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Article

Change and Human Activities on Date Palm Growth and Distribution in Al-Mamal, Baghdad

Nagham Dawood Salman[1], Raghda Safaa Alddin[2], Baraa Hussein Abdulhadi[3], Reyam Naji Ajmi[4]

1. National Center for Blood Diseases Research and Treatment, Baghdad, Iraq
2. Department of Biology, College of Education for Sciences, University of Diyala, Diyala, Iraq.
3. University of Diyala, College of Science, Department of Forensic Sciences, Diyala, Iraq
4. Department of Biology Science, Mustansiriyah University, Baghdad, Iraq.

*Correspondence: Nagham.dawood24@uomostansiriyah.edu.iq, raghdasafaaalddin@uodiyala.edu.iq, dr.baraahussein@uodiyala.edu.iq, reyam80a@yahoo.com

Abstract: The study was conducted in the Al-Maamel area, east of Baghdad, which represents an urban ecosystem highly affected by human activities, including small industries, indiscriminate burning sites, and unregulated dumping. A stratified sampling design was adopted that included six sites that differed in pollution severity and land uses. Field data were collected over two years with three seasonal campaigns (December, April, September) to evaluate climatic and human influences on the physiological and chemical characteristics of date palm trees (*Phoenix dactylifera L.).* The climatological data recorded over the years 2015 to 2025 revealed an increase in temperature range of 1-1.5 °C with reduced precipitation rates in industrial areas and leschars, leading to higher thermal and water stress on vegetation. The less polluted areas (S1, S5) recorded higher values in terms of vegetation density, coverage, and diversity compared to the polluted areas (S2, S4, S6) as a result of the direct effect on plant communities. On the physiological aspect, there was a considerable decrease in chlorophyll (SPAD) content, biomass, and relative water content in leaves, as well as reduced stomatal conductance in return for enhanced leaf thickness and reduced specific leaf area (SLA) as a result of heat and water stress. On the chemical aspect, palm leaves recorded considerable reductions in the content of starches, total sugars, and proteins as a result of reduced metabolic rates and suppressed photosynthesis driven by stress factors presented by environmental conditions. NDVI analysis revealed considerable reduced values in the polluted area as compared to others. This corresponds to reduced physiological functions and carbon assimilation as a result of stress effects on vegetation. ANOVA and GLM tests supported the existence of significant difference values between different sites, as well as emphasized the influential role played by climatological data on biological functions. These findings indicate the crucial role presented by the relationship established between climate and human stress on the functions and productivity of palm vegetation as an efficient indicator to evaluate stress effects on semi-arid urban environments.

Keywords: Global Warming, *Phoenix dactylifera*, Physiological Stress, NDVI, Applied Climatology.

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1. Introduction

Global warming has been ranked as one of the most prominent environmental issues in the 21st century, which has occurred as a result of the rising levels of greenhouse gases such as carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), and chlorofluorocarbons (CFCs) in the Earth's atmosphere [1]. As these gases accumulated in large quantities, they were able to trap more long-wave radiation emitted from the Earth's surface, and as such, these gases were able to radiate these wavelengths back towards the lower parts of the Earth's atmosphere, which resulted in a global increase in the average surface temperature of the Earth's surface [2]. In accordance with the intergovernmental panel on climate change, there has been an average global surface temperature increase by about 1.2°C since the start of the 20th century, which has occurred partly as a result of human actions such as burning fossil fuel and cutting down forests, and not because of solar activity and volcanic aerosol, which have been proven to have little impact on global climate change [3]. The global climate change has also led to disturbances in ecosystems, which have caused increased rates of temperature on land compared with water, changes in precipitation, and increased drought and heat waves conditions that have remained for a significantly longer period than usual [4], [5]. The above conditions have had direct and indirect impacts on agricultural production, ecological balance, and vegetation, particularly in desert and semi-arid areas, as well as in urban environments [6]. The vegetation has also been ranked as one of the most affected components of ecosystems by changes caused by climate change and human factors; these changes have caused modifications in photosynthesis, respiration, and water balance, which have resulted in modifications in chlorophyll, carbohydrates, and proteins, and have led to a reduction in growth and production as a result of decreased biomass production by vegetation under such conditions caused by climate change and human impacts on natural ecosystems [7], [8]. In this aspect, dates palm tree "Phoenix dactylifera L." has been ranked as one of the most prominent plant species that has environmental and economic importance in arid and semi-arid regions, particularly in Iraqi environments [9]. The expansion in the implementation of industries and construction, which has occurred in large environments such as large industries locations within Baghdad, has also exposed "dates palm tree" species to increased environmental pressures as a result of increased climate and industry pollutants within these environments, which has resulted in increased impacts on these species under these environmental conditions [10]. The above factors and pressures have reflected on the palm tree's physiological and biochemical properties, making dates palm tree a promising environmental indicator that can be utilized for assessing impacts caused by environmental changes within desert and semi-arid ecosystems as well as within urban and industry ecosystems that have increased levels of pollutants as a result of industry impacts within large environments such as large industry locations within Baghdad, which have affected these ecosystems and environmental conditions, particularly desert and arid ecosystems within these environments with increased levels of pollutants that have impacted dates palm objectives of this research are intended to explore the direct and indirect impacts of changes in climate and human action on the growth and physiology and biochemical properties of palm trees within the region of Al-Maamel in Baghdad[11]. It combines application methodologies of climatology with an analytical model of geographical distribution and projections of future climates (CMIP6) [12]. The paper also conducts an analytical comparison between locations of gradient levels of human action and pollution of environment and implementing analysis of variance tests and correlation tests for assessing correlations between environment and physiology and biochemical properties of plants [13]. The setting of this study is founded on the assumption of its hypotheses and takes into consideration these premises:

