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Article

Warm Index and Growing Degree Days as Indicators of Climate Changes for Growth of *Quercus Eagilops* and *Pistacia Khinjuk* Trees in the Dohuk Region

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Abstract: This study investigates the impact of climate change on the growth and vitality of vegetation, specifically focusing on two tree species, Pistacia khinjuk and Quercus aegilops, in dry and semi-dry sites (Dohuk-Sarsink). Climate-induced temperature increases have exceeded the trees' tolerance, leading to physiological changes and reduced productivity. The research aims to assess growth decline and environmental factor changes, using random samples to measure tree morphology (diameter, height, and crown dimensions). The Warm Index (WI) and Growing Degree Days (GDD) were estimated for both sites, revealing suboptimal temperature conditions for tree growth. The results show that current temperatures significantly hinder growth, emphasizing the need for climate-adaptive strategies to support tree development in these regions.

Keywords: Warm Index, Growing Degree Days, Climate Changes, Quercus eagilops, khinjuk Pistacia.

1. Introduction

Climate is one of the environmental elements that control the growth of trees of various types on the surface of the Earth. Its effect appears clearly through temperature and is reflected in the development of tree growth (IPCC 2007). The most important element affecting the temperature rise is the increase in the concentration of carbon dioxide in the atmosphere, as its concentration was 280 ppm approximately 800 years ago. In comparison, its percentage exceeded 380 ppm at present [1]. Many studies have indicated a high correlation between temperature and tree growth [2].

Forests are the most important natural stores of carbon dioxide, which is one of the basic elements in the carbon cycle in nature, and the change in absorption or loss from this cycle at the global level leads to an increase in its concentration, which causes an increase in Temperatures of different locations on the surface of the Earth, including ocean waters and widespread snow melting, as well as the rise in global average temperature, and with a high degree of certainty that greenhouse gas emissions cause a rise in temperatures on the surface of the Earth,(IPCC 2007), the carbon stored in vegetation and soil and its release into the atmosphere in the form of carbon dioxide (CO2) is one of the most important greenhouse gases caused by human activities, and it was also found that temperatures play the most important role in the geographical distribution of forest tree species because each type of tree has specific requirements for temperatures during which it can grow well and the differences in them lead to variations in the growth of these trees, especially during the growth period, and the study area is characterized by representing

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the Mediterranean region [3] Many studies have shown that there is a relationship between tree growth and environmental indicators defined by the (WI) index, which depends on determining both temperatures and relative humidity of the site and the Growing Degree Days (GDD), and through (GDD) and (WI), we estimate the maximum temperature for the growth that the species can tolerate, thus we can measure the thermal range of the studied species [4].

We can predict in the future about the growth of these trees and the suitability of the site's temperatures for their growth and vitality, so we took two types of forest trees with large ages and naturally growing in the (Dohuk-Sarsink) region, which are the green seed tree Pistacia khinjuk and the eating oak tree Quercus eagilops, to study the relationships between the growth of these trees and the indicators of the warm index and the daily growth temperature to estimate the impact of climate change.

2. Materials and Methods

The study area is a mountainous area with high altitudes, and its climate falls within the Mediterranean climate, which is characterized by climatic elements that led to the spread of many species with special characteristics that can grow in dry and semi-dry areas with many plant covers [5], the coordinates of the site under study are at longitude (43° 4' 1.18'') east and latitude (36° 50' 0.17'') north (43° 18' 1.67'') and (37° 1' 29.84'') respectively, and the sites (Dohuk - Sarsink) are located within the mountainous geographical area represented by wide differences in slopes and elevations, which show very different geomorphology ranging between (0-87.9°) and the geomorphological extension of these two sites is subject to secondary geomorphological units, these geomorphological units include the flood plain, the accumulated glacial slope, the alluvial fan, and the mountains, and these geomorphological units on which the city extends range in elevation from (438) m in the flood plains to (1136) m in the mountainous region, while the alluvial fans cover a large area in the area under study, which is located at altitudes ranging between (593.1 - 748.2 m) [6].

The climate of a site represents the long-term weather conditions of the changes occurring in meteorology, mainly represented by temperature rates and rainfall. The temperature of the site is affected by many other factors, the most important of which are topography, elevation above sea level, water bodies, and air currents (Salila et al. 2020), and temperatures in dry and semi-dry areas are climate elements among the most important natural factors affecting the growth, production, and plant distribution of various plant covers and have a high impact on the vitality of forest trees and their development, as trees affect the different properties of the soil. Temperatures play the most important role in the geographical distribution of forest tree species because each type of tree has specific temperature requirements that can grow well and lead to variations in the growth of these trees, especially during the growth period. The study area is characterized by representing the Mediterranean region [7], as in the following table (1).

