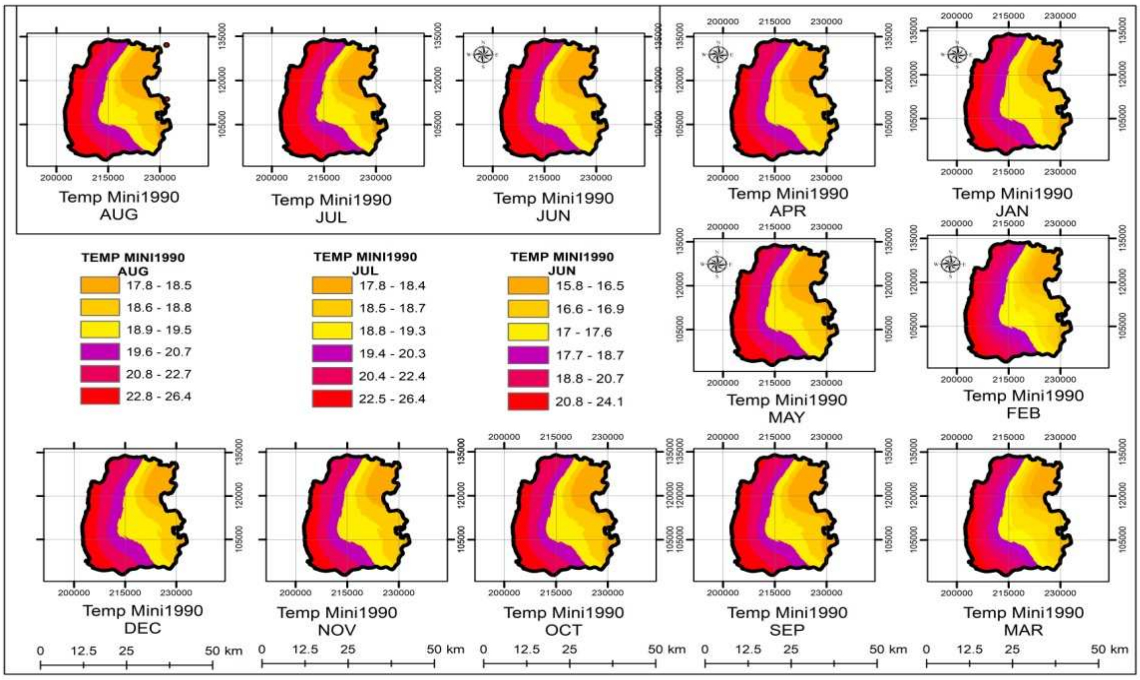

Figure 6. Average monthly minimum temperatures (C) in the study area for 1990.

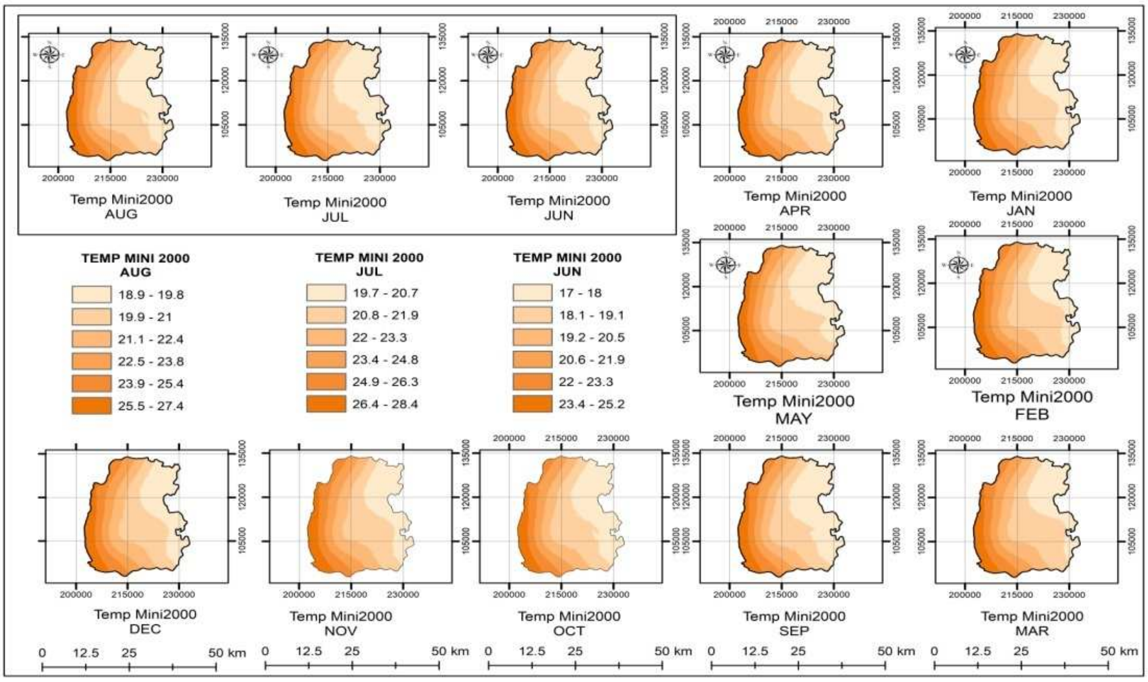

Figure 7. Average monthly minimum temperatures (C) in the study area for 2000.

