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Impact of Climate Change on Vegetation Cover and Fruit Trees in Nalut Municipality, Libya: A Comparative Study of the Periods 2002–2007 and 2013–2018

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ABSTRACT

This study aimed to analyze climate change in Nalut Municipality, western Libya, and evaluate its impact on vegetation cover and fruit trees through a comparison of two periods, 2002–2007 and 2013–2018. The study relied on the analysis of temperature and rainfall data using descriptive statistical methods. The results revealed a slight decrease in the mean annual temperature from 19.7°C to 19.5°C, representing a change rate of −1.02%, along with a decline in the annual maximum temperature from 24.3°C to 22.0°C. Rainfall amounts also showed a significant decrease, with the annual average declining from 11.97 mm to 9.90 mm, corresponding to a reduction of 17.29%, which negatively affected natural vegetation cover and fruit trees. Field observations confirmed the deterioration of some olive trees and a decline in vegetation density. The findings highlight the importance of adopting effective water resource management strategies and climate change adaptation measures to ensure the sustainability of ecological and agricultural systems.

Keywords: Climate Change, Vegetation Cover, Fruit Trees, Rainfall Change, Temperature Trends, Nalut (Libya).

أثر التغيرات المناخية على الغطاء النباتي والأشجار المثمرة في بلدية نالوت (ليبيا): دراسة مقارنة للفترتين 2002–2007 و2013–2018

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ملخـــــــص البحـــــــث

هدفت هذه الدراسة إلى تحليل التغيرات المناخية في بلدية نالوت بغرب ليبيا وتقييم تأثيرها على الغطاء النباتي والأشجار المثمرة من خلال مقارنة فترتين زمنيتين هما (2002–2007) و(2013–2018). اعتمدت الدراسة على تحليل بيانات درجات الحرارة والأمطار باستخدام الأساليب الإحصائية الوصفية. أظهرت النتائج انخفاضاً طفيفاً في متوسط درجة الحرارة السنوية من (19.7°م) إلى (19.5°م) بنسبة تغير بلغت (−1.02%)، مع انخفاض درجات الحرارة العظمى السنوية من (24.3°م) إلى (22.0°م). كما سجلت كميات الأمطار انخفاضاً ملحوظاً، حيث تراجع المتوسط السنوي من (11.97 ملم) إلى (9.90 ملم) بنسبة انخفاض بلغت (17.29%)، وهو ما انعكس سلباً على الغطاء النباتي الطبيعي والأشجار المثمرة. وأكدت الملاحظات الميدانية وجود تدهور في بعض أشجار الزيتون وتراجع في كثافة الغطاء

النباتي. وتبرز النتائج أهمية تبني استراتيجيات فعالة لإدارة الموارد المائية والتكيف مع التغيرات المناخية للحفاظ على استدامة النظم البيئية والزراعية.

الكلمات المفتاحية: التغيرات المناخية، الغطاء النباتي، الأشجار المثمرة، درجات الحرارة، تغير الأمطار، نالوت (ليبيا).

1. Introduction

Climate change is considered one of the most significant environmental challenges facing the world in recent decades. Accelerated increases in temperature and changes in precipitation patterns have resulted in widespread impacts on ecosystems, natural resources, and agricultural production [1]. These impacts are particularly evident in arid and semi-arid regions, which are highly sensitive to climatic fluctuations due to their limited water resources and the dependence of their ecological and agricultural systems on the delicate balance between temperature and rainfall [2].

Libya is located within the arid and semi-arid zones of North Africa, making it particularly vulnerable to the consequences of climate change [3]. During recent decades, many parts of the country have experienced noticeable climatic changes, including rising temperatures, fluctuating rainfall patterns, and recurrent drought periods. These changes have adversely affected natural vegetation cover and agricultural productivity, while accelerating desertification processes and land degradation [4].

Nalut, in the Jabal Nafusa region of western Libya, depends largely on rain-fed agriculture and supports extensive olive, fig, and date palm cultivation, alongside natural vegetation. Recent climatic changes have raised concerns regarding the sustainability of these vegetation resources and agricultural productivity, The study area is located in western Libya within the Jabal Nafusa region, extending between latitudes 31.53°–32.04° N and longitudes 10.59°–11.04° E Figure 1 Geological and geomorphological features associated with the Nafusa Plateau [5] characterize the area. It consists of sedimentary sequences dating from the Lower Triassic to the Upper Cretaceous periods [6], which have significantly influenced the prevailing environmental and physical characteristics of the region.