1. An increase in annual temperatures leads to lower densities of biomass for temperature-sensitive plants.

Phenological processes, like growth, blooming, and biomass, are directly impacted because of rainfall change patterns.

2. Plant species having greater physiological plasticity, stomatal indices, and high chlorophyll indices exhibit better adaptive capability when subjected to heat and water stress.

3. By interfacing and combining applied climatology and climate predictive models, it becomes possible to accurately generate spatial maps that display vegetation and susceptibility to climate change by 12.

The objective of this approach is to establish a scientific platform to determine the extent to which palm trees have been influenced by local changes in the climate and human behavior, which will enable the design of precise bio-indicators for environmental observation and the management of agricultural land under the influence of accelerated climatic changes.

2. Materials and Methods

Study area:

The study was conducted in Al-Mamal District, Baghdad, Iraq, which is one of the critical areas for human-environmental interaction in the governorate. Land use within the district is highly heterogeneous, including residential neighbourhoods, frequent waste burning sites, small craft industries and uncontrolled waste dumps, creating a gradient in pollution intensity that affects vegetation structure and function [14]. The area is located between 32 and 45 meters above sea level, with an almost flat topography that facilitates the accumulation and spread of pollutants. The soil is sandy-clay, moderately fertile, and has limited water holding capacity, making it sensitive to environmental stresses [15]. Six representative sites were identified through a stratified sampling design, which were selected based on land use type and vegetation condition. Their spatial and ecological characteristics are summarized in Table 1, including land use type, elevation, and precise GPS coordinates. This classification reflects increasing anthropogenic pressures from residential sites (S1, S5) to industrial sites and highly degraded landfills (S3, S4, S6) [16]. According to Table 1, these studied areas were selected.

Climatic data:

Daily climate variables, including maximum, minimum and average temperatures, precipitation, relative humidity, wind speed and direction, and solar radiation, were obtained from local meteorological stations and climate records (2015-2025) were analyzed to capture decadal variation, and were validated with ERA5 reanalysis datasets to ensure Its completeness and reliability were conducted during three seasonal campaigns (December, April, and September) [17]. Five to ten trees per site were randomly selected to ensure full representation of the phenological cycle of the Phoenix dactylifer tree [18]. These climate variables were used as inputs for statistical analyzes and species distribution modeling to evaluate the impact of climate fluctuations on date palm growth and physiological traits according [19].

Table 1. Characteristics of Study Sites Land Use and Geographic Coordinates

Site	Land Use	Elevation (m)	Geographic Coordinates
S1	Residential	32	33.3200°N, 44.3500°E
S2	Waste Burning	35	33.3250°N, 44.3550°E
S3	Artisanal Industry	38	33.3300°N, 44.3600°E
S4	Unmanaged Dumpsite	40	33.3350°N, 44.3650°E
S5	Residential	43	33.3400°N, 44.3700°E
S6	Artisanal Industry	45	33.3450°N, 44.3750°E

Table 2 summarizes the main climate variables for the 2015–2025 baselines, showing mean values and standard deviations. The results indicate a gradual trend toward warming of 1 to 1.5 °C, accompanied by decrease in precipitation, especially in sites affected by industrial activities and waste burning. These conditions impose significant water and thermal stress on palm physiology [20].