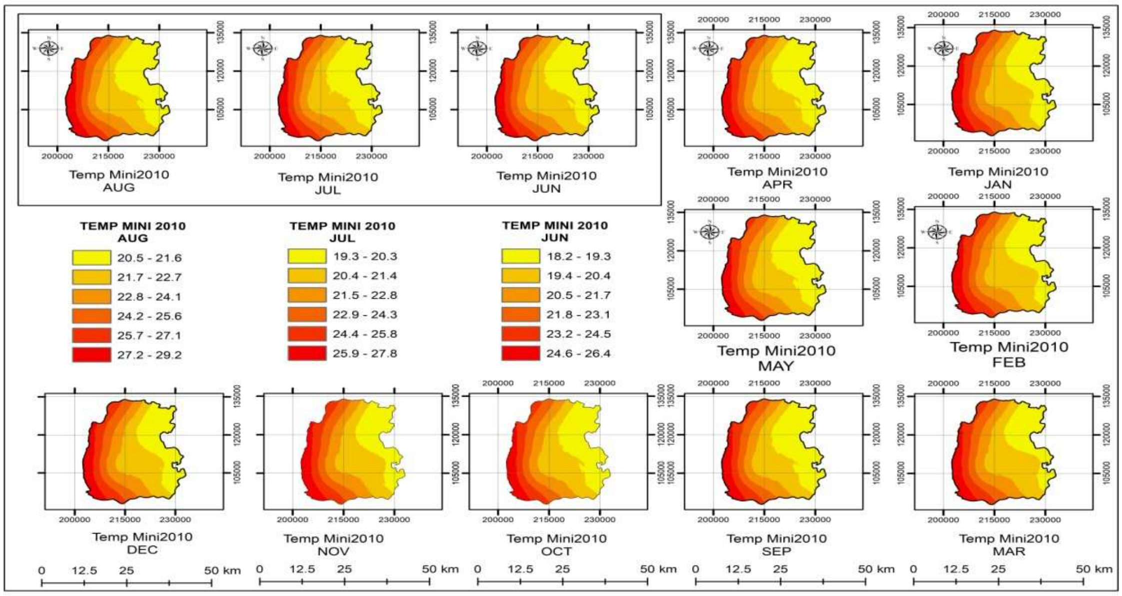

Figure 8. Average monthly minimum temperatures (C) in the study area for 2010.

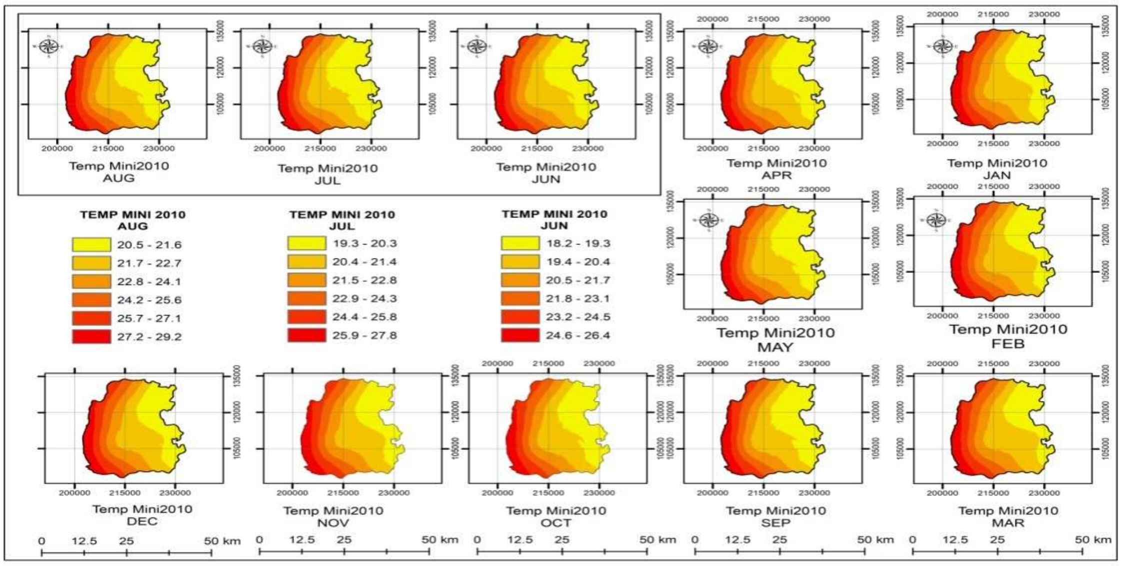

Figure 9. Average monthly minimum temperatures (C) in the study area for 2018.