Figure 1: Location of the study area

Source: Modified from [7]

Temperature and rainfall are the primary climatic factors controlling vegetation distribution and productivity in arid and semi-arid regions. Variations in these factors directly influence ecosystem stability and agricultural production [8]. Although numerous studies have investigated climate–vegetation relationships using climatic data, remote sensing, and GIS techniques, research focusing on Nalut Municipality remains limited. Therefore, this study analyzes changes in temperature and rainfall between 2002–2007 and 2013–2018 and evaluates their impacts on vegetation cover and fruit trees, providing scientific evidence to support climate adaptation and sustainable natural resource management**.**

2. Materials and Methods

The study adopted a descriptive–analytical approach to investigate climatic changes and their environmental impacts in Nalut Municipality. A temporal comparative analysis was conducted between two periods (2002–2007) and (2013–2018) to identify trends in temperature and rainfall variations and evaluate their effects on natural vegetation cover and fruit trees.

Temperature and rainfall are among the most influential climatic elements affecting the local environment. Rising temperatures increase evaporation and transpiration rates and reduce soil moisture, thereby intensifying drought conditions and negatively affecting plant growth and the productivity of fruit trees [9]. In addition, declining and fluctuating rainfall contributes to greater water stress and a reduction in vegetation density.

From a geomorphological perspective, intense rainfall events can accelerate erosion processes and trigger slope failures and landslides on hillsides and steep terrain [10], whereas prolonged drought and vegetation degradation increase soil susceptibility to erosion and land degradation. Therefore, analyzing changes in temperature and rainfall provides an essential framework for understanding their environmental and geomorphological impacts and assessing their implications for vegetation resources in the study area.

2.1 Data Sources

The study relied primarily on climatic data obtained from the Nalut Meteorological Station (Table 1), in addition to field data collected through site visits and direct observations of vegetation cover and fruit trees during 2024.

Table 1: Summary of Data Used in the Study

Variable	Time Period	Purpose
Maximum Temperature	2002–2007	Analysis of temperature changes
Minimum Temperature	2002–2007	Assessment of thermal variability
Maximum Temperature	2013–2018	Temporal comparison
Minimum Temperature	2013–2018	Temporal comparison
Rainfall	2002–2007	Analysis of rainfall variability
Rainfall	2013–2018	Temporal comparison
Wind Direction	2013–2018	Interpretation of climatic conditions
Relative Humidity	2013–2018	Support for climatic analysis
Natural Vegetation Cover	2024	Assessment of vegetation condition
Fruit Trees	2024	Evaluation of environmental impacts

Source: Nalut Meteorological Station records and field surveys conducted by the researcher.

2.2 Field Survey

Field surveys were conducted at several locations within Nalut Municipality, including Biblo, Al-Daqiqah, and selected valleys and natural rangelands. The surveys aimed to assess the condition of natural vegetation cover and fruit trees, as well as to document evidence of drought, environmental degradation, and desertification. Photographic documentation was employed to record the condition of affected trees, particularly olive trees, which exhibited clear signs of decline in vigor and productivity. These observations were associated with reduced rainfall amounts and increased temperatures recorded in the region during recent years.

2.3 Statistical Analysis

The study employed a set of descriptive and comparative statistical techniques (Table 2) to analyze climatic data and identify trends of change during the two study periods.

Table 2: Statistical Methods Used in the Study

Analytical Objective	Statistical Method
Description of climatic data	Mean
Analysis of seasonal variability	Seasonal averages
Comparison between study periods	Absolute difference (Δ)
Measurement of climatic change magnitude	Percentage change (%)
Analysis of temporal distribution	Monthly and annual averages
Interpretation of climate impacts on vegetation	Comparative descriptive analysis

Monthly, seasonal, and annual averages of temperature, rainfall, relative humidity, and wind direction were calculated and compared between the periods 2002–2007 and 2013–2018 to identify trends in climatic variability. In addition, absolute differences and percentage changes were computed to quantify variations in climatic elements and assess their impacts on natural vegetation cover and fruit trees in Nalut Municipality. The results were interpreted in conjunction with field observations and the environmental characteristics of the study area to provide a comprehensive understanding of the relationship between climatic variability and observed vegetation changes.

