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Trend Analysis of Seasonal Temperature in the Al-Bardi region, Northeastern Libya

Mahmood M.M. Soliman*

*Department of Geography, Faculty of Arts, University of Tobruk, Libya

Email address: soliman4075@tu.edu.ly

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https://orcid.org/0000-0003-4192-4894
Phone: 00218925534152

Abstract: This study investigates seasonal temperature trends in the Al-Bardī region, northeastern Libya, to identify potential climate change over recent decades. Due to limited local meteorological data, NASA POWER's 2-meter temperature records were used. Three statistical tools were applied: the Mann-Kendall test, simple linear regression, and first difference method. Findings from the Mann-Kendall test reveal statistically significant warming trends in both maximum and average temperatures during spring and autumn, indicating a clear signal of climate warming in transitional seasons. In contrast, summer and winter exhibited no significant trends, suggesting a relative thermal stability during these periods. The observed decline in spring minimum temperatures may reflect increased nighttime variability, potentially driven by changes in cloud cover or humidity—factors that contribute to a wider diurnal temperature range. Simple linear regression confirmed that spring experienced the most pronounced warming, while the first-difference method highlighted sharp fluctuations in maximum temperatures and irregular patterns in minimum temperatures, underscoring potential exposure to extreme climate events. This study enhances the understanding of local climate dynamics in an understudied region and provides valuable insights for agriculture, water resource management, and environmental planning in the context of ongoing climate change.

1. Introduction

Climate change is considered one of the most important topics currently being widely discussed due to the broad scope of its impacts. It has garnered significant attention across various scientific disciplines, including Earth sciences, natural sciences, environmental studies, geography, economics, politics, and social sciences. Indeed, climate change has been addressed in most fields of both the humanities and applied sciences. Since the late 19th century, the Earth has experienced a noticeable rise in temperatures, primarily attributed to human activities—particularly the burning of fossil fuels. According to the Intergovernmental Panel on Climate Change (IPCC), global surface temperatures during the period 2011–2020 increased by approximately 1.1°C compared to the levels recorded between 1850 and 1900. This warming is mainly attributed to human activities, especially the emission of greenhouse gases, notably carbon dioxide and methane (IPCC, 2023).

The World Meteorological Organization (WMO) reported that greenhouse gas concentrations reached new record highs again in 2023, with carbon dioxide levels rising by 11.4% (WMO, 2024). Temperatures are expected to continue rising unless effective measures are taken to reduce greenhouse gas emissions.

Temperature fluctuations serve as a significant indicator in identifying the general characteristics of climate. Accordingly, climate change studies have particularly focused on analyzing temperature trends, as temperature is the most prominent indicator in determining whether climate change is occurring. Meanwhile, increases or decreases in precipitation rates and storm frequency at the regional level, in addition to extreme weather events, represent other important indicators of climate change (Şen, 2013). Some studies conducted in Libya on the analysis of climate element trends have shown varying trends in climatic variables such as temperature and precipitation (Soliman, 2020; Salim & Haweel, 2024; Soliman, 2022).

This study aims to analyze temperature trends and identify their temporal patterns in the Al-Bardī region, located in northeastern Libya, by employing three advanced time series analytical tools. These tools include the Mann-Kendall Test, a widely used non-parametric statistical test for detecting upward or downward trends in climate time series without assuming any specific data distribution—making it ideal for analyzing climatic data, which are often volatile and non-linear. In addition, the simple linear regression equation was used to estimate the annual rate and direction of temperature change by quantitatively and graphically representing the relationship between time and temperature. Finally, the method of successive differences was applied to detect time intervals that experienced irregular or abrupt changes within the climate series. The significance of this study lies in enhancing the scientific understanding of local climate dynamics in the Al-Bardī region, particularly those that directly affect water resources, agricultural activities, and tourism. It also contributes to guiding future environmental and developmental policies, while documenting the thermal characteristics of a remote area that has received limited attention in previous climate studies.

Due to the absence of local meteorological stations in the study area, maximum and minimum temperature data for the town of Al-Bardī at a height of 2 meters were obtained from the NASA POWER platform, which provides climate records derived from numerical models and remote sensing data. The Tobruk meteorological station is the nearest to the region, located approximately 120 kilometers away; however, its climate records suffer from discontinuity and data gaps, with published observations ceasing in 2010.

Several climate studies conducted in areas lacking ground-based meteorological observations or where such data are incomplete have indicated that satellite-derived and model-based climate data possess acceptable accuracy for research purposes. This makes them valuable for climatic and hydrological studies (Rodrigues and Braga, 2021). In another study, statistical analyses and visual comparisons demonstrated the reliability of gridded data in representing near-surface air temperature at 2 meters (Marzouk, 2021). Furthermore, Badawy (2020) confirmed that the gridded NASA POWER dataset demonstrates a high level of agreement with observations from 40 conventional meteorological stations across Egypt, with maximum surface temperature data exhibiting higher accuracy than minimum temperature data. Similarly, (Çiçek, 2004) reported that climatic data obtained from the NASA POWER database show good to moderate agreement with ground-based meteorological data, particularly in the continental regions of Turkey, while accuracy tends to decline in the Mediterranean coastal zones. Moreover, they highlighted that wind speed data from NASA POWER exhibit noticeable discrepancies when compared to station-based measurements, suggesting reduced reliability for this specific variable.

