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DERNA UNIVERSITY JOURNAL OF HUMANITIES AND SOCIAL SCIENCES
Available online at https://dujhss.uod.edu.ly/
P-ISSN: 2959-6475 E-ISSN: 2959-6483 Impact Factor: 0.82

Assessment of Local Climate Change Trends in Temperature in the Sirte Area Using Gridded Platform Data (NASA Power) as a Model

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https://www.doi.org/10.58987/dujhss.v3i6.14

Received: June 11, 2025 **Accepted**: July 28, 2025 **Published**: September 1, 2025

Abstract

This study aims to analyze the temporal and spatial trends of seasonal maximum and minimum temperatures in the Sirte area during the period from 1985 to 2024, using open-source climatic data from NASA POWER. A simple linear regression model was applied to assess temporal trends, while spatial analysis tools within ArcMap GIS 10.4 were used to produce seasonal trend maps. The results showed an upward trend in both maximum and minimum temperatures, with most monitoring sites recording positive tendencies. At some locations, cumulative temperature changes exceeded 1.2°C over four decades, indicating a clear effect of global warming. Spatial analyses revealed a stable thermal pattern, where maximum temperatures increase from the northeast to the southwest, while minimum temperatures decrease southward in all seasons. Additionally, this indicates a climatic signal associated with the exacerbation of climate change effects. The study emphasizes the need to enhance ground monitoring networks and verify the accuracy of satellite data by comparing them with available field observations.

Keywords: maximum temperature, minimum temperature, temporal trend, spatial analysis, climate change, Sirte region.

المستخلص:

تهدف هذه الدراسة إلى تحليل الاتجاهات الزمنية والمكانية لدرجات الحرارة العظمى والصغرى الفصلية في منطقة سرت خلال الفترة من 1985 إلى 2024، باستخدام بيانات مناخية مفتوحة المصدر من NASA POWER. تم تطبيق نموذج الانحدار الخطي البسيط لتقييم الاتجاهات الزمنية، بينما استُخدمت أدوات التحليل المكاني ضمن برنامج ArcMap GIS 10.4 لإنتاج خرائط الاتجاهات الفصلية. أظهرت النتائج وجود اتجاه تصاعدي في كل من درجات الحرارة العظمى والصغرى، حيث سجلت معظم مواقع الرصد ميولاً إيجابية. في بعض المواقع، تجاوزت التغيرات التراكمية في درجات الحرارة 1.2 درجة مئوية على مدى أربعة عقود، مما يشير إلى وجود أثر واضح للاحتباس الحراري. وكشفت التحليلات المكانية عن نمط حراري مستقر، حيث تزداد درجات الحرارة العظمى من الشمال الشرقي إلى الجنوب الغربي، وتنخفض درجات الحرارة الصغرى باتجاه الجنوب في جميع الفصول. بالإضافة إلى ذلك، مما يشير إلى إشارة مناخية مرتبطة بتفاقم آثار تغير المناخ. تؤكد الدراسة على الحاجة إلى تعزيز شبكات الرصد الأرضية والتحقق من دقة بيانات الأقمار الصناعية من خلال مقارنتها بالملاحظات الميدانية المتوفرة.

الكلمات المفتاحية: درجة الحرارة العظمى، درجة الحرارة الصغرى، الاتجاه الزمني، التحليل المكاني، تغير المناخ، منطقة سرت.

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1. Introduction:

Climate change is one of the most pressing challenges facing the world in the 21st century. Monitoring and analyzing climate shifts has become a scientific priority in light of the increasing intensity of extreme weather events such as heatwaves, droughts, and floods, which have direct impacts on natural resources and human activities. Climate projections indicate a high probability of global temperatures exceeding 1.5°C above pre-industrial levels between 2021 and 2040, reflecting the expected climate changes under current emission scenarios (IPCC, 2021; 2023). These projections underscore the urgent need for immediate measures to address the impacts of climate change in the near future.

Temperature is considered one of the most critical climate indicators for understanding the dynamics of climate change, particularly when tracking seasonal variations in maximum and minimum temperatures. These variations are closely linked to seasonal climate cycles and regional thermal balance (NOAA, 2020).

There is an increasing need for long-term, reliable climate data, especially in developing countries that suffer from weak terrestrial monitoring networks. This lack limits researchers' ability to accurately analyze climatic phenomena. In this context, the U.S. National Aeronautics and Space Administration (NASA), through its Prediction of Worldwide Energy Resources (NASA POWER) project, has provided a free-access climate database. This database relies on satellite-derived models and covers various climatic elements such as temperature, humidity, solar radiation, and wind speed and direction (NASA, 2020). The data are characterized by a spatial resolution of 0.5° × 0.5°, equivalent to approximately 55 km × 55 km at the equator, and a temporal resolution at daily and monthly scales. These features make NASA POWER data a valuable resource for studies related to energy, agriculture, climate, and climate change.

Despite the diversity of climate data sources, NASA POWER data have demonstrated accuracy and reliability in several studies through their statistical agreement with ground-based measurements, particularly in arid and semi-arid environments, making them a dependable tool for analyzing long-term seasonal climate trends. These data provide deeper insights into climate variability in regions with limited direct observation stations, thus representing a reliable option for regional climate studies.

For instance, NASA POWER data have shown statistically acceptable concordance with field measurements, especially in dry and semi-dry areas (Abbaspour et al., 2022). Through statistical analysis and visual comparison between gridded and ground-based datasets, NASA POWER has proven reliable in representing near-surface air temperatures at two meters above ground level (Marzouk, 2021). These data enable the investigation of long-term seasonal trends, supporting improved understanding of climate changes in vulnerable environments, and therefore constitute a trustworthy choice in data-scarce regions.

The Sirte region holds particular climatic importance in Libya due to its geographical location, which lies within a transitional zone between Mediterranean climatic influences and the arid extensions of the Sahara Desert. This atmospheric interplay makes the region subject to pronounced thermal fluctuations at the seasonal level, potentially reflecting regional climate change patterns and their linkage to global climate transformations.