3. Results and Discussion

3.1 Temperature

3.1.1 Temperature Characteristics During the Period (2002–2007)

Table 3 presents the monthly maximum, minimum, and mean temperatures recorded in Nalut during the period 2002–2007. The results indicate that the mean annual temperature was 19.7°C, reflecting the semi-arid climatic conditions of the study area. A clear seasonal variation was observed, with the highest monthly mean temperatures recorded during summer, reaching 29.1°C in July and 28.1°C in August, while the lowest value was recorded in January (9.5°C). Maximum temperatures ranged from 13.3°C in January to 33.8°C in August, whereas minimum temperatures varied between 5.8°C and 24.7°C. This wide thermal range reflects the continental influence and limited maritime moderation in the region.

Table 3. Monthly Temperature Averages (°C) in Nalut (2002–2007)

Month	Dec	Jan	Feb	Ma	Apr	May	Jun	Jul	Aug	Sep	Oct	No	Mean
Tmax°C	15.3	13.3	16.1	21.3	26.1	29.9	28.4	33.6	33.8	26.5	28.5	19.8	24.3
Tmin °C	7.6	5.8	7.5	11.2	14.5	17.6	24.4	24.7	22.3	17.1	16.9	11.4	15.1
Mean°C	11.4	9.5	11.8	16.2	20.3	23.7	26.4	29.1	28.1	21.2	22.7	15.6	19.7

The high summer temperatures increase evaporation and soil moisture loss, thereby intensifying water stress on natural vegetation and fruit trees. Consequently, temperature represents a key climatic factor influencing vegetation growth, distribution, and productivity in Nalut. These conditions increase the vulnerability of vegetation resources to drought and environmental degradation, particularly under declining rainfall conditions.

3.1.2 Temperature Characteristics During the Period (2013–2018)

Table 4 presents the monthly maximum, minimum, and mean temperatures recorded in Nalut during the period 2013–2018. The results indicate that the mean annual temperature was 19.5°C, confirming the persistence of semi-arid climatic conditions in the study area. The highest monthly mean temperature was recorded in July (29.9°C), followed by August and September (27.8°C), while the lowest value occurred in January (6.6°C).

Table 4: Mean Monthly Maximum and Minimum Temperatures (°C) in Nalut (2013–2018)

Month	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Mean
Tmax °C	12.3	12.3	14.1	17.7	21.6	24.4	26.9	32.1	29.9	29.1	25.3	18.7	22.0
Tmin °C	10.2	0.9	10.3	10.1	15.8	22.4	21.0	27.7	25.7	25.7	18.9	14.5	16.9
Mean °C	11.0	6.6	12.2	13.9	18.7	23.4	23.5	29.9	27.8	27.8	22.1	16.6	19.5

Maximum temperatures ranged from 12.3°C in December and January to 32.1°C in July. Minimum temperatures varied between 0.9°C in January and 27.7°C in July, reflecting substantial seasonal thermal variability.

The persistence of high summer temperatures increases evaporation and evapotranspiration rates, leading to greater soil moisture loss and water stress. Combined with limited and irregular rainfall, these conditions negatively affect natural vegetation and fruit trees, particularly olive, fig, and date palm trees. The observed thermal regime therefore represents a significant climatic pressure on vegetation resources in Nalut and contributes to drought conditions and vegetation degradation documented during field surveys.

3.2 Rainfall

3.2.1 Rainfall Characteristics During the Period (2002–2007)

Table 5 presents the monthly and annual rainfall totals recorded in Nalut during the period 2002–2007. The results indicate that the mean annual rainfall was 14.2 mm, with considerable temporal variability among months and years. The highest monthly averages were recorded in December (40.7 mm) and February (37.7 mm), whereas rainfall was minimal during summer, reaching only 1.7 mm in June and nearly zero in July.