Table 1. The number of ideal months for growth for temperatures for the two sites (Dohuk and Sarsink) for the years (1900-2020) AD

Year	Sarsink		Dohuk	
	The optimal number of months for growth (20−36)	Number of months of low growth rate (5−20) C°	The optimal number of months for growth (20−36) C°	Number of months of low growth rate (5−20) C°
1900	5-6-7-8-9	3-4-10-11	6-7-8-9	3-4-5-10-11
1910	5-6-7-8-9-10	3-4-11	6-7-8-9	4-5-10-11
1920	5-6-7-8-9	3-4-10-11	6-7-8-9	3-4-5-10
1930	5-6-7-8-9-10	3-4-11	6-7-8-9	3-4-5-10-11
1940	5-6-7-8-9-10	3-4-11	6-7-8-9	4-5-10-11
1950	5-6-7-8-9-10	3-4-11	6-7-8-9	4-5-10-11
1960	5-6-7-8-9-10	3-4-11	6-7-8-9	4-5-10-11
4970	5-6-7-8-9-10	3-4-11	6-7-8-9	3-4-5-10-11
1980	5-6-7-8-9-10	3-4-11	6-7-8-9	4-5-10-11
1990	5-6-7-8-9-10	3-4-11	6-7-8-9	3-4-5-10-11
2000	5-6-7-8-9-10	3-4-11	6-7-8-9	4-5-10-11
2010	5-6-7-8-9-10	3-4-11	6-7-8-9	3-4-5-10-11
2020	5-6-7-8-9-10	3-4-11	6-7-8-9	3-4-5-10-11

*Space source of heat in months and for a century (1900-2022) http://cru.uea.ac.uk Climatic Research Unit (Groups and Centers) for the sites (Sarsink-Dohuk).

Table (1) shows us that the number of months in which there can be good growth in the trees of the Dohuk site is the months (9-8-7-6), while growth declines to its lowest limits in the months (3-4-5-10-11), which are the months that are at the beginning of spring and autumn of the year, while we see in the Sarsink site that the months suitable for growth increase, which are (5-6-7-8-9-10) for the study years for the period from(1900-2022) AD, and decrease in only three months (3-4-11), which are the beginning of spring and the end of the growth period of the year. From the above, we note that the Sarsink site is more suitable for growth compared to the Dohuk site (Ryan, 2010), and the maximum GDD value is estimated based on the Warm Index, which is determined through the following relationship:

$$\text{Warm Index} = -42.379+(2.04901523*T)+(10.14333127*rh) -(0.22475541*T*rh)-(6.83783*10^{-3}*T^2) -(5.481717*10^{-2}*rh)+(1.2287*10^{-3}*T^2*rh) +(8.5282*10^{-4}*T*rh^2)-(1.99*10^{-6}*T^2*rh^2)$$

Where WI = warm index, T = temperature. C°, rh = relative humidity (%), and GDD was calculated using the relationship proposed by Lim (1998).
GDD = 30.838 WI

We have prepared a relationship between (GDD) and (WI) based on the data collected in the field, and from it, we estimate the maximum growth temperature that the species can tolerate, and thus we can measure the thermal range of the studied species (Kim et al. 2017) for Growing Degree Days (GDD) for the Dohuk and Sarsink region for the years (1901-2022) AD. Thus, we know the thermal range in which trees spread in different geographical areas and calculated it through the following relationship (Kauppi et al. 2014)

$$GDD = \sum (T_i - T_b), \text{ when } T_i - T_b > 0$$

Where: T_i = average daily temperature in the year. C, T_b = critical growth temperature, which is estimated at 5 °C and which was recommended by(Kira 1977).

3. Results and Discussion

Temperatures at any location are an important indicator for predicting the annual growth rate of trees. Maximum temperatures lead to evaporation of water from the soil surface, increased transpiration from trees, and thus continuous depletion. If this is not accompanied by a source such as rainfall, this leads to the trees being exposed to physiological death of the plant [8]. Therefore, knowing the temperatures and their distribution is necessary for any region. Temperature data were taken for the sites (Dohuk-Sarsink) to determine the maximum temperatures for these two sites, as [9] in Figures (1) and (2).