This study seeks to explore the spatial characteristics of seasonal and annual changes in maximum and minimum temperatures within the Sirte region and to assess the extent to which these changes reveal meaningful spatial climate trends over the period from 1985 to 2024. The study also evaluates the reliability of (NASA POWER) open-source data as an alternative source for tracking regional climate variability, particularly in the absence of extensive ground-based observation stations. Accordingly, the main objectives of this research are to analyze the spatial and seasonal patterns of temperature, identify prevailing thermal distributions across the four seasons, and assess the effectiveness of NASA POWER data in representing the local climate characteristics of the Gulf of Sirte.

2. Study Area:

The study area is located in north-central Libya, between latitudes 28.51°–31.38°N and longitudes 14.74°–18.84°E. It forms a semi-rectangular polygon extending approximately 395 kilometers from east to west and about 204 kilometers from north to south, with a total area of around 74,600 square kilometers. This region falls within the administrative division of municipalities in Libya and was selected as the study area due to its diverse natural characteristics. It serves as a transitional zone between the coastal Mediterranean climate in the north and the arid desert climate in the interior.

The area is characterized by evident topographical diversity, including sandy beaches, coastal sabkhas, wide plains, agricultural lands within valley bottoms, as well as desert highlands rising over 400 meters in elevation in the southern part of the region (Figure 1). This topographic variety significantly influences the distribution of temperatures. The annual average of maximum temperatures at the Sirte weather station reaches 25.04°C, while the annual average of minimum temperatures is 15.98°C. The annual relative humidity in the region stands at 70.73%, and the annual rainfall recorded at the Sirte meteorological station during the period (1971–2010) is approximately 199.8 mm (LNMC, 2011). The region is also exposed to extreme weather events such as heatwaves and drought in its northern parts and frost in the south. According to various climatic indices, the climate of the Sirte region is classified as arid to semi-arid (Soliman, 2020).

The Sirte region is rich in natural resources, including agricultural land and marine wealth. It also hosts several ports and oil refineries that constitute an essential part of Libya’s economic activities. Among these facilities, the Ras Lanuf Refinery stands out as one of the largest industrial establishments in the area. Considering that oil refineries are sources of greenhouse gas emissions and air pollutants, they may have an impact on local temperatures. Therefore, studying climate change in this region is of great importance—not only to understand the climatic effects on economic activities but also to examine whether such activities, like the Ras Lanuf Refinery, contribute to changes in local thermal patterns.

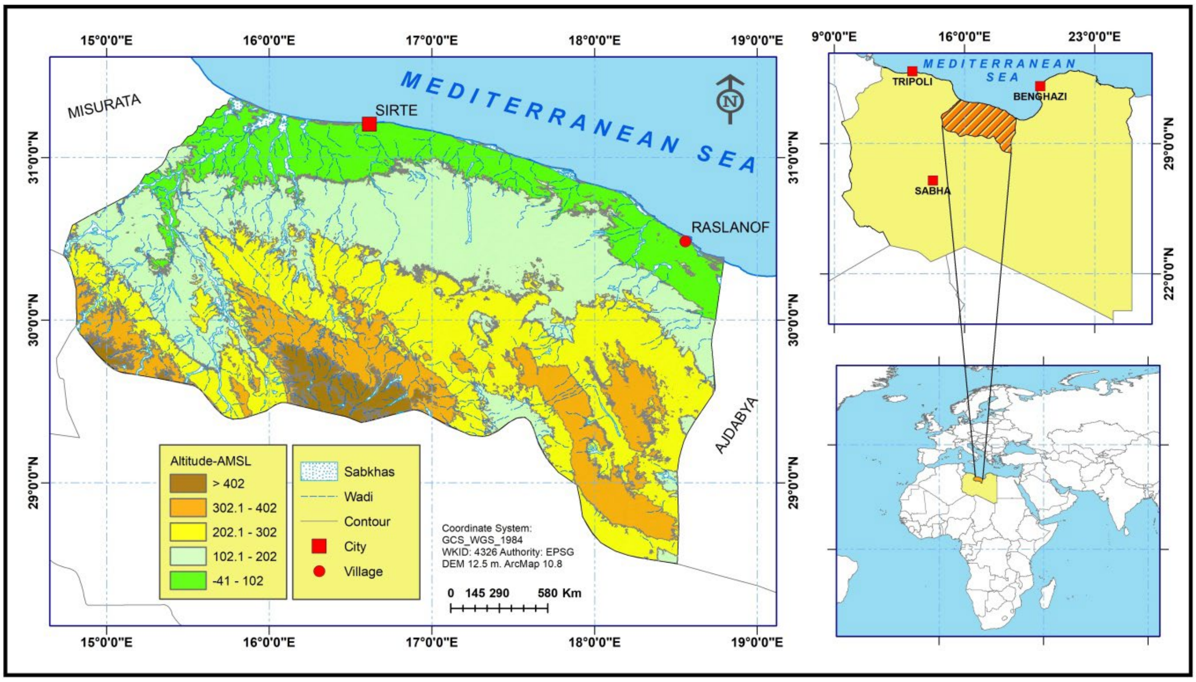

Figure 1. Geographical location and surface topography of the Sirte region

Several studies have addressed temperature changes in the Sirte region, including the study by Salim (2017), which investigated temperature trends during the period 1946–2010, and the study by Onaybah (2014), which examined trends in some climatic elements in Sirte, including temperatures from 1970–2009. Both studies employed various methods, including moving averages and linear regression models, to analyze the temporal trends of monthly and seasonal temperatures. The findings of both studies indicated a clear upward trend in maximum and minimum temperatures in the region.

In the present study, in addition to using the simple linear regression model**,** spatial analysis was employed to produce maps illustrating the spatial distribution of seasonal temperature differences, followed by an investigation of their trends. A systematic comparison was also conducted between the results of the spatial analysis and those of the linear regression model, in order to verify the consistency of temperature trends at both the temporal and spatial levels, and to provide a more comprehensive interpretation of climate change in the study area.