2. Trend Analysis Methodology

2.1. Mann-Kendall (MK) Test

The Mann-Kendall test is one of the most widely recognized non-parametric tests and is among the most commonly employed methods for trend analysis in time series, particularly in disciplines such as climatology and hydrology. Across various studies on trend analysis, this test has demonstrated greater efficiency compared to other methods (Karpouzos, 2010; Bonfils, 2012; Karabulut, 2012; Ageena, 2013; Yılmaz, 2018; Soliman, 2020).

To assess the strength and direction of relationships between variables—regardless of whether they are independent or dependent—statistical methods known as correlation techniques are utilized. When the application of the parametric Pearson correlation test is not feasible, the Mann-Kendall test provides a robust non-parametric alternative. The equations underlying the Mann-Kendall test were originally formulated by Kendall (1975) and subsequently refined by (Gilbert, 1987):

$$S = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} sign(x_j - x_i)$$

Where S > 0 then later observations in the time series tend to be larger than those that appear earlier in the time series, while the reverse is true if S < 0.

The variance of S is given by

$$var = \frac{1}{18}\left[n(n-1)(2n+5) - \sum_t f_t(f_t - 1)(2f_t + 5)\right]$$

where t varies over the set of tied ranks and f_t is the number of times (i.e. frequency) that the rank t appears.
The MK Test uses the following test statistic (Bulut et al., 2006):

$$z = \begin{cases} (S-1)/se, & S > 0 \\ 0, & S = 0 \\ (S+1)/se, & S < 0 \end{cases}$$

where se = the square root of var. If there is no monotonic trend (the null hypothesis), then for a time series with more than 10 elements, $z \sim N(0, 1)$, i.e. z has a standard normal distribution.

This test provides a statistical method for detecting trends in time series data, whether positive (increasing) or negative (decreasing), by formulating two main hypotheses:

- Null hypothesis (H_0): Indicates that there is no trend in the data.
- Alternative hypothesis (H_1): Indicates the presence of a trend in the data.

If the Z-value is less than 1.96 at a 95% confidence level, the null hypothesis (H_0) is accepted, implying no significant trend. If the Z-value exceeds 1.96, the alternative hypothesis (H_1) is accepted. A positive Z-value indicates an upward (increasing) trend, while a negative Z-value indicates a downward (decreasing) trend.

2.2. Simple Linear Regression (SLR):

This method is used as a regression test to determine the relationship between two or more variables that have a causal relationship (Yılmaz, 2018). The model expresses the relationship between a single independent variable (x) and a dependent variable (y) through a linear function. Trend analysis in time series is conducted using the simple linear regression model represented by the following equation:

$$\boldsymbol{\varepsilon} + \boldsymbol{\beta_1 X} + \boldsymbol{\beta_0} = \boldsymbol{Y}$$

Where:

- x represents the independent variable (time),
- y denotes the values of the time series variable,
- β_0 is the intercept,
- β_1 is the slope coefficient indicating the rate and direction of change,
- and $\boldsymbol{\varepsilon}$ is the error term.

If the slope coefficient β_1 is positive, this indicates an upward trend in the data; if negative, the trend is downward. If the value of a is close to zero, it suggests that there is no significant change in the data over time.

2.3. First Difference Method (FDM):

The First Difference Method was employed as a supplementary analytical approach to visually identify general patterns of change within the time series by calculating the simple differences between successive observations over time. Although it does not provide explicit measures of statistical significance (such as confidence levels), it offers an initial indication of annual or periodic trends, thereby facilitating the detection of broader shifts and complementing more rigorous statistical analyses (Thomas, 1998). This method is represented by the following equation:

$$\boldsymbol{\delta} = \boldsymbol{x_t} - \boldsymbol{x_{t-1}}$$

Where $\boldsymbol{x_t}$ is the temperature in the current year, $\boldsymbol{x_{t+1}}$ is the temperature in the previous year, and $\boldsymbol{\delta}$ is the difference between the two values. If most of the $\boldsymbol{\delta}$ values are positive, this indicates an upward trend. If most of the $\boldsymbol{\delta}$ values are negative, this indicates a downward trend. If the values fluctuate without a clear pattern, there may be no clear trend.

3. Study Area and Its Climatic Characteristics:

The Al-Bardi region is located in the far northeastern part of Libya, between latitudes 31.38° and 31.48° North and longitudes 24.56° and 25.09° East. The area slopes towards the Mediterranean Sea from the northeastern side and is bordered by the Al-Dafna Plateau to the southwest. To the south lies the town of Umm Saad, which marks the Libyan-Egyptian border. The total area of the region is approximately 240 square kilometers. The region's topography is diverse, featuring coastal valleys through which water flows during the rainy season, as well as a narrow coastal plain and small hills, with elevations not exceeding 225 meters above sea level (see **Figure 1**).