Field sampling design:

In the six locations, 3-5 permanent quadrats per site have been used to monitor the vegetation changes in conditions of varying degrees of disturbance. These observed variables per vegetation structure square included relative cover (%), plant density (individuals/m²), species richness, and abundance index with physiological and phenological characteristics of date palms, such as plant height, aboveground biomass, phenological phases (bud burst, flowering, fruiting), chlorophyll content (measured by SPAD values and chemical analysis), and conductivity. Stomata, transpiration rate, relative water content (RWC), and osmotic potential with leaf functional traits, such as thickness, specific leaf area (SLA), and dry matter ratios, ensured an excellent dataset for assessing the structural and physiological plasticity of date palms against climatic and human-induced stress conditions [21].

Species distribution modeling and statistical analysis:

Prediction of the distribution of the species P. dactylifera was carried out using different modeling approaches, such as Random Forest, Boosted Regression Trees (BRT), and Random Forest. A combination modeling approach was used for higher reliability. The data was split into 70% for training and 30% for testing, and the reliability of the model was checked by k-fold cross-validation (k = 5-10). The variables used in the model were temperature, rainfall, humidity, soil type, and vegetation/land use type, and these will be presented in the results sections as per [22]. According to research, the trend of variables for the climate and vegetation over the time scale was calculated using the Mann Kendall trend test, and the magnitude of change was measured using Sen's slope, and correlation between the climatic variables and the physiological parameters was carried out for the factors affecting the growth response [23].

Table 2. Summary of Climatic Conditions (2015–2025)

Variable	Mean (2015–2025)	Variability among sites (±SD)
Temperature (°C)	27.8	1.5
Precipitation (mm)	157	25
Relative Humidity (%)	45	6
Wind Speed (m/s)	3.2	1.0
Solar Radiation (W/m²)	210	15

3. Results and Discussion

The research areas exhibited considerable climatic variability; this is reflected in Table 2 below where the temperature, rainfall, and humid conditions were considerably different in the polluted and unpolluted areas. These climatic factors directly influenced the physiological function of the plants in the research areas. From the research findings, the residential areas (S1 and S5) were less impacted by human influence; therefore; plant growth and diversity could thrive when compared to industrial areas and landfills (S2, S4, and S6) [24]. The flat nature of the region influences the concentration of heat and moisture in the region; this directly impacts the physiological processes of the date palms (Phoenix dactylifera L.) due to changes in the concentration of heat and moisture [10]. These results are consistent with previous studies showing that less disturbed urban areas constitute climatic refugia for plants, while intensive industrial activities and unmanaged waste burning reduce plant diversity and productivity [23]. The spatial distribution of sites reflects the impact of human pressures on natural resources, which is critical for land use planning in agricultural and urban environments according to [21]. And compared to the climate variables for the period 2015-2025 from local meteorological stations as in Table 2, including maximum and minimum temperatures, average temperatures, precipitation, relative humidity, wind speed and direction, and solar radiation. ERA5 data were combined to produce high-resolution time series.

There is also a gradual increase in the average annual temperature by 1-1.5 °C, especially in industrial sites and waste dumps (S2, S4, S6), which reflects regional warming trends in Baghdad [25]. This increase has led to an increased frequency of extreme heat days (>35°C), which has imposed significant physiological stress on palm trees. Precipitation patterns showed slight decreases in densely built-up and industrialized areas, suggesting that human activity contributes to local water scarcity and increased drought stress during critical phenological stages [26]. Relative humidity and wind speed remained relatively stable, with slight variations due to land use differences, which affected rates of leaf water loss and transpiration, and solar radiation was high at all sites, which enhanced photosynthetic activity but also increased potential evapotranspiration and thus water stress under high temperatures [27] according to Figure 1,2.