Table 5: Monthly Rainfall Totals (mm), Nalut (2002–2007)

Year	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Mean
2002	–	3.3	85.4	0.1	6.2	–	–	–	–	4.0	17.0	14.8	10.9
2003	67.9	12.6	56.3	8.9	1.0	0.2	–	–	–	11.7	1.0	0.1	13.3
2004	13.4	25.5	–	58.7	3.0	–	–	–	–	–	–	13.3	9.5
2005	82.7	9.0	0.9	2.0	2.1	–	9.2	–	2.8	3.2	9.3	17.2	11.4
2006	15.2	34.1	28.1	–	18.0	7.2	–	–	Trace	Trace	17.6	11.0	10.9
2007	66.0	–	56.0	27.0	17.3	6.0	1.1	–	–	2.0	–	–	29.2
Mean	40.7	14.0	37.7	16.1	8.0	2.2	1.7	0.0	0.4	3.5	7.5	9.4	14.2

Rainfall was concentrated mainly during the winter season, consistent with the Mediterranean climatic influence affecting northwestern Libya. Significant interannual variability was observed, with annual rainfall ranging from 9.5 mm in 2004 to 29.2 mm in 2007. In addition, exceptionally high rainfall events were recorded in February 2002 (85.4 mm) and December 2005 (82.7 mm). The winter concentration of rainfall plays a critical role in sustaining natural vegetation and rain-fed agriculture, including olive, fig, and date palm cultivation. However, the pronounced seasonal and annual variability in rainfall increases drought risk and may negatively affect vegetation density and agricultural productivity. These findings highlight the importance of rainfall as a key climatic factor controlling environmental and agricultural conditions in the study area during the period 2002–2007.

3.2.2 Rainfall Characteristics During the Period (2013–2018)

Table 6 presents the monthly and annual rainfall totals recorded in Nalut during the period 2013–2018. The results show that the mean annual rainfall was 9.8 mm, lower than the 14.2 mm recorded during 2002–2007, indicating a decline in rainfall during the second period.

Table 6: Monthly and Annual Rainfall Totals (mm), Nalut (2013–2018)

Year	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Mean
2013	18	6	6	–	–	–	–	–	0	–	–	45	6.25
2014	27	–	54	39	–	0	3	–	0	0	0	0	10.25
2015	Trace	3	9	0	–	–	–	–	–	27	18	69	9.60
2016	27	–	12	–	0.3	–	–	–	–	9	–	–	4.00
2017	90	–	0	54	5.4	0	–	–	–	–	87	–	19.70
2018	–	18	21	6	–	0	0.6	Trace	–	36	27	–	9.10
Mean	27.0	4.5	17.0	16.5	0.9	0.0	0.6	0.0	0.0	12.0	22.0	19.0	9.8

Rainfall exhibited considerable interannual variability, ranging from 4.0 mm in 2016 to 19.7 mm in 2017. On a monthly basis, rainfall was concentrated mainly during autumn and winter, with the highest monthly averages recorded in October (22 mm), November (19 mm), February (17 mm), and March (16.5 mm). In contrast, rainfall was extremely limited during summer, reaching only 0.6 mm in June and nearly disappearing in July and August. Several intense rainfall events were recorded, including 90 mm in December 2017 and 87 mm in October 2017, highlighting the irregular distribution of rainfall throughout the year. The observed decline and increasing variability in rainfall likely contributed to greater drought stress, reduced soil moisture availability, and deterioration of natural vegetation and fruit trees, particularly olive trees. These findings indicate that rainfall variability represents a major environmental constraint affecting vegetation resources and rain-fed agriculture in Nalut.

3.3 Supporting Climatic Factors

In addition to temperature and rainfall, the climate of Nalut is influenced by several supporting climatic factors, including atmospheric pressure, air masses, wind patterns, and relative humidity. During winter, the area is affected by Mediterranean low-pressure systems that bring cooler temperatures and rainfall, whereas summer conditions are dominated by the Azores High and Saharan low-pressure systems, resulting in hot and dry weather [11,12].

The region is influenced by maritime polar and continental tropical air masses. Maritime air masses originating from the Mediterranean and Atlantic Ocean provide moisture and contribute to winter precipitation, while continental tropical air masses from the Sahara are associated with high temperatures, low humidity, and drought conditions [13].

Wind also plays an important role in the distribution of heat and moisture. Moist northwesterly winds prevail during winter, whereas dry easterly and northeasterly winds dominate in summer, increasing evaporation rates and soil moisture loss [14]. In addition, the hot and dry Ghibli winds contribute to higher temperatures and greater water stress on vegetation .