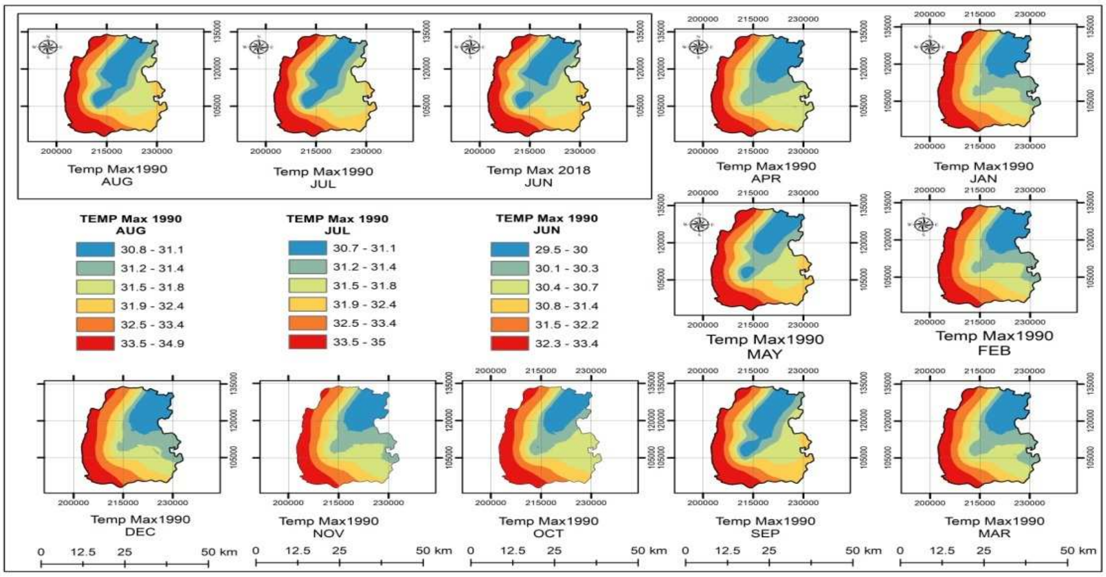

Figure 10. Maximum monthly temperatures (C) in the study area for 1990

In 2018, the lowest and highest maximum temperatures were 15.37 and 33.25 in January and Shahrab, with an annual average of 24.47. As shown in Figure 13, the maximum temperature for 2010, 2000, and 1990 increased by 2.43, 1.46, and 1.34 °C, respectively.

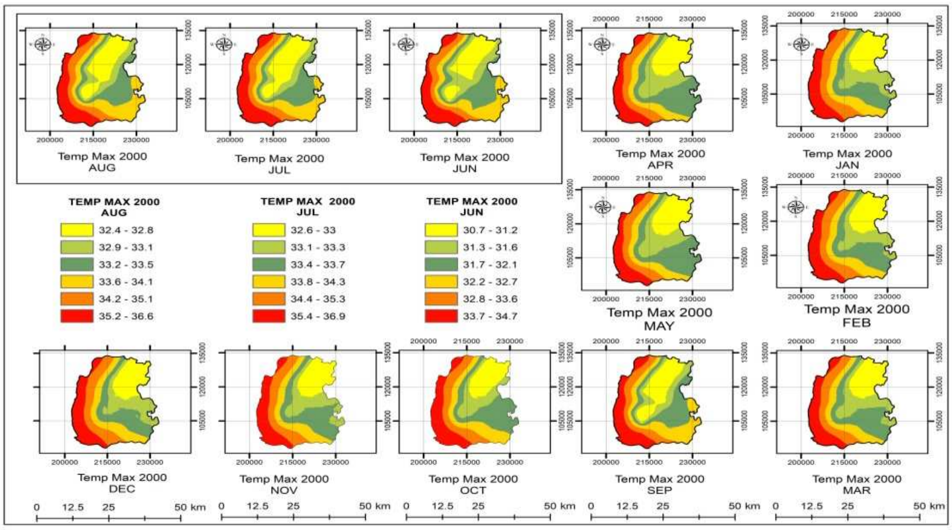

Figure 11. Maximum monthly temperatures (C) in the study area for the year (2000)

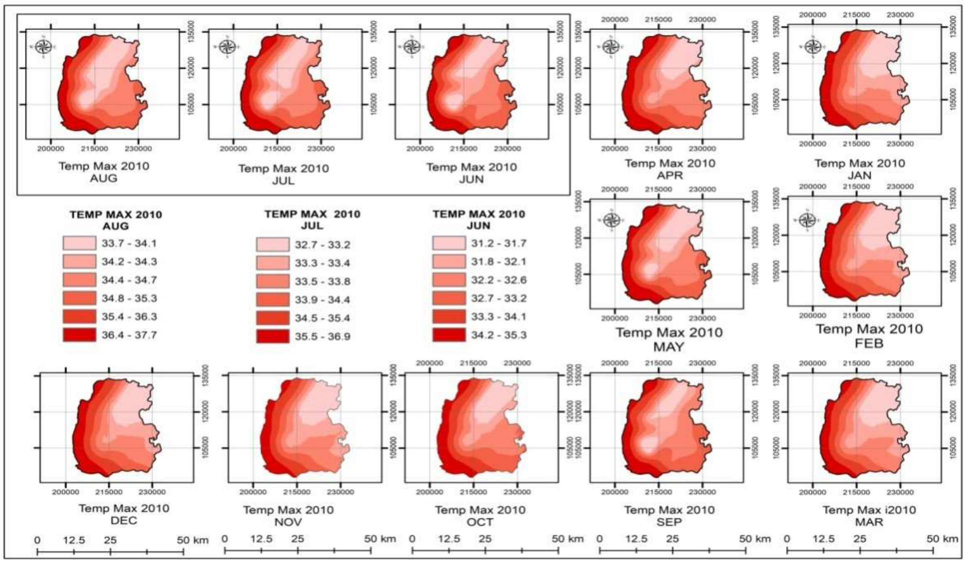

Figure 12. Maximum monthly temperatures (C) in the study area for the year (2010)