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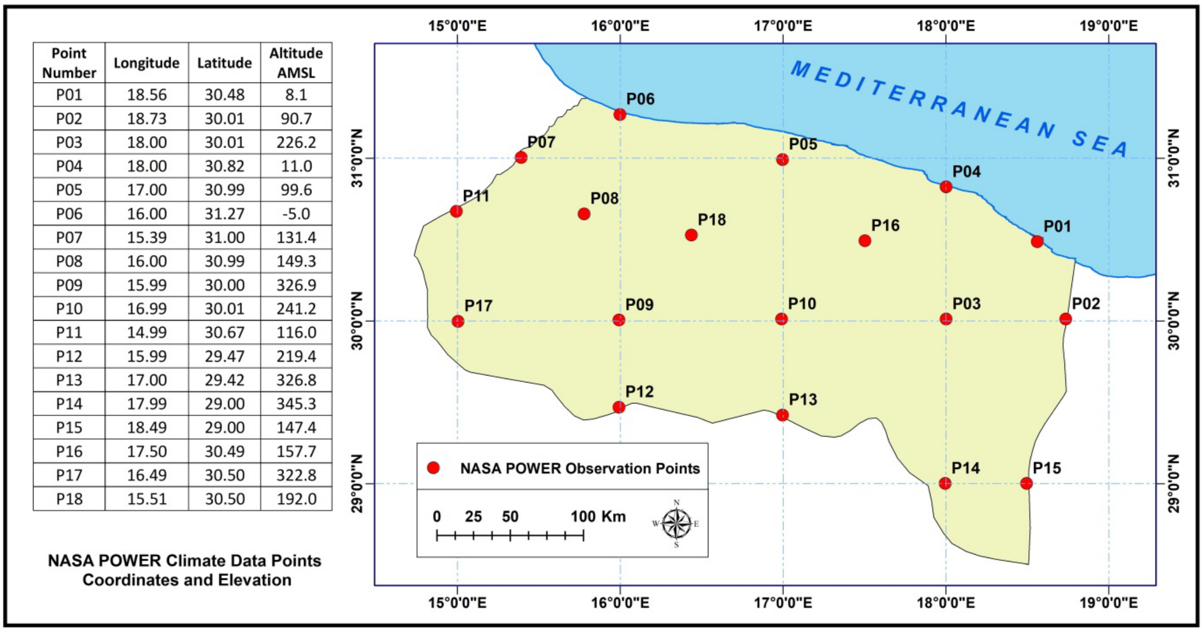
3. Data and Methods

3.1. Design of the Observation Network and Collection of Temperature Data: A total of 18 observation points were selected and evenly distributed within the boundaries of the study area polygon, as shown in Figure (2). The average distance between the points ranged between 60–90 kilometers. The geographic coordinates of each point were determined and documented in an Excel file for use in extracting relevant climate data. Based on these coordinates, monthly data for maximum and minimum temperatures at a height of 2 meters were obtained from the NASA POWER database for the period 1985–2024.

3.2. Preparation and Seasonal/Temporal Processing of Data Matrices: The temperature data retrieved from the NASA POWER database were organized into 18 separate tables, each representing a distinct observation point. Each table included a total of 960 thermal variables—comprising 480 maximum temperature values and 480 minimum temperature values—corresponding to monthly records over a 40-year period (1985–2024). Preliminary statistical processing involved calculating seasonal averages for spring, summer, autumn, and winter, in addition to the annual mean.



Point Number	Longitude	Latitude	Altitude AMSL
P01	18.56	30.48	8.1
P02	18.73	30.01	90.7
P03	18.00	30.01	226.2
P04	18.00	30.82	11.0
P05	17.00	30.99	99.6
P06	16.00	31.27	-5.0
P07	15.39	31.00	131.4
P08	16.00	30.99	149.3
P09	15.99	30.00	326.9
P10	16.99	30.01	241.2
P11	14.99	30.67	116.0
P12	15.99	29.47	219.4
P13	17.00	29.42	326.8
P14	17.99	29.00	345.3
P15	18.49	29.00	147.4
P16	17.50	30.49	157.7
P17	16.49	30.50	322.8
P18	15.51	30.50	192.0

Figure 2. Locations of climate observation points in the Sirte region

3.3. Spatial Analysis: The maps generated using spatial analysis tools in ArcMap GIS enable the identification of spatial patterns in climate changes over time (Longley et al., 2015). Accordingly, the use of Geographic Information Systems (GIS) is vital in assessing the spatial distribution of climatic variables, as they provide high accuracy in data representation and help identify climatically vulnerable areas (Lagrini et al., 2020). After calculating seasonal averages

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of maximum and minimum temperatures, a spatial database was constructed using ArcMap GIS 10.8, incorporating thermal values for all observation points. To analyze seasonal changes in maximum and minimum temperatures at the spatial level, Spatial Analysis tools within the ArcToolbox environment were utilized. The Interpolation – Kriging tool was applied to create seasonal maps showing the detailed spatial distribution of temperatures across the four seasons. Additionally, the Interpolation – Trend (Polynomial Surface) tool was used to determine the general spatial trend of seasonal temperature variations, helping to detect broad-scale thermal gradients. Temporal changes in temperature were also analyzed by preparing sequential seasonal maps for each time period individually, allowing for the comparison of climatic changes both spatially and temporally, and for tracking the evolution of seasonal trends.

3.4. Temporal Trend Analysis of Temperature: Temporal trends in maximum and minimum temperatures were analyzed using the Trendline feature in Microsoft Excel. This method was applied separately to the data from each observation point to compute the coefficient of determination (R^2), which reflects the strength of the relationship between time and temperature. The trendline displays the overall direction of data across the specified time span and helps identify whether there are increasing or decreasing trends in temperature over the observation period. The results were represented graphically to illustrate the prevailing annual trends at each point, thereby enhancing the understanding of climate change in the region. Using the trendline in a simple linear regression equation is considered a straightforward and effective method for detecting temporal patterns in climate data (Montgomery et al., 2012).