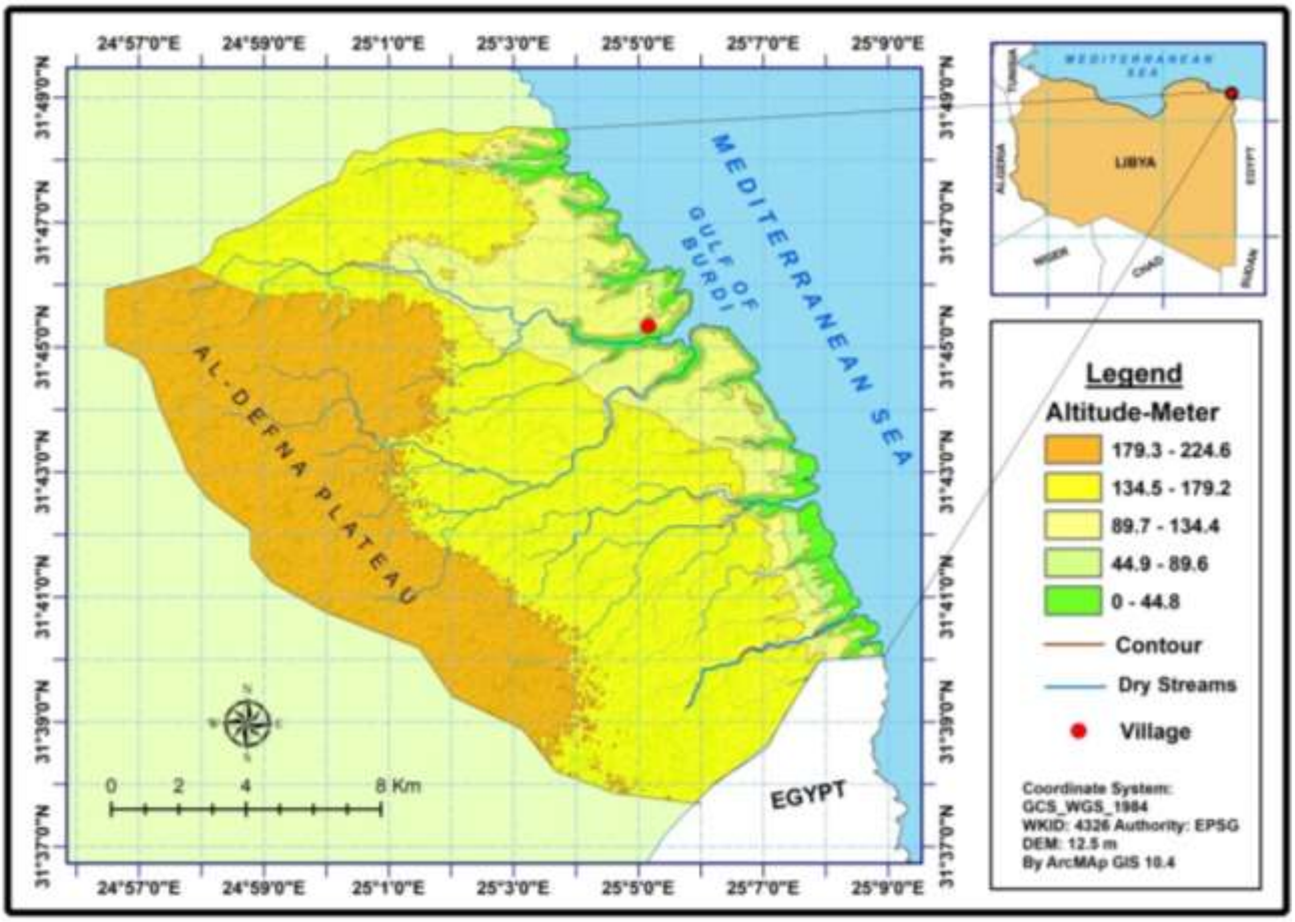


Figure 1. Map of the Geographical Location and the Morphology of the Al-Berdi region.

The study area is characterized by a semi-arid climate influenced by the Mediterranean climate. Summers are marked by high temperatures and dry conditions, while winters are characterized by mild temperatures and variable rainfall. During the summer season, average maximum temperatures reach 30.13°C, while minimum temperatures drop to 22.05°C. In winter, maximum temperatures average 20.51°C and minimum temperatures average 11.51°C. In spring, temperatures range from 26.46°C (maximum) to 13.84°C (minimum). In autumn, maximum temperatures reach 28.91°C and minimum temperatures drop to 19.38°C. The annual average temperature is 26.51°C for the maximum and 16.69°C for the minimum (**Figure 2**). Additionally, the annual average precipitation is 228.8 mm, and the annual average relative humidity is 72.4% (NASA POWER, 1981–2022).

Figure (2) clearly illustrates seasonal fluctuations in maximum temperatures, with a general trend indicating a gradual increase, particularly after the year 2000. This reflects the impacts of global warming and local climate changes. Certain years experienced exceptional spikes in maximum temperatures, which may be associated with climatic phenomena such as heat waves or local effects like drought. Minimum temperatures also exhibit an upward trend, albeit at a slower rate compared to maximum temperatures. Changes in minimum temperatures significantly influence nocturnal cooling rates, which play an important role in shaping the local climate and determining nighttime heat loss. The figure also reveals distinct seasonal variations between the different seasons, with more pronounced differences between summer and winter. Summers have become increasingly hotter, while winters tend to be milder compared to long-term averages.