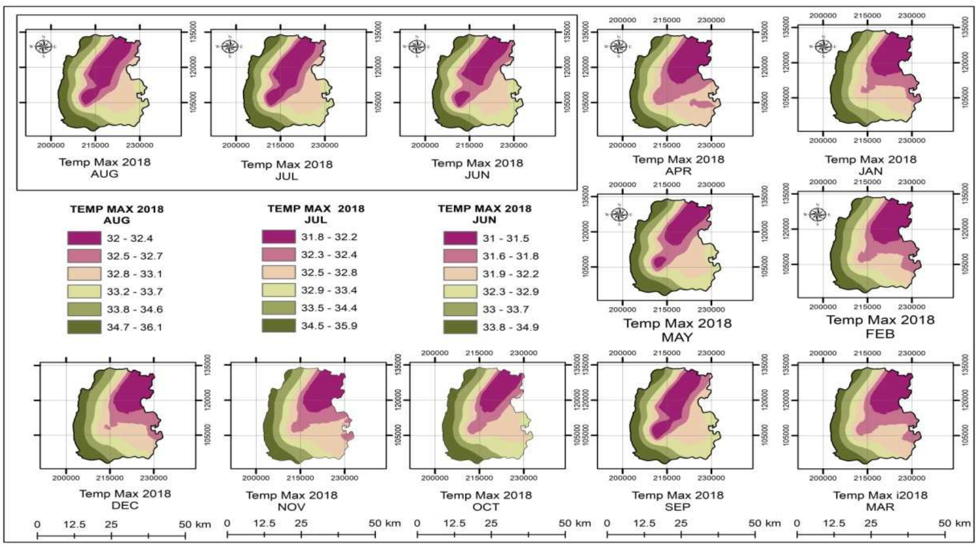

Figure 13. Maximum monthly temperatures (C) in the study area for the year (2018).

Average monthly rainfall over the years (1990-2018)

According to Figure 14, the lowest and highest rates of rainfall were in November and January at 1.99 mm and 36.18 mm, with an annual average of 14.69 mm.

According to Figure 15, the lowest and highest average rainfall for 2000 occurred in April and January, with a total of 1.92 and 93.64 mm. The average annual rainfall was 13.38 mm and there was a decrease of about 1.31 mm in 1990.

In 2010, the lowest and highest average rainfall was 2.97 and 73.62 mm in May and January, with an annual rate of 14.45 mm. Subsequently, there was an increase and decrease in rainfall for 2000 and 1990 by 1.31 and 0.24 mm, as shown in Figure 16.

The lowest and highest average rainfall in 2018 was 4.31 and 65.60 mm in May and January, where the annual average was 16.03 mm. Meanwhile, there was an increase in the amount of rainfall for 2010, 2000, and 1990 by 1.59 mm, 2.65 mm, and 1.34 mm, as shown in Figure 17.

4. Conclusion

In conclusion, there were changes in the general trend of climate due to temporal variation between the seasons