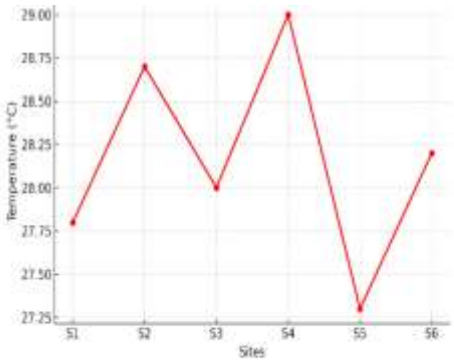

Figure 1. Temporal trends of mean annual temperature (2015–2025), highlighting increases at industrial sites.

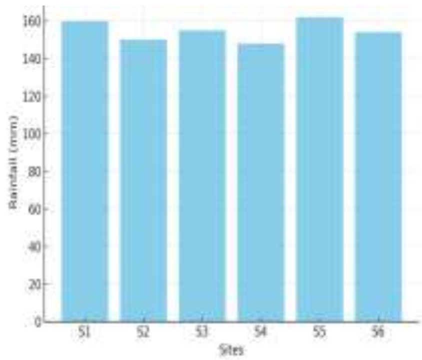

Figure 2. Seasonal precipitation patterns with reductions observed at S2 and S4.

In the Table 3, the reduction in chlorophyll concentration is primarily attributed to heat and drought stress, which disrupts chloroplast structure and pigment stability. Similar declines in starch and protein concentrations indicate an adaptive response to limited photosynthetic activity and increased oxidative stress. These findings are consistent with earlier studies that reported reduced chlorophyll concentration under combined heat and drought stress [26].

Table 3. Vegetation Structure and Date Palm Abundance (Mean ±SD)

Site	**Relative Cover (%)**	**Density (ind/m²)**	**Species Diversity**	**Abundance Index**
S1	65 ±4	4.5 ±0.5	3	0.80
S2	50 ±6	3.2 ±0.4	2	0.60

S3	58 ±5	3.8 ±0.3	3	0.70
S4	42 ±5	2.5 ±0.2	2	0.50
S5	68 ±3	4.8 ±0.4	3	0.85
S6	55 ±4	3.5 ±0.3	2	0.70

Less impacted sites (S1, S5) exhibited higher relative cover, density, and ground coverage, reflecting the positive effect of low human pressure on structural complexity and abundance. Industrial and dumpsite sites showed decreased vegetation indices, indicating habitat degradation and lower resource availability, in line with previous studies [27]. Phenological stages and leaf traits were recorded, with budburst beginning in December (earlier in low-stress sites S1, S5), flowering in April (delayed 2–3 weeks in stressed sites S2, S4), and fruit maturation in September with smaller fruits in stressed areas. Physiological traits including plant height, biomass, chlorophyll content, stomata conductance, leaf relative water content, leaf thickness, and SLA are presented in **Table 4**.

Table 4. Physiological Traits of Date Palm (Mean ±SD)

Trait	S1	S2	S3	S4	S5	S6
Height (m)	4.5 ±0.3	3.8 ±0.2	4.0 ±0.2	3.2 ±0.3	4.6 ±0.2	3.9 ±0.2
Biomass (kg)	18.5 ±1.2	13.2 ±1.0	15.0 ±1.1	10.5 ±0.8	19.0 ±1.3	14.8 ±1.0
Chlorophyll (SPAD)	46 ±3	38 ±2	42 ±2	35 ±2	48 ±3	41 ±2
Leaf Water Content (%)	82 ±3	72 ±2	75 ±2	68 ±2	84 ±3	74 ±2
Leaf Thickness (mm)	0.55 ±0.04	0.65 ±0.05	0.60 ±0.04	0.70 ±0.05	0.53 ±0.03	0.62 ±0.04
SLA (cm^2/g)	18 ±1.5	15 ±1.2	16 ±1.3	13 ±1.0	19 ±1.4	16 ±1.2

Sites with high human pressure (S2, S4, S6) exhibited greater physiological stress, including reductions in biomass, chlorophyll content, leaf water content, and stomatal conductance. Leaf traits showed drought-adaptive modifications, with increased thickness and decreased SLA in stressed sites, reducing water loss under heat and drought conditions [27]. Phenological delays in flowering and fruiting indicate that climatic and anthropogenic pressures negatively affect reproductive success, consistent with previous research [28].