4. Spatial Variability of Temperature in the Study Area During the Observation Period (1985–2024):

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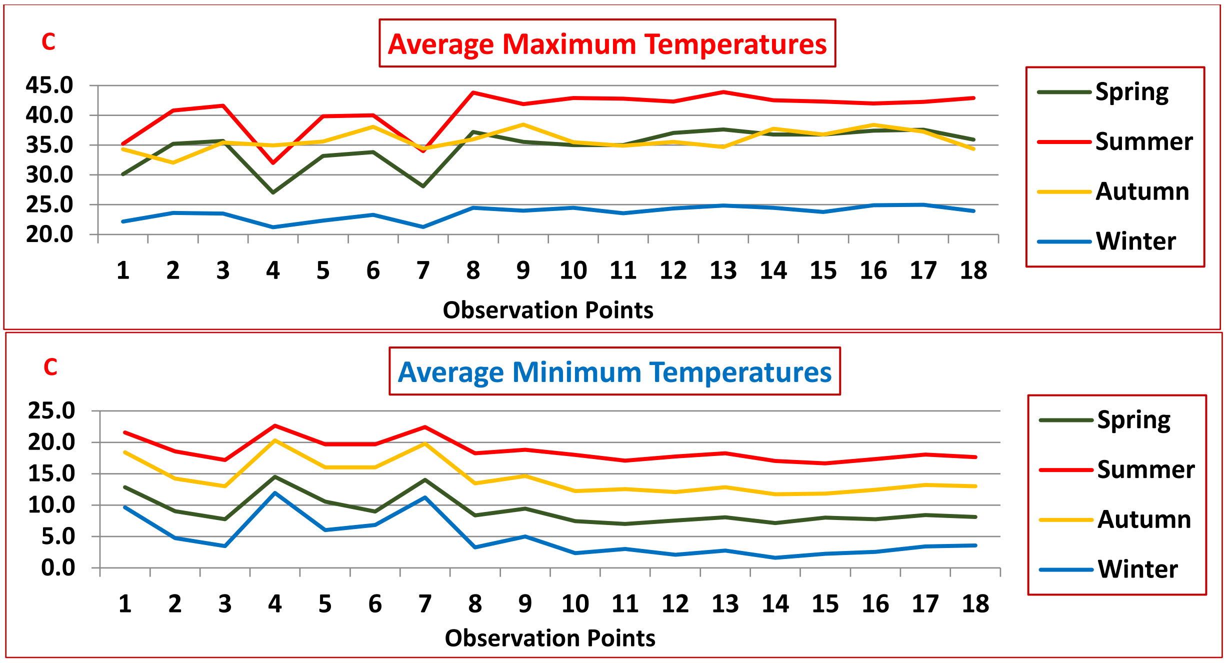

Figure 3. Spatial variation of maximum and minimum temperatures at observation stations in the study area during the period 1985–2024.

Figure (3) illustrates the seasonal averages of maximum and minimum temperatures across 18 observation points distributed throughout the study area, covering the four seasons: spring, summer, autumn, and winter. In the first chart, summer clearly records the highest values, with maximum temperatures exceeding 40°C at some stations. This reflects the influence of hot and dry air masses during this period, as well as potential local effects such as topography or the distance of the observation point from the coast. Winter emerges as the coolest season, with temperatures generally ranging between 21–25°C, indicating the influence of cold air masses originating from the north or from continental interiors. Spring and autumn represent transitional periods, with temperature values gradually shifting between summer and winter. Certain stations exhibit noticeable local variations, possibly due to factors such as elevation, proximity to the Mediterranean Sea, or anthropogenic influences. Overall, the spatial variation between stations indicates the presence of local climatic heterogeneity within the study area, likely driven by differences in topographic elevation and distance from the coast.

In the second chart, winter shows a marked decline in minimum temperatures, with values dropping below 5°C at some stations. This reflects cold winter nights and the possible occurrence of frost in interior areas. Summer records relatively high minimum temperatures (reaching up to 25°C), indicating warm night-time conditions. Spring and autumn display transitional patterns, with relatively moderate values. The spatial variability among stations can be attributed to topographic conditions—valleys and desert depressions typically experience lower night-time temperatures during winter.

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5. Results and Discussion

5.1. Spatial Analysis of Seasonal Characteristics of Maximum and Minimum Temperatures in the Study Area:

This section presents the results of the spatial analysis of maximum and minimum temperatures across the Sirte region during the period 1985–2024. The analysis focuses on the spatial distribution of seasonal temperature values to identify prevailing thermal patterns. The maps were generated using the Kriging interpolation tool to highlight climatic variations across the different periods. These results serve as a foundation for discussing the general temperature trends within the region.

The maps displayed in Figure (4) reveal a clear spatial variability in seasonal maximum and minimum temperatures. Maximum temperatures tend to increase toward the southwestern part of the region and gradually decrease as one approaches the Mediterranean coastline. In contrast, minimum temperatures show an opposite pattern—declining in the southwestern interior and increasing gradually toward the northwestern coastal areas. This inverse spatial trend highlights the significant role of land–sea distribution in shaping thermal characteristics, with maritime influence moderating temperatures near the coast, while continental conditions dominate further inland.