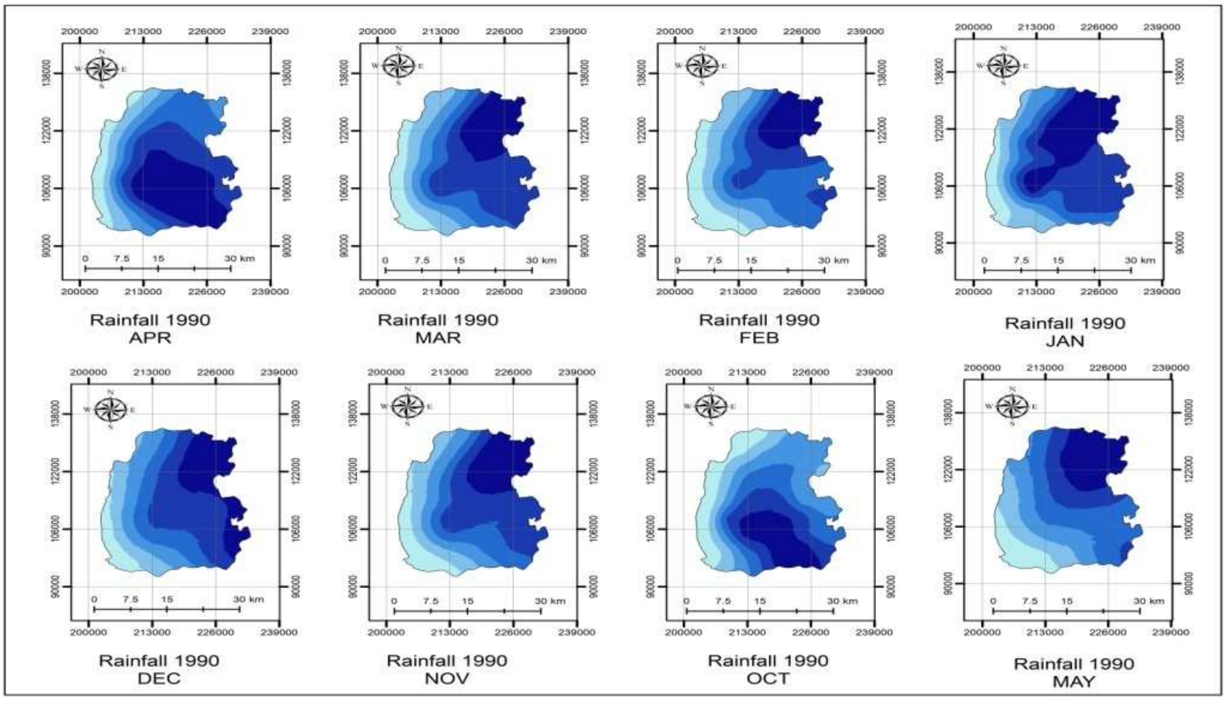

Figure 14. Monthly rainfall rates (mm) in the study area for the year (1990).

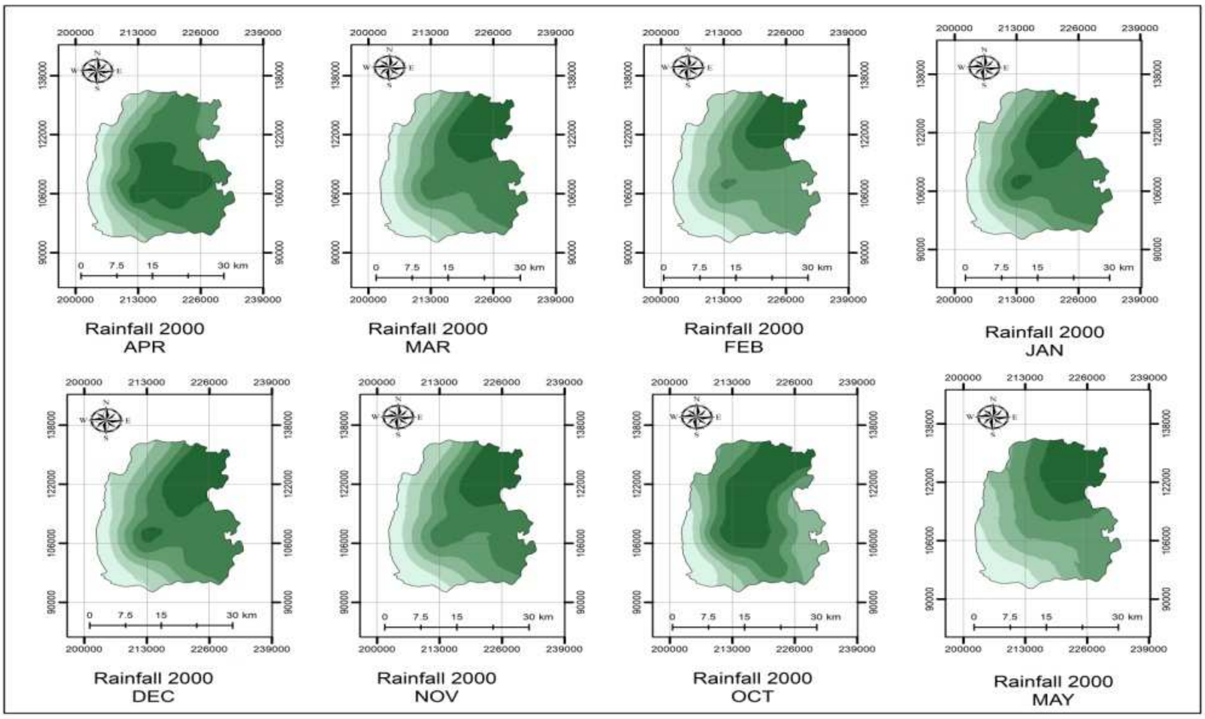

Figure 15. Monthly rainfall rates (mm) in the study area for the year (2000)