The average relative humidity in Nalut is approximately 48.4%, reflecting the relatively dry climatic conditions of the region [15]..

3.4 Vegetation Cover in the Study Area

3.4.1 Natural Vegetation and Fruit Trees

Natural vegetation and fruit trees represent important environmental and economic resources in Nalut Municipality, where rain-fed agriculture depends largely on rainfall and prevailing climatic conditions. The area is characterized by the presence of several fruit tree species, particularly olive, fig, and date palm trees, in addition to pomegranate, grapevine, almond, and mulberry trees [16]. In addition to climatic pressures, human activities such as urban expansion at the expense of agricultural land have contributed to vegetation degradation. Figures 3 and 4 illustrate examples of deteriorated olive trees in the Biblo area, providing field evidence of the impacts of climatic variability on vegetation resources in Nalut.

Figure 2: **Degradation of Olive Trees in the Biblo Area (Zaher Nalut).**

These observations highlight the close relationship between climatic change and vegetation condition and emphasize the importance of sustainable water management and climate adaptation measures.

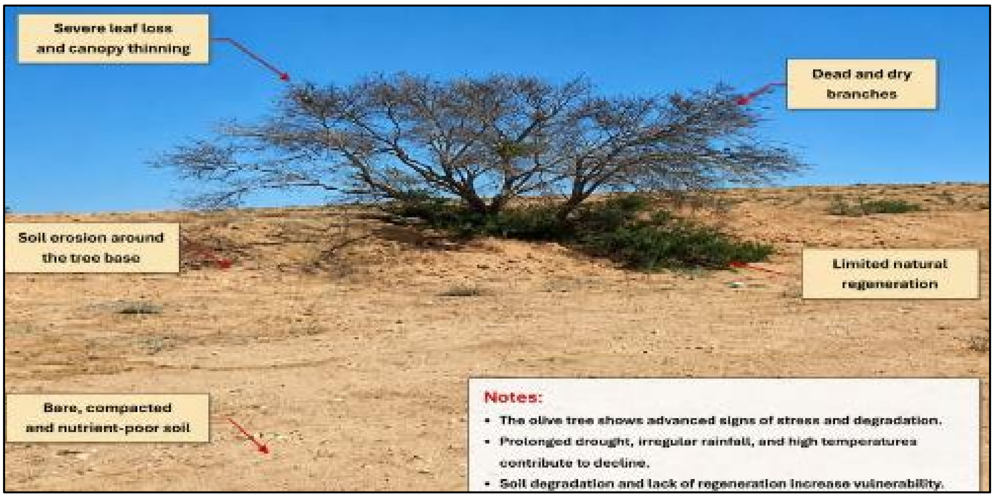

Figure 3: **Drought-Affected Olive Tree in the Biblo Area.**

3.4.2 Natural Vegetation in the Study Area

Natural vegetation is an essential component of the environmental system in Nalut Municipality, contributing to soil protection, ecological stability, and the provision of natural grazing resources. The distribution and density of vegetation are closely linked to climatic conditions, particularly rainfall and temperature, as well as soil and topographic characteristics. The study area supports several drought-tolerant plant species, including Ziziphus spina-christi (sidr), Retama raetam, Stipa spp., Cynodon dactylon, Malva sylvestris, Solanum nigrum, and Citrullus colocynthis. These species are commonly distributed across valleys, slopes, and rangelands and are adapted to the semi-arid environmental conditions of the region.

Field surveys indicated that natural vegetation is more abundant in areas such as Al-Sharaf, Al-Khamasa, Al-Daqiqah, and Biblo, where it serves as an important grazing resource for livestock. However, a decline in vegetation density was observed in recent years, which can be attributed to reduced and irregular rainfall, rising temperatures, and increased evaporation rates. In addition, intensive grazing has contributed to vegetation degradation in some locations.

These observations suggest that natural vegetation in Nalut is highly sensitive to climatic variability and can serve as an important environmental indicator of the impacts of changing temperature and rainfall patterns on local ecosystems

4. Results of Statistical Analysis

4.1 Temperature

The statistical analysis of temperature was based on calculating annual means, standard deviations, absolute differences, and percentage changes between the periods 2002–2007 and 2013–2018 to identify temperature trends in the study area.