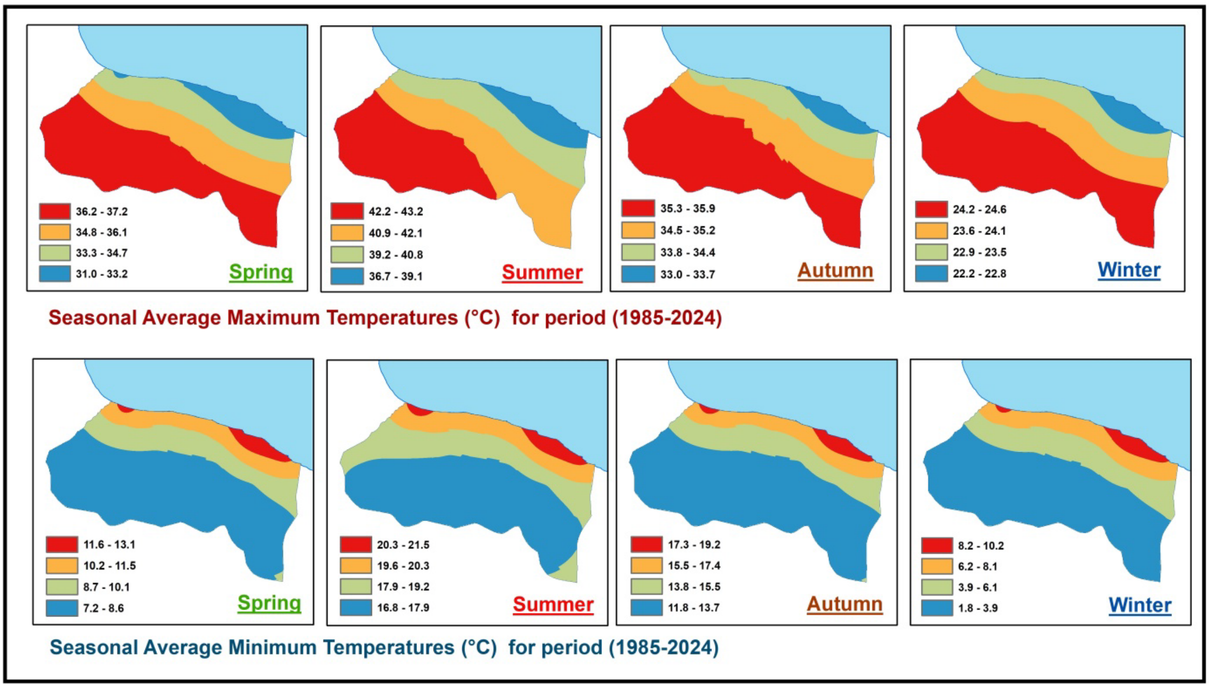

Figure 4. Spatial analysis of the seasonal variability in the distribution of maximum and minimum temperatures in the Sirte region.

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5.2. Identifying the General Trend of Spatial - Seasonal Temperature Changes Using the Trend Tool:

The Trend tool, available under Spatial Analyst > Interpolation, was employed to identify the general pattern of change in maximum and minimum temperatures across the seasons. This tool generates a surface based on polynomial regression, which highlights broad thermal trends across the study area. The output is presented as a spatially colored map that reflects the general direction of temperature variation. Warm colors indicate an upward trend in temperatures, whereas cool colors denote a downward trend. This visualization aids in understanding the spatial heterogeneity of thermal changes and in identifying areas experiencing significant climatic shifts. This method was applied to the study area, and the results are illustrated in Figure 5.

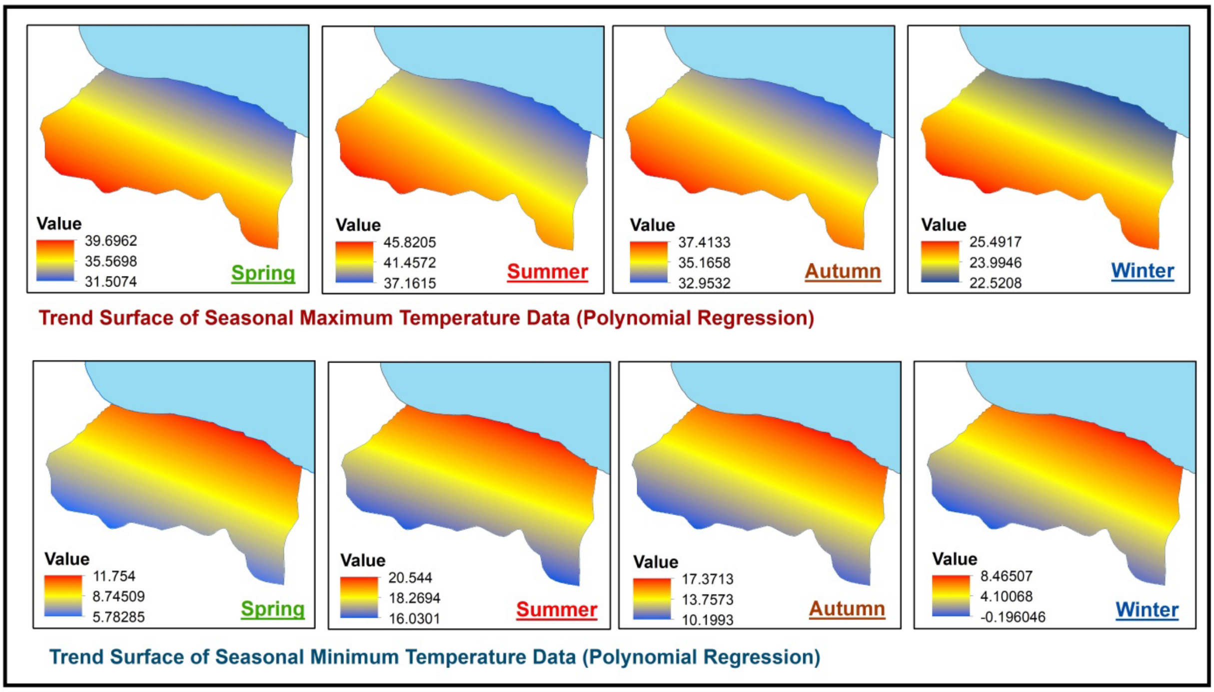

Figure 5. General Spatial Trends of Seasonal Maximum and Minimum Temperatures in the Sirte Region (Using the Trend Tool – ArcGIS)

Figure (5) presents the spatial trend surface maps for maximum temperatures, revealing a consistent spatial pattern across the seasons, characterized by an increase in thermal values from the northeast toward the southwest. For instance, in summer, the inland areas recorded maximum temperatures exceeding 45.8°C, compared to approximately 37.1°C in coastal zones, highlighting the pronounced continental effect in the southern part of the study area.