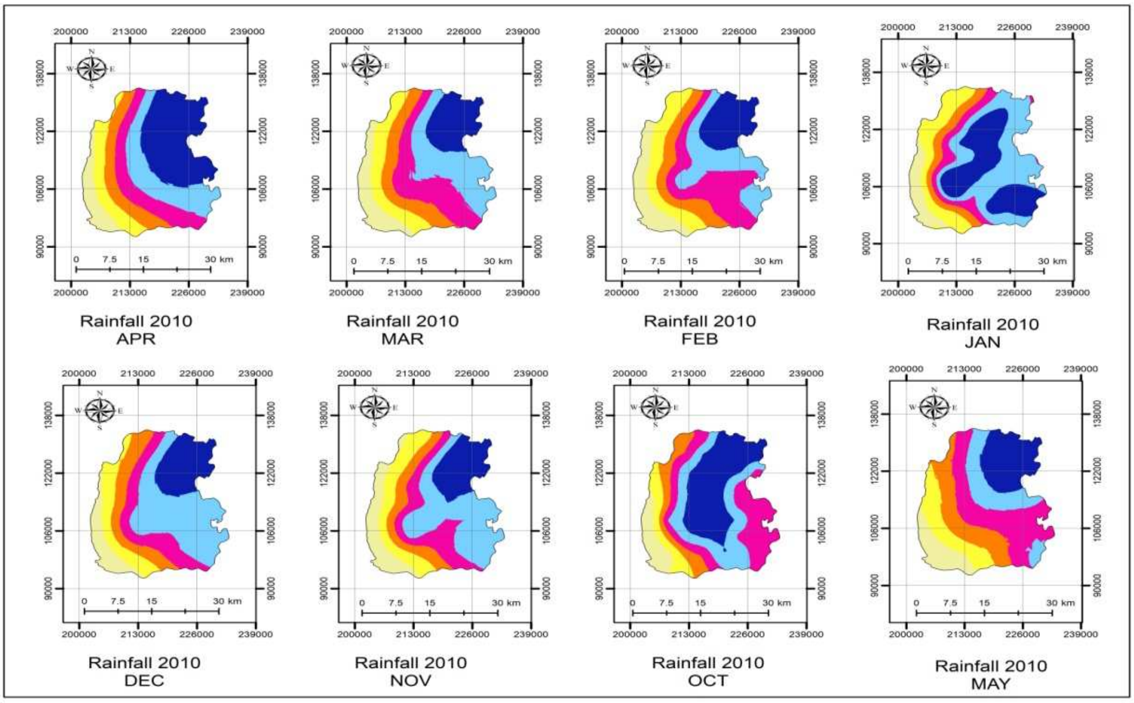

Figure 16. Monthly rainfall rates (mm) in the study area for the year (2010)

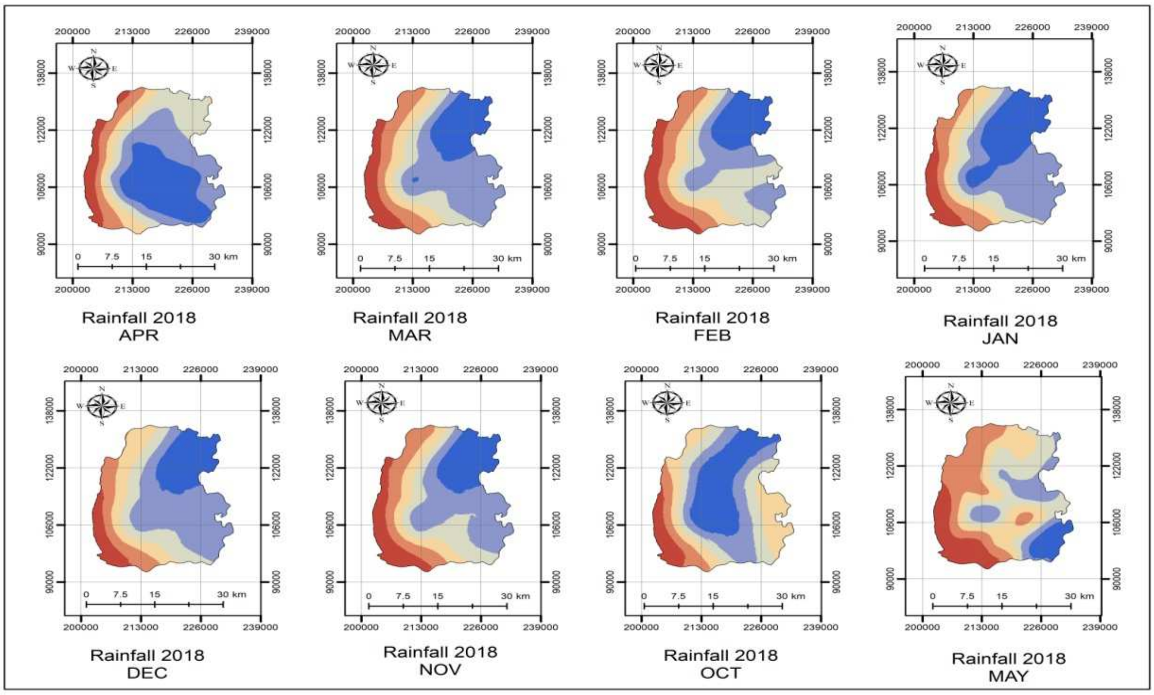

Figure 17. Monthly rainfall rates (mm) in the study area for the year (2018)

Seasonal minimum temperature for the years (1990-2018)

Table 1. The lowest seasonal temperatures from 1990 to 2018

Average	Autumn	summer	spring	winter	years
13.52	16.57	19.35	11.49	6.69	1990
14.18	15.20	20.74	14.54	6.27	2000
15.83	18.02	21.58	14.20	9.51	2010
15.44	17.29	21.06	14.67	8.72	2018
14.74	16.77	20.68	13.73	7.80	Mean