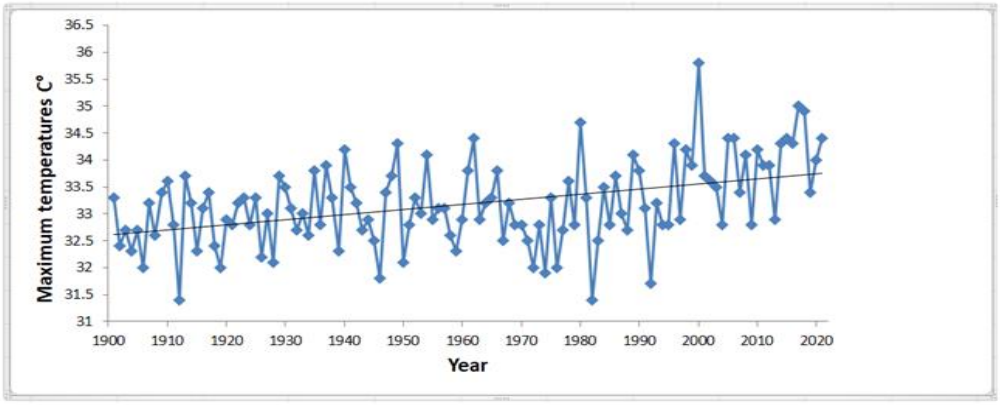

Figure 1. Maximum temperatures and general trend line for the Dohuk site 1900-2022 AD.

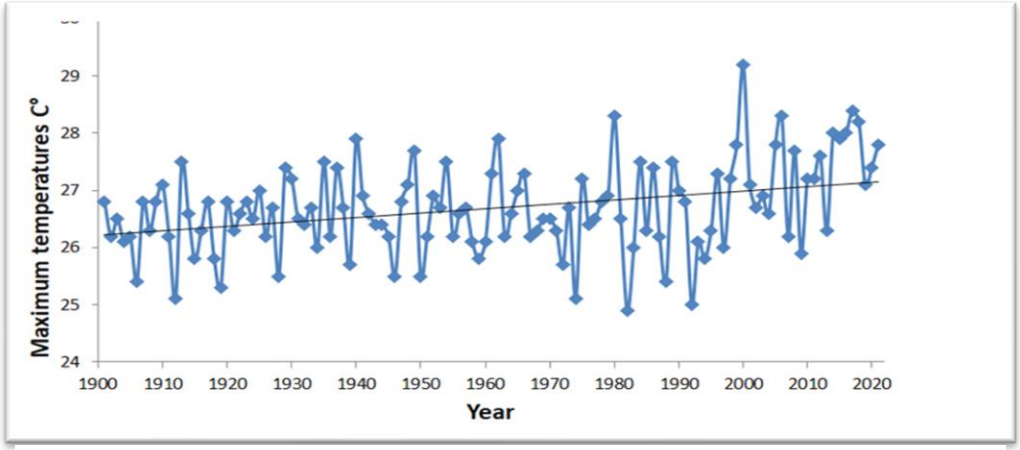

Figure 2. Maximum temperatures and general trend line for the Sarsink site 1900-2022 AD.

We see from Figure (1) that the maximum temperatures are constantly increasing, and this is by observing the temperature trend line for the study years, as we find that in the year (1910) AD it was approximately (32) degrees Celsius, while in the year (2020) AD it was approximately (34) degrees Celsius, which indicates an increase in temperatures by two degrees Celsius, and the general trend of the temperature trend line is increasing for this site, while we note in Figure (4-2) that the maximum temperatures in the site were in the year (1900) AD (26.2) C, but showed a gradual increase with the passage of years, from the above we note that the changes in the maximum temperatures for the two sites (Dohuk - Sarsink) are different.

In the Dohuk site, we note that there is an increase in temperatures estimated at approximately two degrees, while in the Sarsink site, we note that there is an increase of one degree Celsius, so the maximum temperatures range from (35.5-31.5) C for the Dohuk site, while the maximum temperatures for the Sarsink site are from (29-25) m, that is, there is a range of temperatures within which they fluctuate, that is, the maximum temperatures for the Sarsink site are closer to the optimal temperatures required for the trees to grow vitally and develop, while in the Dohuk site we see that they increase above the optimal condition, which affects the vitality and activity of the trees.