In spring, values ranged between 31.5°C in the north and 39.7°C in the south, indicating a significant spatial disparity even during transitional seasons. During winter, despite overall lower

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temperatures, this spatial difference remained evident, with southern regions recording values above 25.5°C, while northeastern areas remained below 22.5°C. These variations reflect the influence of topography, solar radiation exposure, and the absence of maritime moderating effects in inland regions, which collectively explain the southward-increasing thermal gradient.

As for the minimum temperature maps, a similar spatial pattern was observed, with a gradual increase from the northeast toward the southwest, particularly pronounced in winter and spring. In winter, minimum temperatures approached -0.2°C in coastal zones, while exceeding 8.4°C in the southern interior, underscoring the stark contrast in nocturnal cooling. In summer, minimum temperatures ranged between 16.0°C in the north and 20.5°C in the south, indicating the emergence of the “warm night” phenomenon, increasingly evident in interior areas.

The recorded differences in autumn and spring, with values ranging between 10.2°C and 17.4°C, further support this overall spatial pattern. These findings align with the observed temporal trends and reinforce the hypothesis of a more consistent increase in minimum temperatures, likely driven by ongoing climate change.

5.3. Annual Trend Analysis of Temperatures Using Simple Linear Regression

The general trend of maximum and minimum temperatures during the study period (1985–2024) was identified using the Simple Linear Regression (SLR) model. In this context, the slope of the regression line represents the annual rate of change in temperature, while the coefficient of determination (R^2) indicates the extent to which temporal variation explains the observed temperature fluctuations.

In climate time series, values typically exhibit slow but consistent changes; thus, a modest trend such as +0.03°C/year equates to a change of +0.3°C per decade, and approximately +1.2°C over four decades—a shift considered climatically significant.

In this section, the linear trendline was applied individually to the data from each observation point to detect the prevailing climatic trends—whether increasing or decreasing—throughout the study period. The resulting trends provide insight into the long-term thermal evolution of the study area and are summarized as follows.