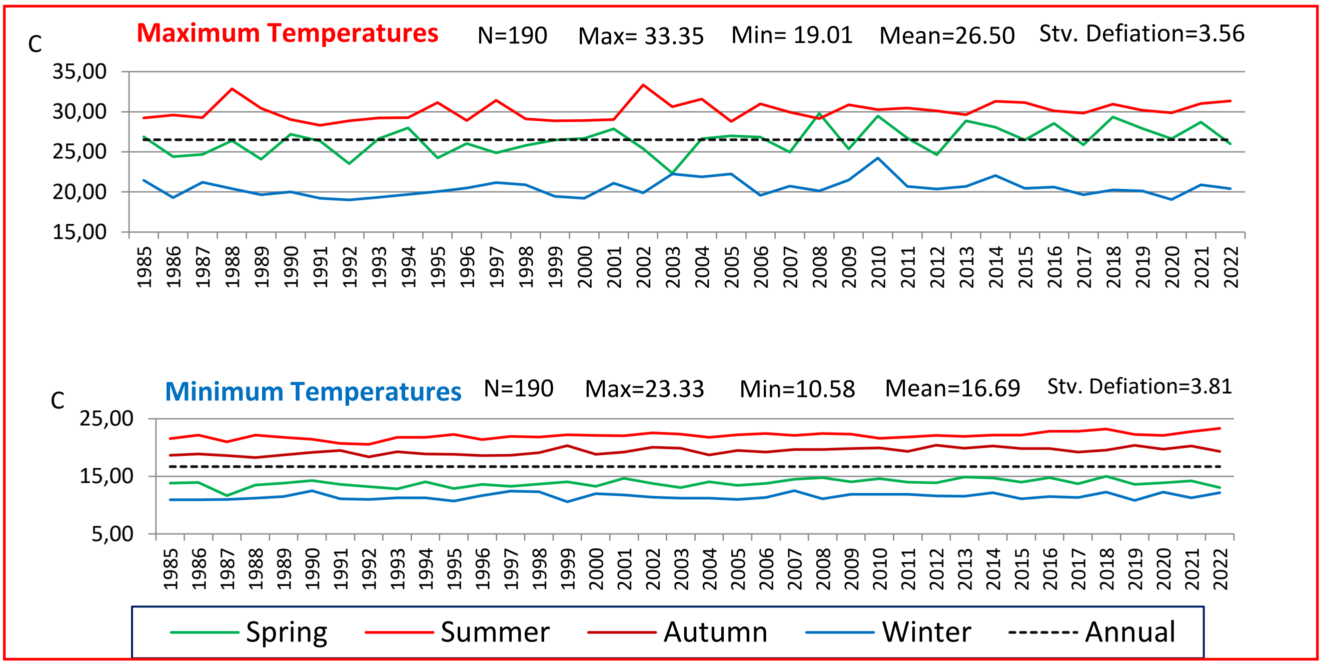


Figure 2. Seasonal and Annual Maximum and Minimum Temperatures in the Al-Berdi region.

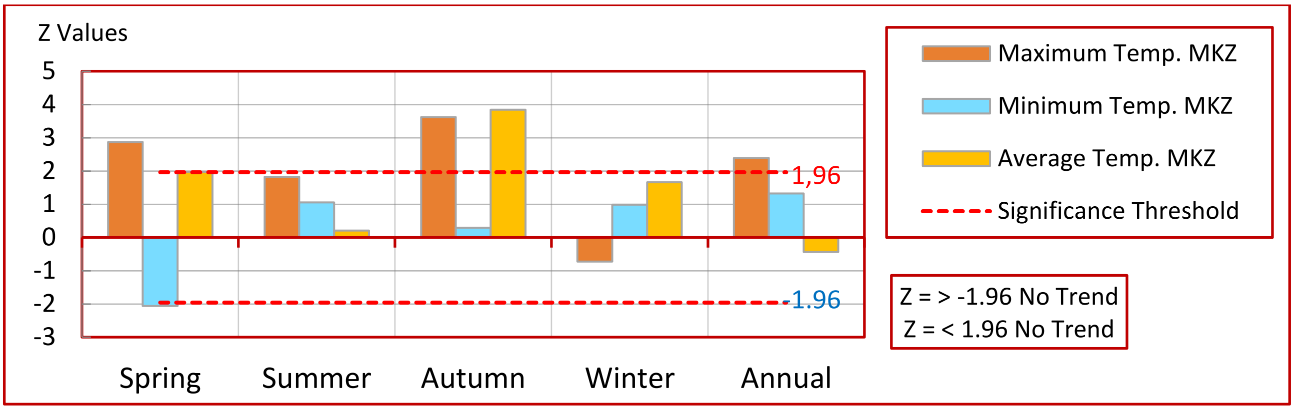
3. Results and Discussion

3.1. Results of the Mann-Kendall (MK) Test Application:

Table 1. Mann-Kendall test results for maximum, minimum, and average temperatures in the Al-Berdi region during the period 1985–2022.

Variables	Mann-Kendall Test Results								
	Maximum Temperatures			Minimum Temperatures			Average Temperatures		
	Z	p	Trend	Z	p	Trend	Z	p	Trend
Spring	2.87	0.004	Significant Decrease	-2.06	0.039	Significant Decrease	1.98	0.047	Significant Decrease
Summer	1.82	0.161	No Trend	1.05	0.293	No Trend	0.21	0.833	No Trend
Autumn	3.62	0.000	Significant Decrease	0.29	0.771	No Trend	3.84	0.000	Significant Decrease
Winter	- 0.73	0.465	No Trend	0.99	0.322	No Trend	1.66	0.096	No Trend
Annual	2.39	0.016	Significant Decrease	1.32	0.186	No Trend	-0.44	0.659	No Trend

Notes: The null hypothesis H_0 (no trend) is accepted if the Z value is < 1.96 at a 95% confidence level. If the Z value is > 1.96, the alternative hypothesis H_1 is accepted. The trend is toward an increase if the Z value is positive, and toward a decrease if the Z value is negative. H_0 (no trend) is accepted if the $p > 0.05$.



Note: Dashed lines represent significance thresholds at Z = ±1.96

Figure 3. Z-values of the Mann-Kendall Test for maximum, minimum, and average temperatures in the Al-Berdi region during the period 1985–2022.