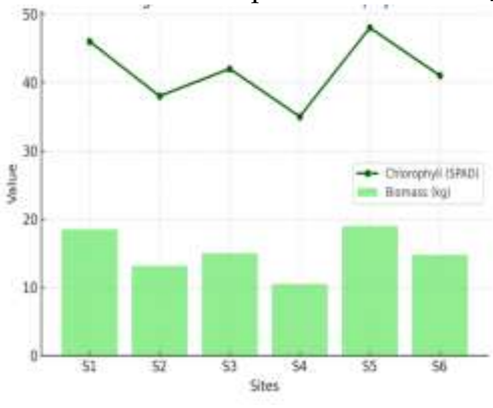

Figure 3. Biomass and chlorophyll variations site, highlighting stress effects.

Leaf contents of chlorophyll, starch, total sugars, and proteins were analyzed across the six sites. Stressed sites (S2, S4, S6) exhibited significantly lower levels compared to less stressed sites (S1, S5) (**Table 5**).

Table 5. Chemical Traits of Date Palm Leaves (Mean ±SD)

Trait	S1	S2	S3	S4	S5	S6
Chlorophyll (mg/g FW)	2.15 ±0.10	1.65 ±0.08	1.85 ±0.09	1.50 ±0.07	2.20 ±0.10	1.80 ±0.09
Starch (%)	12.5 ±0.8	9.0 ±0.6	10.2 ±0.7	8.5 ±0.5	13.0 ±0.9	10.0 ±0.7
Total Sugars (%)	6.8 ±0.4	5.2 ±0.3	5.8 ±0.4	4.8 ±0.3	7.0 ±0.4	5.6 ±0.3
Proteins (%)	3.5 ±0.2	2.8 ±0.2	3.0 ±0.2	2.5 ±0.2	3.6 ±0.2	3.0 ±0.2

Decreased chlorophyll and starch in stressed sites indicate the effect of heat and drought stress on the plant's chemical composition, reducing photosynthetic efficiency and carbohydrate storage [28]. Protein content also decreased in industrial and dumpsite locations, reflecting reduced metabolic activity a direct indicator of environmental stress, these results show a clear link between human pressure and the chemical quality of date palm leaves, consistent with previous studies on the impact of pollution and climatic stress on plant chemistry according **Figure 4 and 5** [29]**:**

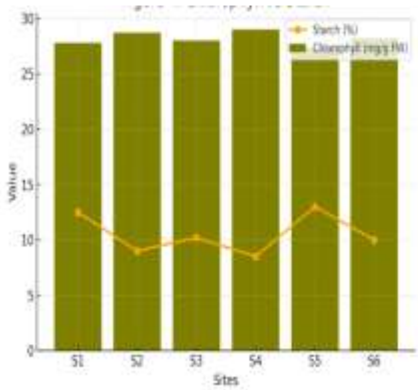

Figure 4. Variation of chlorophyll and starch content across sites.

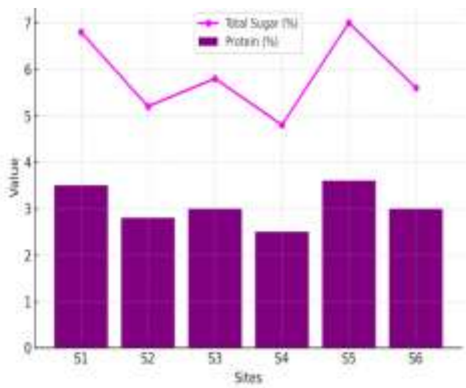

Figure 5. Protein and sugar contents in stressed versus less stressed sites

Measurements included leaf relative water content (RWC), stomatal conductance, leaf thickness, and specific leaf area (SLA). Stressed sites showed lower stomatal conductance and increased leaf thickness in Table 6 and Figure 6.

Table 6. Water Stress Indicators and Leaf Traits (Mean ±SD)

Trait	S1	S2	S3	S4	S5	S6
Leaf Water Content (%)	82 ±3	72 ±2	75 ±2	68 ±2	84 ±3	74 ±2

Stomatal Conductance (mol m⁻² s⁻¹)	0.23 ±0.02	0.18 ±0.01	0.20 ±0.02	0.15 ±0.01	0.24 ±0.02	0.19 ±0.01
Leaf Thickness (mm)	0.55 ±0.04	0.65 ±0.05	0.60 ±0.04	0.70 ±0.05	0.53 ±0.03	0.62 ±0.04
SLA (cm²/g)	18 ±1.5	15 ±1.2	16 ±1.3	13 ±1.0	19 ±1.4	16 ±1.2

Increased leaf thickness and decreased SLA are adaptive responses to conserve water under heat and drought stress reduced stomatal conductance limits water loss but also decreases photosynthetic efficiency, leading to lower growth and biomass [30].