5.3.1. Temporal Trend Analysis of Maximum Temperatures (1985–2024)

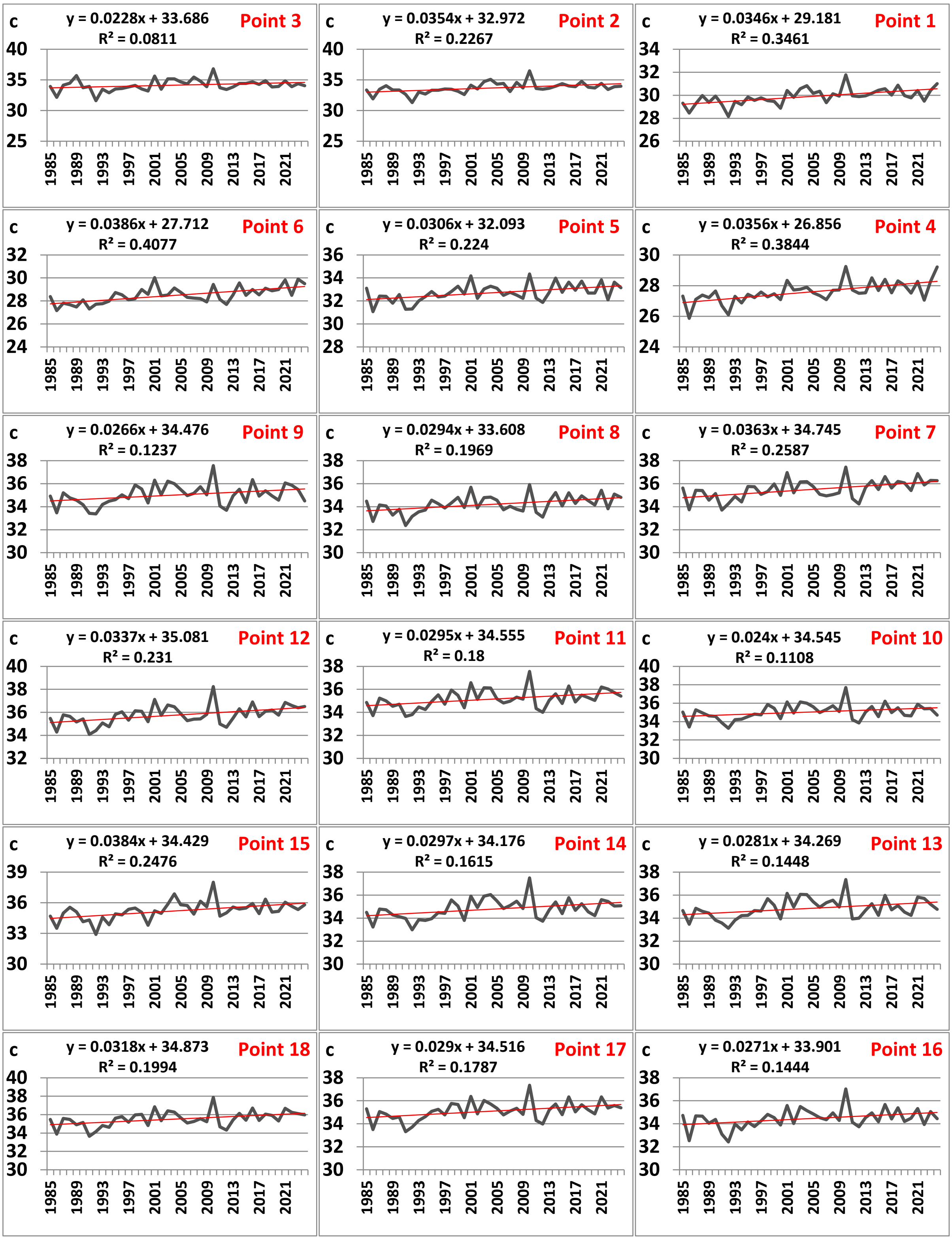

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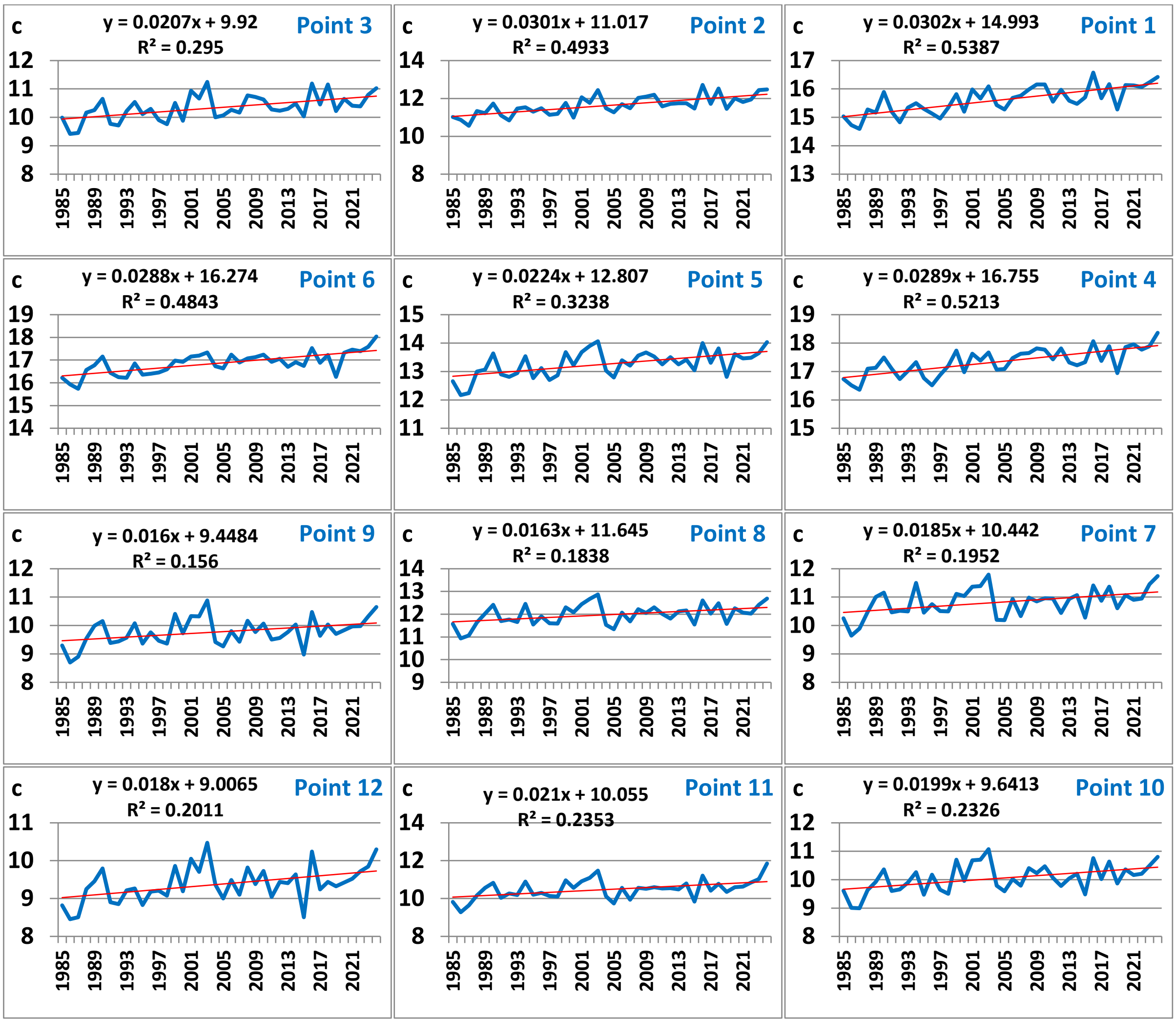
Figure 6. Annual Trend Analysis of Maximum Temperatures at Observation Points in the Study Area During the Period (1985–2024)

5.3.2. Temporal Trend Analysis of Maximum Temperatures (1985–2024)



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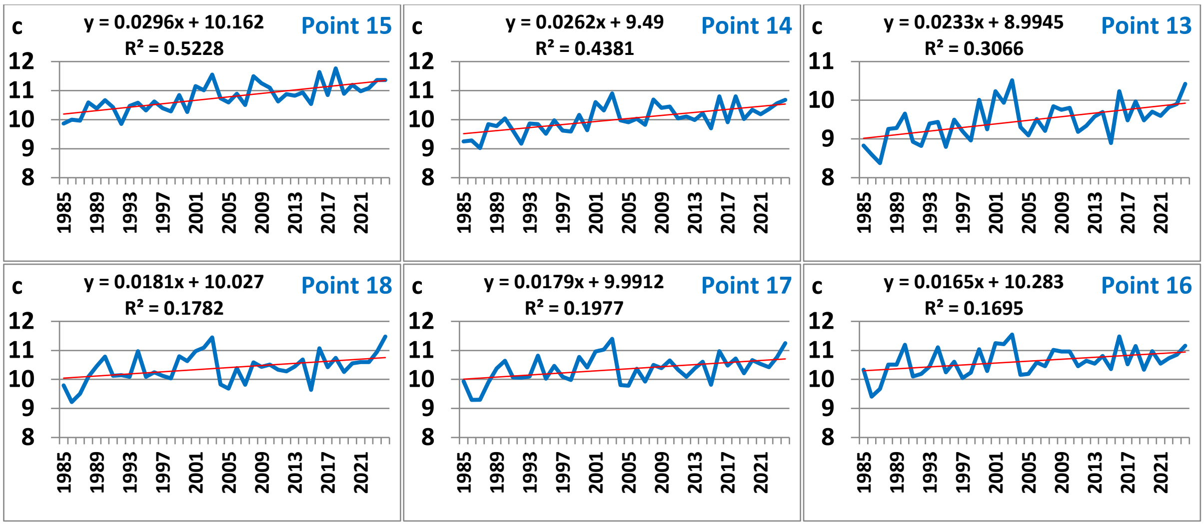

Figure 7. Annual Trend Analysis of Minimum Temperatures at Observation Points in the Study Area During the Period (1985–2024)

The temporal trends of maximum and minimum temperatures, as illustrated in Figures (6) and (7), were derived from data recorded at 18 meteorological stations across the study area for the period 1985–2024. This analysis is based on the simple linear regression model, where the slope coefficient represents the annual rate of change in temperature, while the coefficient of determination (R^2) reflects the regularity of the time series and the extent to which the temperature variation is explained by time as an independent variable.