The results of the Mann-Kendall test (**Table 1 and Figure 3**) reveal clear seasonal and annual variations in the trends of maximum, minimum, and average temperatures in the Al-Berdi region during the period 1985–2022. These trends serve as important climatic indicators of regional thermal change and carry tangible environmental implications.

❖ **Spring:**

Maximum temperature: A statistically significant upward trend was recorded (Z = 2.87, p = 0.004), indicating a notable increase in extreme temperatures during this season. This may lead to elevated evaporation rates and increased thermal stress on crops.

Minimum temperature: A statistically significant decreasing trend was observed (Z = -2.06, p = 0.039), reflecting an expansion of the diurnal temperature range (DTR), which indicates a growing disparity between daytime and nighttime temperatures.

Average temperature: A statistically significant increasing trend was also detected (Z = 1.98, p = 0.047), marking a clear onset of seasonal warming that could influence the timing of spring agricultural cycles.

❖ **Summer:**

Maximum temperature: No statistically significant trend was observed (Z = 1.82, p = 0.161), although the relatively high Z value suggests a latent warming tendency that may become significant in the future.

Minimum temperature: No statistically significant change (Z = 1.05, p = 0.293).

Average temperature: No significant trend was noted (Z = 0.21, p = 0.833), reflecting a relatively stable thermal regime during the summer season.

❖ **Autumn:**

Maximum temperature: A strong and statistically significant increasing trend was observed (Z = 3.62, p = 0.000), indicating a rapid transition toward a warmer autumn, which could impact the timing of the end of the growing season.

Minimum temperature: No significant trend was found (Z = 0.29, p = 0.771).

Average temperature: A strong significant upward trend was recorded (Z = 3.84, p = 0.000), confirming a marked seasonal warming pattern.

❖ **Winter:**

Maximum temperature: No statistically significant change was detected (Z = -0.73, p = 0.465), indicating stability in maximum temperatures during this season.

Minimum temperature: No significant trend was observed (Z = 0.99, p = 0.322).
Average temperature: No statistically significant change was found (Z = 1.66, p = 0.096), although the Z value approaches the threshold for significance.

❖ **Annual:**

Maximum temperature: A statistically significant upward trend was detected (Z = 2.39, p = 0.016), suggesting an increase in the intensity or frequency of extremely hot days on an annual scale.
Minimum temperature: No significant trend was recorded (Z = 1.32, p = 0.186).
Average temperature: No significant change was observed (Z = -0.44, p = 0.659), indicating that the dominant thermal signal lies in the rise of maximum temperatures, without corresponding increases in the overall thermal average.