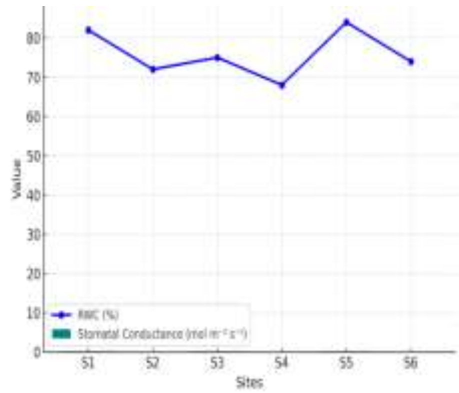

Figure 6. Stomatal conductance and leaf RWC across sites.

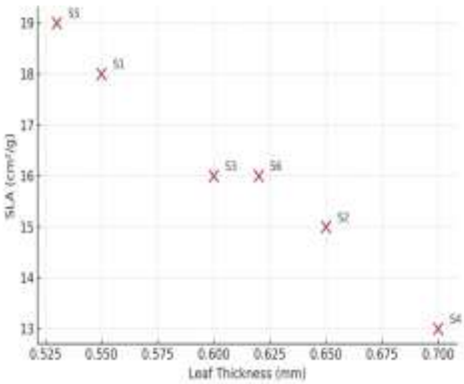

Figure 7. Relationship between SLA and leaf thickness, showing adaptations for environmental stresses.

NDVI value analysis among the sites showed some variation in the health of vegetation. Some palm sites, which experience higher human and climatic factors, recorded low NDVI, thus lesser greenness and photosynthesis. This trend in the pattern indicates the impact of pollution and variation in the climate on the physiological state and production capacity of the date palm, Phoenix dactylifera [31].

Table 7. NDVI and Climatic Variables (Mean ±SD)

Site	NDVI	Mean Temperature (°C)	Precipitation (mm)
S1	0.78 ±0.03	27.5	160
S2	0.60 ±0.04	28.7	150
S3	0.68 ±0.03	28.0	155
S4	0.55 ±0.03	29.0	148

S5	0.80 ±0.02	27.3	162
S6	0.66 ±0.03	28.2	154

According Figure 8 NDVI decreased in stressed sites due to combined effects of high temperatures and reduced precipitation, leading to reduced effective vegetation cover and overall plant health [31]. This confirms that NDVI is an effective indicator for monitoring environmental and anthropogenic stress on vegetation over time.

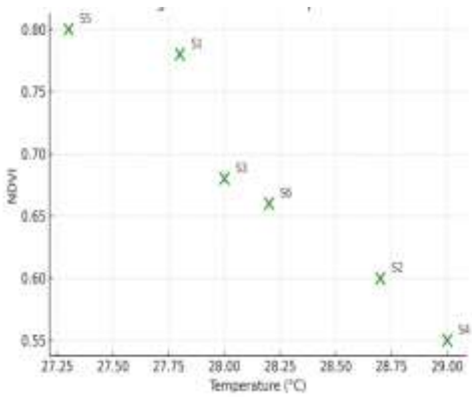

Figure 8. Relationship between NDVI, temperature, and precipitation across sites.

Statistical analysis using ANOVA followed by the Tukey test ($p < 0.05$) confirmed significant differences in physiological and biochemical concentrations between sites. LSD values were included in the tables to indicate the significance of differences among treatment means [32]. Overall, the comparative assessment highlights that both climatic fluctuations and human activities in the Al-Ma'amal area play a crucial role in shaping the physiological, biochemical, and spatial responses of date palm. The integration of climatic data, NDVI indicators, and biochemical concentrations provides a comprehensive understanding of plant adaptation to environmental stressors in Figure 9 [33]

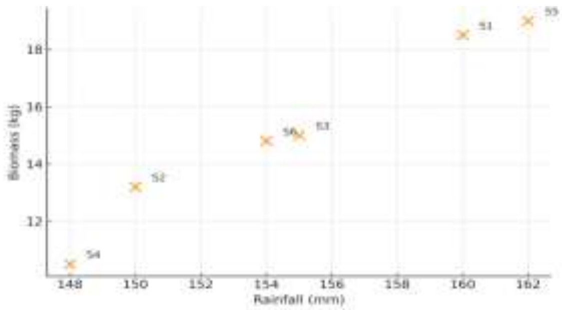

Figure 9. Regression analysis between precipitation and biomass.