The results presented in Table 7 indicate a slight change in the mean annual temperature, which decreased from 19.7°C during the first period to 19.5°C during the second period, representing a change of −1.02%. However, a more detailed analysis reveals that the mean annual maximum temperature decreased by 2.3°C, while the mean annual minimum temperature increased by 1.8°C.

Table 7: Statistical Indicators of Temperature During the Study Periods

Statistical Indicator	2002–2007	2013–2018	Absolute Difference (Δ)	Change (%)
Mean Annual Temperature (°C)	19.7	19.5	-0.2	-1.02
Mean Annual Maximum Temperature (°C)	24.3	22.0	-2.3	-9.47
Mean Annual Minimum Temperature (°C)	15.1	16.9	+1.8	+11.92
Standard Deviation	6.71	7.48	+0.77	+11.48

The standard deviation increased from 6.71 to 7.48, indicating greater thermal variability during the second period. This suggests that climate change in the study area is reflected not only in changes in average temperature but also in the seasonal distribution of temperature, which may influence plant growth and phenological cycles. Seasonal comparison showed that autumn experienced the largest increase in temperature (+2.4°C), whereas winter, spring, and summer recorded slight decreases ranging from 0.8°C to 1.4°C (Table 8).

Table 8: Seasonal Mean Temperatures During the Study Periods

Season	2002–2007 (°C)	2013–2018 (°C)	Difference (°C)
Winter	10.9	9.9	-1.0
Spring	20.1	18.7	-1.4
Summer	27.9	27.1	-0.8
Autumn	19.8	22.2	+2.4

The observed increase in autumn temperatures may contribute to prolonged drought conditions and increased soil moisture loss toward the end of the growing season, thereby negatively affecting natural vegetation and fruit trees.

4.2 Rainfall

The results presented in Table 9 indicate a significant decline in rainfall during the second period. The mean annual rainfall decreased from 11.97 mm to 9.90 mm, representing a reduction of 17.29%. Similarly, the highest monthly rainfall average declined from 40.7 mm to 22.0 mm, reflecting a decrease in rainfall intensity during recent years.

Table 9: Statistical Indicators of Rainfall During the Study Periods

Statistical Indicator	2002–2007	2013–2018	Absolute Difference Δ	Change %
Mean Annual Rainfall (mm)	11.97	9.90	-2.07	-17.29
Highest Monthly Average mm	40.7	22.0	-18.7	-45.95
Standard Deviation	14.24	8.85	-5.39	-37.85

The standard deviation decreased from 14.24 to 8.85, mainly due to the overall reduction in rainfall amounts rather than an improvement in rainfall regularity. The seasonal analysis revealed that the largest decline occurred during winter, when rainfall decreased by 47.7% compared with the first period, a critical finding given the dependence of natural vegetation and rain-fed agriculture on winter precipitation.

Table 10: Seasonal Rainfall Averages During the Study Periods

Season	2002–2007 (mm)	2013–2018 (mm)	Difference (mm)	Change (%)
Winter	30.8	16.1	-14.7	-47.7
Spring	8.8	5.8	-3.0	-34.1
Summer	0.7	0.2	-0.5	-71.4
Autumn	6.8	17.6	+10.8	+158.8

Rainfall also declined during spring and summer, while autumn rainfall increased considerably. However, this increase was insufficient to compensate for the substantial reduction in winter rainfall, resulting in an overall decline in annual precipitation. These findings suggest that reduced rainfall availability, particularly during the winter season, has intensified environmental stress on vegetation resources and rain-fed agricultural systems in Nalut Municipality.

5. Conclusions

The study revealed significant climatic changes in Nalut Municipality between 2002–2007 and 2013–2018, characterized by a decline in mean annual rainfall from 11.97 mm to 9.90 mm (−17.29%) and a substantial reduction in winter rainfall (−47.7%), accompanied by increased temperature variability. These changes have adversely affected natural vegetation and fruit trees, particularly olive trees, as evidenced by reduced vegetation density and signs of drought-related degradation observed during field surveys. The findings confirm a strong relationship between climatic variability and vegetation conditions in the study area and highlight the need for sustainable management of water and vegetation resources to enhance resilience to future climate change impacts.

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