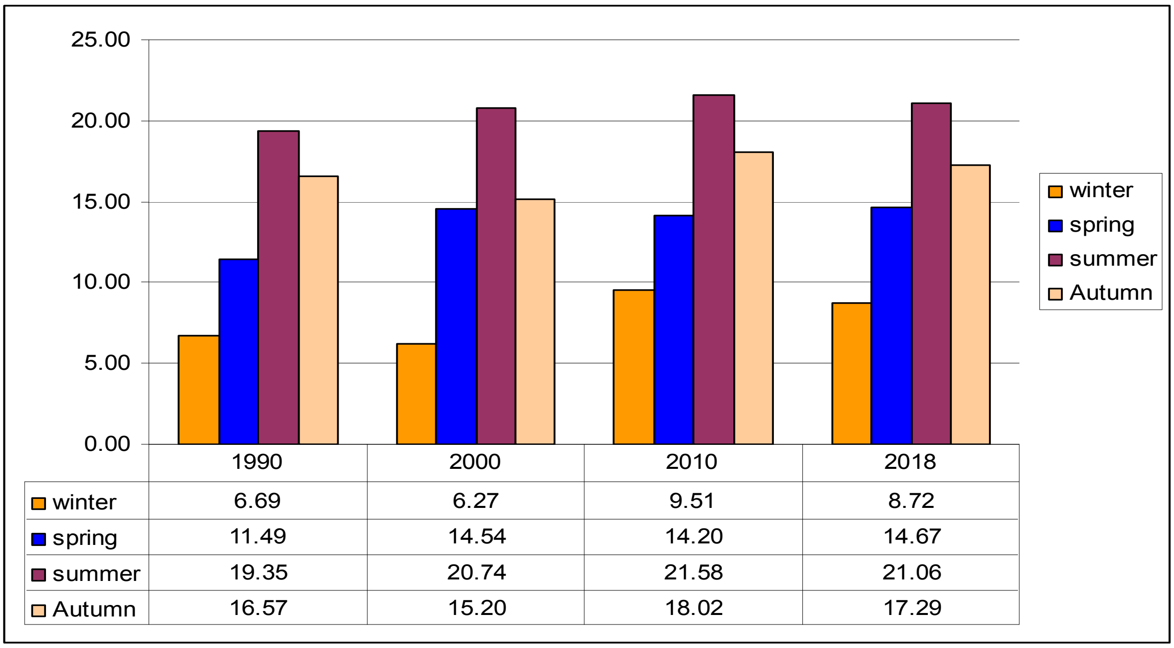

Figure 18. The seasonal minimum temperatures for 1990–2018.

The maximum seasonal temperature for 1990-2018

Table 2. Maximum seasonal temperatures for 1990-2018

Average	Autumn	summer	spring	winter	years
24.61	27.62	31.60	23.26	15.97	1990
24.43	26.32	33.23	22.90	15.25	2000
27.17	29.72	33.91	26.20	18.86	2010
25.87	27.35	32.88	26.18	17.08	2018
25.52	27.75	32.91	24.63	16.79	Mean

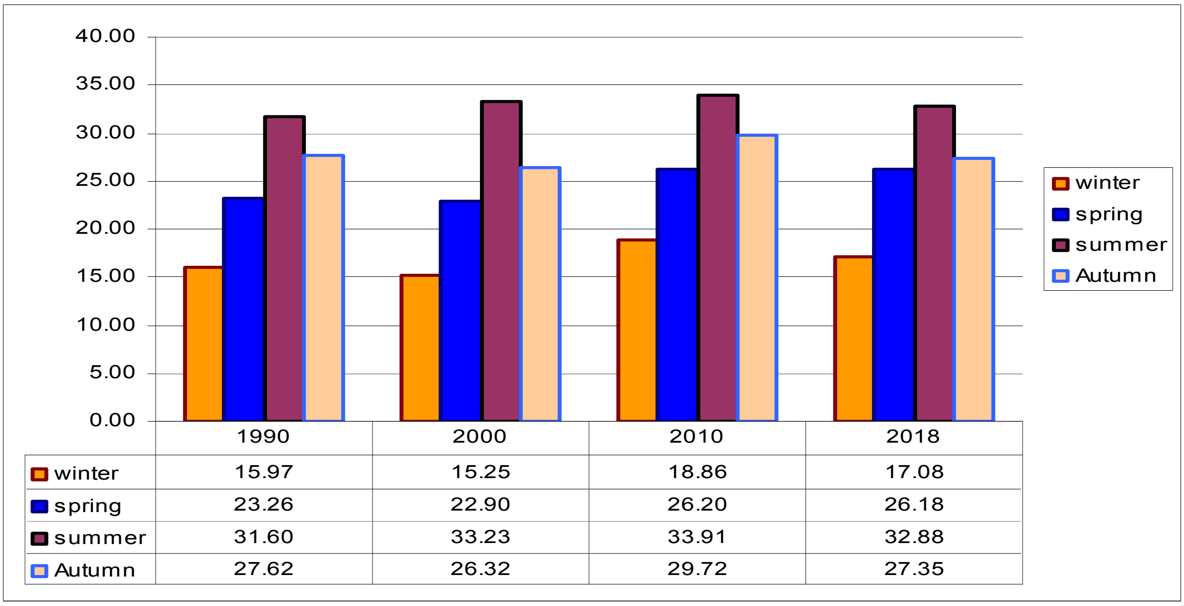

Figure 19. The seasonal maximum temperatures for 1990-2018

Average seasonal rainfall for the years (1990-2018)

Table3. Seasonal rainfall rates over the years (1990-2018)

Average	Autumn	summer	spring	winter	years
14.95	3.04	0.00	32.03	24.72	1990
17.69	5.06	0.00	11.97	53.72	2000
18.88	1.67	0.00	7.70	66.15	2010
21.20	9.42	0.00	14.13	61.26	2018
18.18	4.80	0.00	16.46	51.46	means