NDVI value analysis among the sites showed some variation in the health of vegetation. Some palm sites, which experience higher human and climatic factors, recorded low NDVI, thus lesser greenness and photosynthesis. This trend in the pattern indicates the impact of pollution and variation in the climate on the physiological state and production capacity of the date palm, Phoenix dactylifera [31].

Various human activities (industrial, dumpsites, burning of domestic refuse) have a negative effect on the architecture and physiological health of date palms. Higher temperatures and reduced rainfall enhance the physiological effect of water stress, leading to decreased biomass and reduced levels of chlorophyll. Increased leaf thickness and reduced SLA are generally adaptations to physiological stresses. NDVI is a useful measure in the assessment of physiological health of vegetation impacted by a variety of stresses. The data analyses clearly demonstrate a strong correlation between various climatic parameters and the physiological and chemical properties of date palms.

4. The results revealed that human factors, such as residential areas, craft industries, random burning points, and waste dumps, directly influence the health status of date palm trees and other vegetation. A decline in diversity and vegetation cover emerged in highly affected areas compared to less affected areas, ensuring that human impacts influence the decline in vegetation. Moreover, comparisons between the different sites revealed that environmental changes, such as high temperatures and low rainfall, along with high human influences, influence the physiological and chemical properties of date palm tree vegetation, such as chlorophyll. Starch and protein levels, and the relative water content in the leaf. These influences together hinder tree growth and result in physiological stress for the trees. Environmental changes, such as high temperatures and low rainfall, along with high human influences, influence the physiological and chemical properties of date palm tree vegetation, such as chlorophyll, starch, and protein levels, and the relative water content in the leaf. These influences hinder tree growth and result in physiological stress for the trees.

3. Physiological adaptations of date palm trees. Moreover, date palm trees also demonstrate adaptation to heat stress and drought, such as increased leaf thickness, which results in low specific leaf area (SLA), reducing water loss and improving tolerance to extreme environmental factors. These results demonstrate that there is a certain adaptability for vegetation types under influence from climate and human factors. The results revealed that values for the normalized vegetation index (NDVI) decreased for stressed vegetation areas influenced by high human activity, heat, and drought. This further indicates that vegetation health declines, and date palm tree physiological health also declines due to stress. This further indicates that the index has critical application for monitoring vegetation health under various stress factors. By doing so, this result supports that sustainable management and practices for environmental protection for date palm tree and vegetation types are required in terms of environmental and water management in studied areas influenced by stress from human and climate changes.

4. Conclusion

This study provides robust empirical evidence that the combined effects of climate change and intensified human activities have significantly altered the growth, physiological performance, biochemical composition, and spatial distribution of date palm (*Phoenix dactylifera* L.) in the Al-Maamel area of Baghdad. The findings demonstrate that rising temperatures (by approximately 1–1.5 °C over the past decade), reduced precipitation, and localized anthropogenic pressures—such as industrial activities, waste burning, and unmanaged dumping—collectively exacerbate thermal and water stress on palm vegetation. These stressors were clearly reflected in reduced vegetation cover, biomass, chlorophyll content, carbohydrate and protein levels, stomatal conductance, and NDVI values in highly impacted sites, while less disturbed residential areas maintained comparatively healthier physiological and structural characteristics. The observed increase in leaf thickness and reduction in specific leaf area further indicate adaptive, yet limiting, responses to prolonged drought and heat stress. The integration of field measurements, climatological analysis, NDVI assessment, and advanced statistical modeling confirms the suitability of date palm as a sensitive bioindicator for evaluating environmental stress in semi-arid urban ecosystems. From a practical perspective, the results highlight the urgent need to incorporate climate-responsive land-use planning, pollution control, and sustainable water management strategies into urban and agricultural policies to safeguard palm productivity and ecosystem services. Future research should focus on long-term monitoring, experimental assessment of mitigation measures, genetic and physiological resilience mechanisms of date palms, and the application of predictive climate–vegetation models to support adaptive management under accelerating climatic and anthropogenic pressures

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