3.2. Results of the Simple Linear Regression Equation:

3.2.1. Results of Simple Linear Regression Equation to Maximum Temperatures:

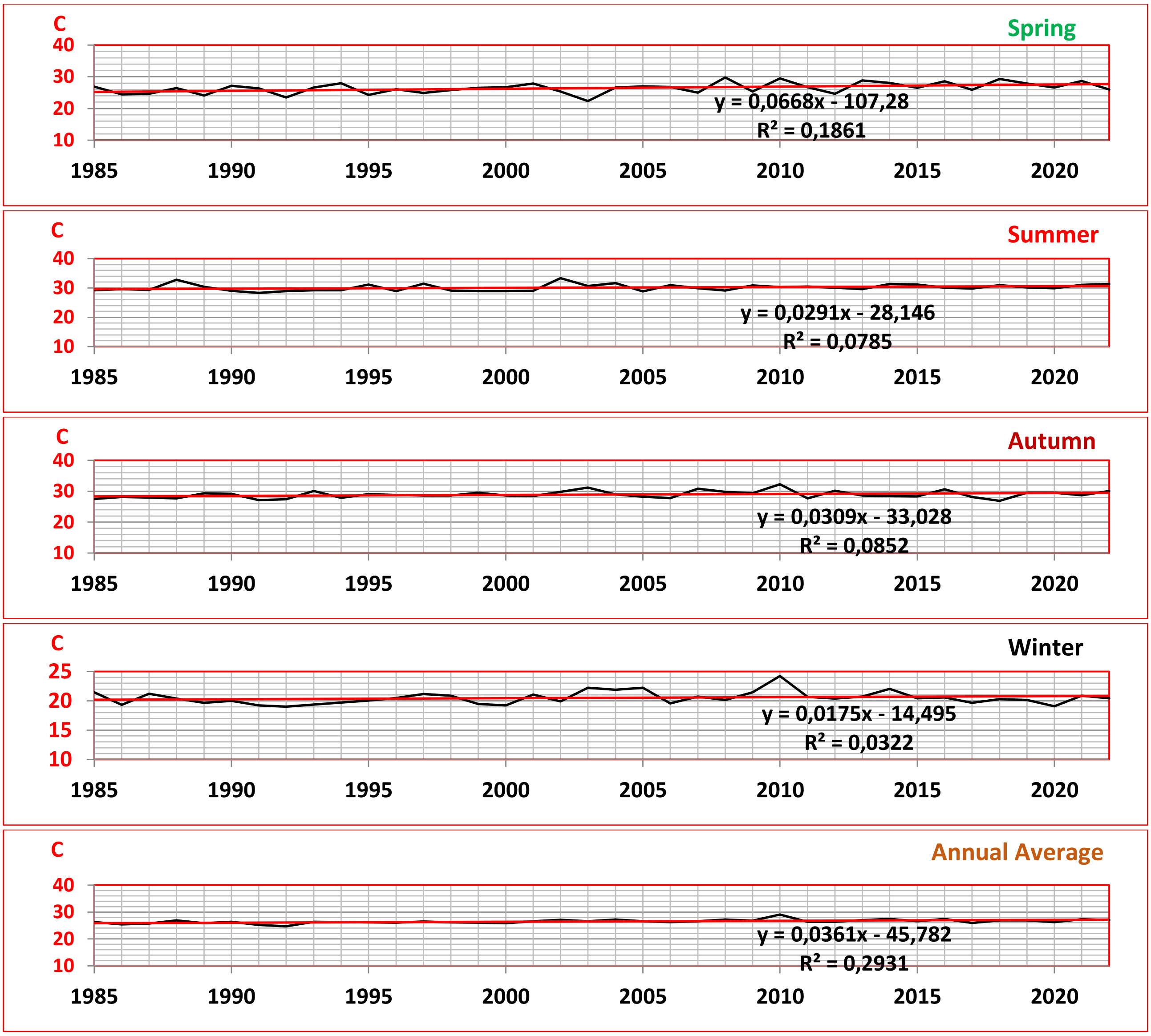


Figure 4. Seasonal trend analysis of maximum temperatures in the Al-Berdi region based on the simple linear regression method.

It is evident from **Figure (4)** that maximum spring temperatures in the Al-Berdi region exhibit a noticeable upward trend, as illustrated by the simple linear regression equation:

($y = 0.0668x – 107.28$), with an estimated annual increase of approximately 0.0668°C. The coefficient of determination ($R^2 = 0.1861$) indicates a weak to moderate relationship between temporal changes and rising temperatures, suggesting that about 18.6% of the variation in temperature can be attributed to the time factor, while the remaining proportion may be explained by other climatic variables.

In summer, a weak upward trend was observed, represented by the regression equation:

($y = 0.0291x – 28.146$), indicating an annual increase of no more than 0.0291°C. The coefficient of determination was low ($R^2 = 0.0785$), reflecting a weak relationship between the temporal variable and changes in summer temperatures.

Regarding autumn, the linear regression results for maximum temperatures show a slight upward trend, represented by the equation:

($y = 0.0309x – 33.028$), with an annual increase of 0.0309°C. The coefficient of determination ($R^2 = 0.0852$) suggests that the relationship between time and temperature during this season remains weak.

As for winter, the data reveal a very weak upward trend in maximum temperatures, expressed by the regression equation:

($y = 0.0175x – 14.495$), with an annual increase of only 0.0175°C. This season recorded the lowest coefficient of determination among the four seasons ($R^2 = 0.0322$), indicating a very weak relationship between time and winter temperature changes.

The overall annual trend of maximum temperatures shows a clear upward pattern, with the regression equation matching that of the spring season:

($y = 0.0668x – 107.28$), and a coefficient of determination ($R^2 = 0.1861$). These results suggest that annual maximum temperatures have experienced a moderate and consistent increase over the past decades at a rate of 0.0668°C per year, constituting a tangible indicator of local climate change.

3.2.2. Results of Simple Linear Regression Equation to Minimum Temperatures:

According to **Figure (5),** the seasonal trend curve for minimum temperatures during spring in the Al-Berdi region demonstrates a noticeable upward trend. This is expressed by the linear regression equation ($y = 0.0262x – 38.562$), indicating an annual increase of approximately 0.0262°C. The coefficient of determination ($R^2 = 0.186$) suggests a weak to moderate relationship between time and temperature change, with approximately 18.6% of the variation attributed to the temporal factor.

The summer season shows a clearer upward trend in minimum temperatures, as indicated by the regression equation ($y = 0.0347x – 47.39$), reflecting an annual increase of nearly 0.0347°C, which represents a relatively significant rise in the context of climate change. The determination coefficient ($R^2 = 0.44$) is the highest among all seasons, suggesting that about 44% of the temperature variation can be explained by the progression of time.

During autumn, minimum temperatures exhibit a moderate increasing trend, represented by the equation (y = 0.0372x – 55.209), with an annual increase of 0.0372°C—the highest rate among the four seasons. This trend is further supported by a relatively strong coefficient of determination (R^2 = 0.4726), reflecting a moderately strong relationship between time and the rise in minimum temperatures.