1. Trends in Maximum Temperature

Figure (6) demonstrates that the vast majority of observation stations exhibit a consistent upward trend in maximum temperatures. The slope values range between +0.0228°C and +0.0386°C per year. While some R^2 values are relatively low (e.g., $R^2 = 0.0811$ for the general average), others show moderate to strong explanatory power—for example, Point 1 recorded an R^2 of 0.4077—indicating more regular and detectable trends in specific locations.

These trends suggest a statistically and climatologically significant upward tendency in maximum temperatures over the past four decades, likely linked to large-scale phenomena such as global warming, in addition to local factors including topographic variation, solar exposure, and proximity or distance from the Mediterranean Sea. The stations with the highest annual rates of increase are:

Point 6 (Sirte – coastal):
Slope = +0.0386°C/year | $R^2 = 0.4077$
Point 15 (southeast of the study area – ~150 km from the coast):
Slope = +0.0384°C/year | $R^2 = 0.2476$

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Point 7 (southwest of Sirte – ~90 km inland):
Slope = +0.0363°C/year | R^2 = 0.2587

These stations show rates of change exceeding the regional average, supporting the hypothesis of localized or regional warming, potentially associated with land use changes, urban expansion, or shifts in vegetation cover.

2. Trends in Minimum Temperature

Figure (7), which depicts trends in minimum temperatures, reveals a clear and consistent upward trend across all monitoring stations. Slope values range from +0.016°C to +0.0302°C per year, with higher consistency and stronger explanatory values than those observed for maximum temperatures—indicating a steady rise in nighttime temperatures during the study period. The highest annual rates of increase were recorded at:
Point 1: Slope = +0.0302°C/year | R^2 = 0.5387
Point 2: Slope = +0.0301°C/year | R^2 = 0.4933
Point 15: Slope = +0.0296°C/year | R^2 = 0.5228

These values indicate a robust and statistically significant warming trend in the minimum temperature time series, reinforcing the notion of sustained nocturnal warming in the region.
Comparative analysis of the thermal trends for both maximum and minimum temperatures suggests that nighttime temperatures are increasing more consistently and uniformly. This has led to a noticeable reduction in the Diurnal Temperature Range (DTR), a phenomenon often associated with increased cloud cover, elevated humidity levels, and land use changes—particularly in coastal or near-coastal areas. These findings align with broader hypotheses regarding the impacts of global climate change on arid and semi-arid regions. They also underscore the importance of including nocturnal temperature indicators in assessments of local climate transformations due to their heightened sensitivity and interaction with ecological systems and human activities.

6. Results and Recommendations:

This study presents a comprehensive analysis of temperature trends in the Sirte region during the period 1985–2024, based on open-source climate data from NASA POWER and the application of spatial analysis tools and temporal regression models. The integration of both approaches demonstrated a greater capacity to explain local climatic changes by identifying spatial distribution differences and temporal variations in both maximum and minimum temperatures. This methodological approach represents a scientific step forward in developing tools for monitoring and analyzing climate change at small regional scales, enhancing our understanding of climate patterns in arid and semi-arid environments such as Sirte. The main findings of the study are as follows:

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1. Upward Temperature Trends: Most observation points showed positive trends in both maximum and minimum temperatures, with cumulative changes exceeding 1.2°C over four decades.
2. More Consistent Minimum Temperatures: The coefficients of determination (R^2) indicated that trends in minimum temperatures were more consistent and temporally coherent than those of maximum temperatures.
3. Spatial Analysis Insights: Spatial maps of maximum and minimum temperatures revealed notable spatial variability in seasonal temperature averages, which partially aligned with the temporal trends identified through linear regression. This supports the effectiveness of combining spatial and temporal approaches in climate assessments. Additionally, spatial and surface trend analyses revealed a stable thermal pattern: an increase in maximum temperatures from the northeast to the southwest across all seasons, accompanied by a decrease in minimum temperatures along the same axis.
4. Partial Agreement with Previous Studies: The results of this study are relatively consistent with findings from earlier research (Salim, 2017; Onaybah, 2014) regarding upward temperature trends, with the present study offering the added value of spatial dimension analysis.

Based on the findings, the study recommends expanding spatial climate research to include other regions in Libya. It is crucial to link temperature trend analyses with additional climate indicators such as precipitation, humidity, and evaporation, in order to deepen our understanding of regional climate changes. The study also emphasizes the importance of verifying the accuracy of satellite-derived data—such as NASA POWER—by comparing them with ground-based station records whenever available. This underlines the need to support the establishment of conventional or automated meteorological stations in data-sparse areas. Furthermore, the study advocates for the development of open-access spatial climate databases to support environmental and agricultural planning efforts. It also recommends employing more advanced statistical and spatial analysis tools, such as ARIMA models and the Mann-Kendall trend test, to improve the accuracy of climate trend assessments at both temporal and spatial scales.

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سبتمبر 2025
مجلة جامعة درنة للعلوم الإنسانية والاجتماعية
DERNA UNIVERSITY JOURNAL OF HUMANITIES AND SOCIAL SCIENCES
Available online at https://dujhss.uod.edu.ly/
P-ISSN: 2959-6475 E-ISSN: 2959-6483 Impact Factor: 0.82

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