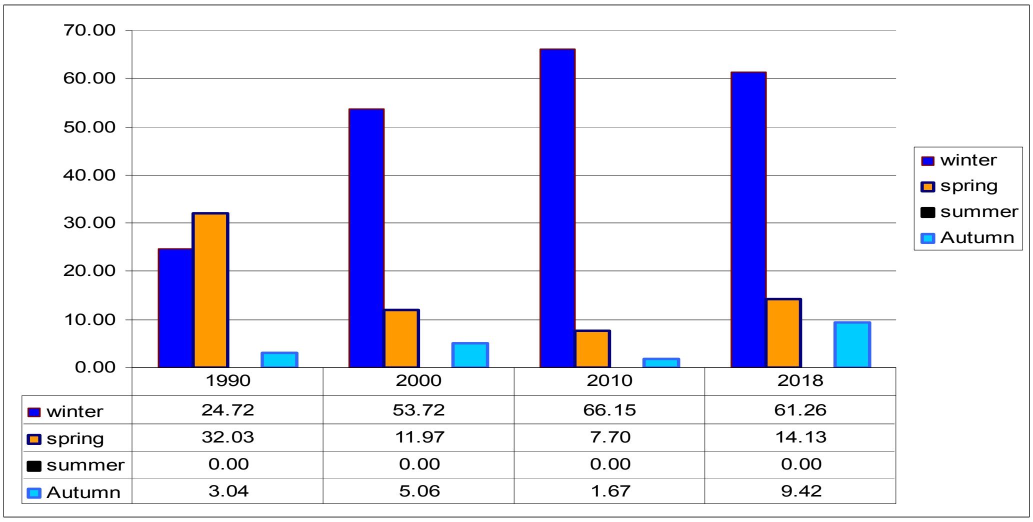

Figure 20. Seasonal rainfall rates during the years (1990-2018).

Table 4. Rainfall rates and annual minimum and maximum temperatures for 1990-2018

Rainfall	Temperature Max	Temperature Mini	years
14.95	24.61	13.52	1990
17.69	24.43	14.18	2000
18.88	27.17	15.83	2010
21.20	25.87	15.44	2018
18.18	25.52	14.74	Average

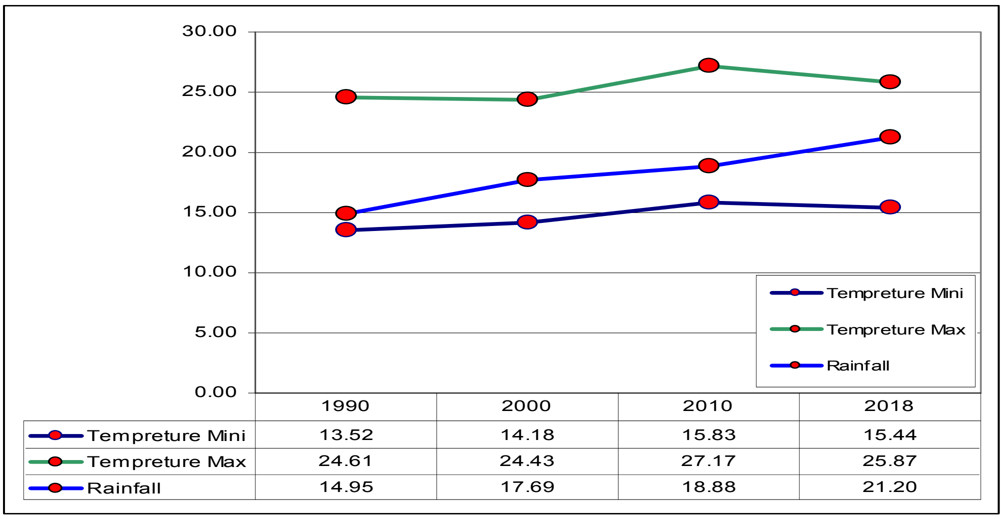

Figure 21. Rainfall rates and annual minimum and maximum temperatures over the years (1990-2018).

by analyzing, exploring, and comparing the elements. The statistical methods used reported an increase in the annual and monthly averages of minimum and maximum temperatures in the study area, as well as variations in the amounts and scarcity of rainfall. These results were consistent with numerous studies that expected a rise in the minimum temperature. According to IPPC reports, 2006 to 1994 AD were among the warmest years in the record of temperature measurements since 1850 AD), and Jones emphasized that the Earth's temperature increased at a rate of 0.5 degrees Celcius during the 20th century.

Jordan experienced several unusual weather phenomena as an indicator of climate change, including snow and heat waves in January 1992 and summer 2010. The Meteorological Department stated that the heat wave affecting the Kingdom in August was caused by climate change. The year was the hottest, with temperatures rising 3–11 °C above the general average, and reaching 43.5 °C in Madaba governorate. Heat waves have not occurred in the Kingdom since 1970, and the intensity and length were reported (Ministry of the Environment, 2007).

Different agencies, including governments, institutions, organizations, and civil society must conduct immediate and urgent action to mitigate climate change's impacts, as well as ensure a safer and more sustainable future. In addition, developing the policies, measures, and procedures necessary to achieve national water security objectives and to manage the scarce resources caused by a lack of rainfall was guided based on strategies, plans, and initiatives. Successful integrated climate change management in Jordan could be achieved through legislative laws regarding individuals who burn waste and garbage, causing high temperatures. Strict laws should also be imposed on factory chimneys not using safe methods to protect the environment.

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