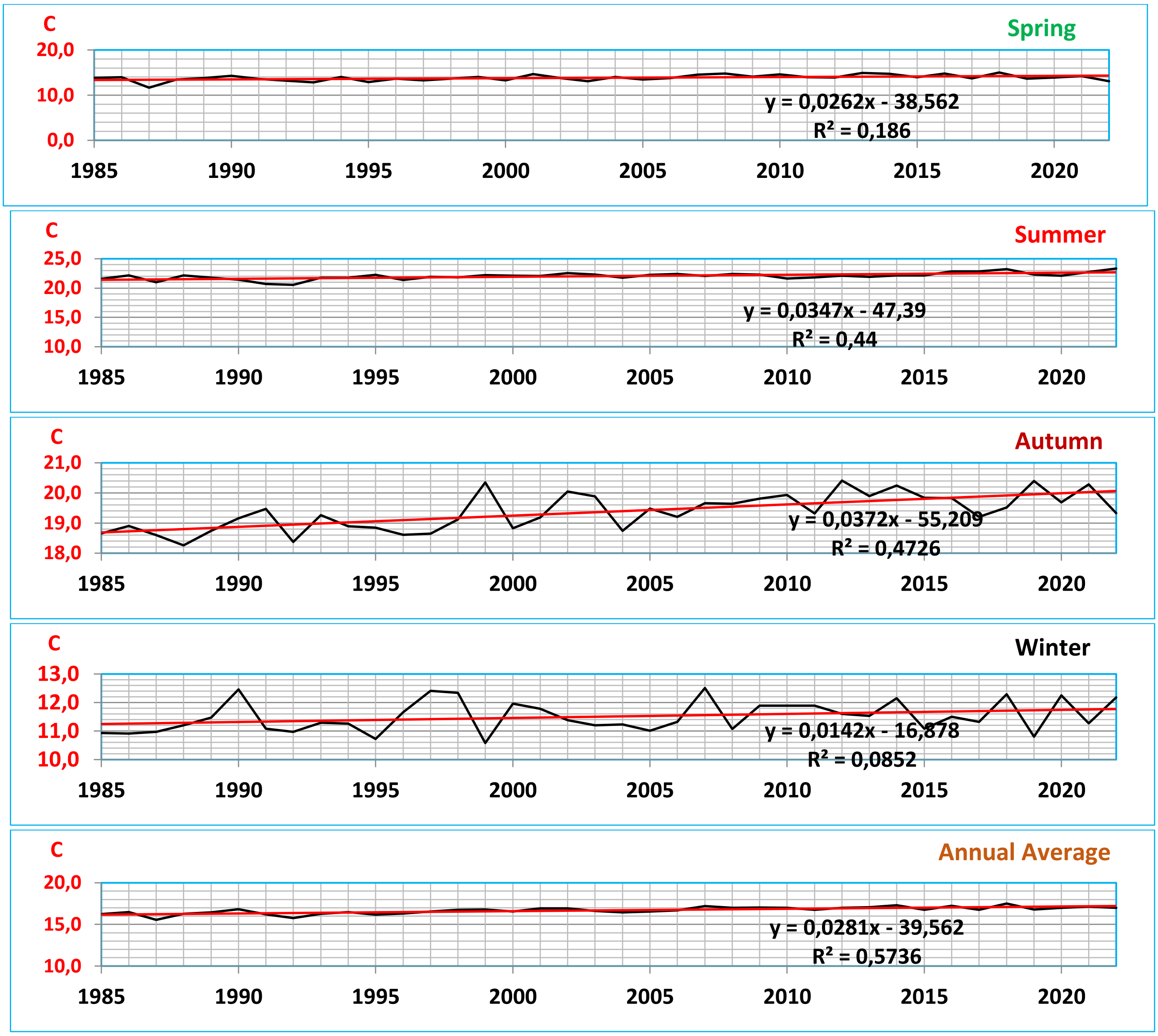


Figure 5. Seasonal trend analysis of minimum temperatures in the Al-Berdi region based on the simple linear regression method.

Winter shows a weak upward trend, described by the regression equation (y = 0.0142x – 16.878), with the lowest annual increase of 0.0142°C among all seasons. The corresponding (R^2 = 0.0852) indicates a very weak relationship between time and temperature change during the winter season.

The overall annual trend in minimum temperatures across the Al-Berdi region reflects a clearly increasing pattern, with a regression equation of (y = 0.0281x – 39.562) and an annual rise of 0.0281°C. The coefficient of determination (R^2 = 0.5736) is the highest across all seasonal and annual trends, suggesting that more than 57% of the variation in annual minimum temperatures can be explained by the temporal factor.

3.3. First Difference Method (FDM):

Figure (6) shows a sharp fluctuation in the successive differences of maximum temperatures during the transitional seasons (spring and autumn), where the highest differences for both positive and negative values were recorded during the observation period. In the spring, the values ranged from +4.40°C in 2008 to -4.80°C in 2007, reflecting a sharp temperature change over a short period. Similarly, the autumn season showed significant variation, with differences reaching +4.54°C in 2010 compared to the previous year. On the other hand, the summer season was characterized by temperature variation from year to year, with the lowest value recorded in 2001 at -4.32°C, followed by another low value in 1987 at -3.58°C. In contrast, the winter season and the overall annual average showed a relative degree of stability, as the temperature difference values were closely aligned throughout the study period, indicating a relatively consistent temperature pattern during the winter season as well as in the overall annual maximum temperature averages.

Figure (7) shows relatively fluctuating trends in minimum temperatures, where the trends for spring, autumn, and winter seasons exhibited increasing differences during the observation period, but these were lower compared to the trends of maximum temperatures. In spring, the differences ranged from a maximum positive value of +2.3°C in 1986 to a minimum negative value of -1.81°C, which are values lower than those of maximum temperatures, indicating relatively greater stability in nighttime temperatures. The summer season and the overall annual average also showed relative consistency in values with limited fluctuation, as the differences rarely exceeded 1°C, which may reflect the stability of the cold air mass during this period.

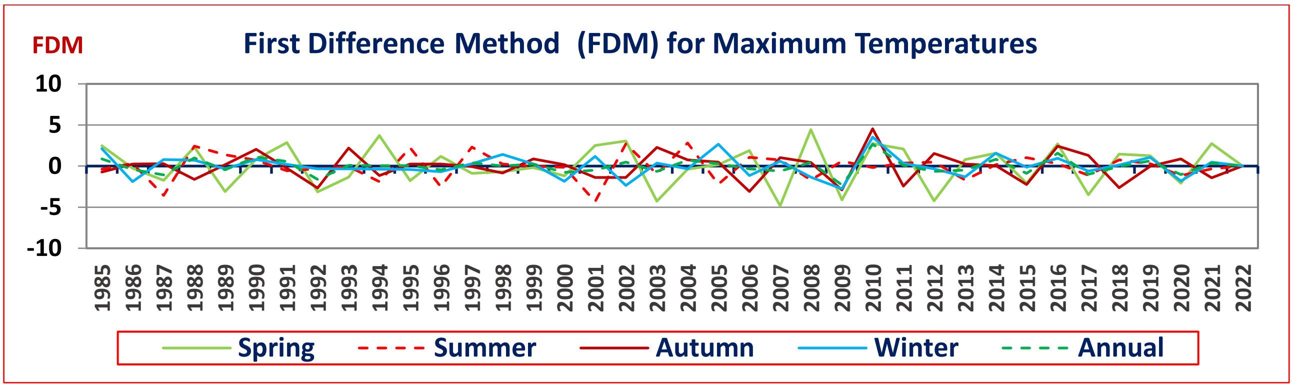


Figure 6. Seasonal and annual Maximum temperatures in the Al-Berdi region analyzed using the Finite Difference Method (FDM).

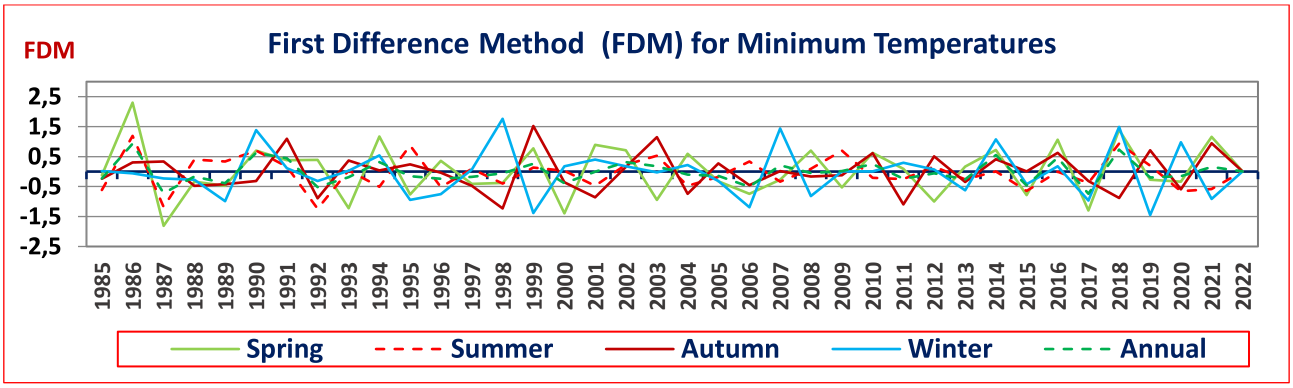


Figure 7. Seasonal and annual Minimum temperatures in the Al-Berdi region analyzed using the Finite Difference Method (FDM).

4. Results and Recommendations:

In light of the climatic findings derived from the analysis of temperature trends in the Al-Bardi region, partial climate change effects are evident, influencing certain seasons more than others. Based on these findings, several conclusions can be drawn that reflect the climatic reality of the region in recent decades.

- Based on the (MK) **test** results, the findings revealed a statistically significant upward trend in maximum temperatures during both spring and autumn, with Z-values of 2.87 and 3.62, respectively. This indicates an accelerated seasonal warming phenomenon during these two seasons. Additionally, an upward trend in the average temperatures during autumn was observed ($Z = 3.84$, $p < 0.001$), indicating a clear climatic shift at the beginning and end of the warm season.

- Annual maximum temperatures exhibited an upward trend ($Z = 2.39$, $p = 0.016$), suggesting unbalanced annual warming dominated by periods of extreme heat. A statistically significant downward trend in minimum temperatures was noted during spring ($Z = -2.06$, $p = 0.039$), which could reflect increased daily temperature variation, reduced nighttime cloud cover, or changes in relative humidity.

- No statistically significant trends were observed for temperatures (maximum, minimum, or average) during the summer and winter seasons, which could reflect relative thermal stability or equilibrium in the influencing climatic factors.

- The Simple Linear Regression equation indicated an annual increase of 0.0668°C in spring, which is relatively consistent with the results of the Mann-Kendall test. In summer, the increase was small, at 0.0291°C. In autumn, the increase was 0.0309°C. In winter, the increase was minimal, at 0.0175°C. The annual trend showed an upward shift of 0.0361°C. The graphical representation of the First Differences Method revealed sharp fluctuations in maximum temperatures while showing homogeneous trends in minimum temperatures.

- The convergence of the results from these three methods confirms that the Al-Bardi region is experiencing an upward trend in maximum temperatures, particularly during spring and autumn, with relative stability in summer and winter. The Mann-Kendall test results throughout the study period support the hypothesis of asymmetric warming, a climatic phenomenon that refers to uneven changes in the daily and nightly temperature extremes.

- **Recommendations:** The study recommends focusing on the impact of warming during the spring and autumn seasons on agriculture, ecosystems, and water resources in the region. This can be achieved by developing heat-resistant technologies, adjusting planting schedules to cope with rising temperatures, and exploring strategies for water conservation and improved water usage due to higher temperatures. Additionally, expanding the scope of research in climate trend analysis to monitor ongoing climatic changes across the entire Al-Dafna Plateau is suggested, especially given that large areas surrounding the study area are suffering from both climatic and hydrological droughts.

- In conclusion, we recommend the establishment of a permanent ground-based meteorological station in the area, equipped with calibrated and certified measurement instruments, to ensure the provision of reliable climatic data for use in climate trend analysis studies, rather than relying solely on gridded datasets.

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