From the above, we note that the temperatures are more suitable for the Sarsink site than the Dohuk site [10]. Temperatures impact the development and growth of trees, as they represent one of the important environmental factors, especially in dry and semi-dry areas. They are evidence of the growth and development of trees, and they are also affected by and affect the various site factors. Therefore, we can use them as an indicator to estimate the growth occurring in trees and estimate the amount of their vitality and the physiological processes that occur in them. Therefore, I took the temperature data for the two sites (Dohuk and Sarsink) and the years (1900-2022) and prepared Table(2).

Table 2. Maximum and minimum temperatures and standard deviation for the locations (Dohuk-SSarsink) for the years (1900-2022) AD.

site	Min	Max	Mean	S.D
Dohuk	0.4	35.8	19.51198	9.46404
Sarsink	-8.2	29.2	12.82927	9.56268

We note from Table (2) that the maximum temperatures with a standard deviation (SD) are (9.46404) and (9.56268) for the locations (Dohuk and Sarsink), respectively, meaning that the fluctuation in the maximum temperatures for both locations was not large and was around the axis of the general trend of temperatures observed from figures (2) and (3). The annual growth of trees depends directly on the various climate elements and soil factors, and temperatures come at the forefront of the elements affecting the growth achieved.

Therefore, the growth achieved in successive annual cycles over the years (Al-Bak, 2009) can be estimated based on the Growing Degree Days (GDD), which is a measure of the growth temperature achieved in trees, and we know the daily temperature range suitable for trees to grow naturally in their geographical distribution areas. The growth degree achieved (GDD) depends directly on another specific factor, which is the degree of warmth (Warm Index (WI), which is one of the important measures in calculating the daily growth temperature of trees).

This depends on the relative humidity ratio present in a location in addition to the temperatures of that location. Therefore, it was estimated Both the degree (WI) and the relative humidity of the study sites were based on climatic data, and then (GDD) was determined through mathematical equations, including what was done by Lim 1998), and from that, we determined the maximum growth temperature that the species can tolerate, and thermal range of the studied species [11], and through the above, table (3) was prepared.

Table 3. The Growing Degree Days (GDD) and the warm index (WI) for the distribution area of Pistacia khinjuk and Quercus eagilops in the two sites (Dohuk and Sarsink).

SP.	site	Growing Degree Days that species can tolerate for optimal growth			Growing Degree Days that species can tolerate for optimal growth		
		WI	GDD	Range of location	WI	GDD	Range of location
Pistacia spp	Dohuk	50.12-810.93	1542.29-25007.74	22175.3-22915.7	111-617	3433-19037	719.09-743.10
	Sarsink	-810.93 78.07	2407.54-25007.74	20509.3-22429.0	154-640	4758-19748	665.06-707.58
Quercus eagilops	Dohuk	50.12-810.93	1542.29-25007.74	22175.3-22915.7	111-617	3433-19037	719.09-743.10
	Sarsink	−810.93 78.07	2407.54−25007.74	20509.3− 22429.0	154− 640	4758− 19748	665.06− 707.58

Table(3) shows a relationship between temperature and growth in trees. To know the Growing Degree Days for the Dohuk site, the Warm Index (WI) was estimated and ranged between (50.12-810.93) m, from which the GDD obtained in the Dohuk site was estimated to range between (25007.741542.29-). Likewise, both (WI) and (GDD) were estimated for the Sarsink site to range between (810.93-78.07) m and (25007.74-2407.54), respectively. This represents periods for the different years in which the *Pistacia khinjuk* and *Quercus eagilops* trees grew in both sites. Therefore, we see in them different periods in the needs of these trees for good growth.

There were years in which GDD was suitable, while others may not be suitable for good growth. Therefore, we calculated the GDD required by these trees. Species for optimal growth based on the temperature data required these species to grow better, the (GDD) and (WI) were estimated for such cases as these two species need. For the Dohuk site, the optimal (WI) was (111-617) m and the (GDD) value was (19037-3433), while for the Sarsink site, both (WI) (640-154 m) and (GDD) (19748-4758) (The estimated truth for both (WI) and (GDD) with the optimal, we notice that there is a discrepancy between these values, especially for (GDD) required by the species, where we see an increase in temperatures to reach its maximum range (25007.74), while in the optimal cases, the maximum growth degree was (19037) [12].

There is a wide difference in the temperatures available in the site, which affects growth, especially if we know that these sites are dry and semi-dry sites that lack moisture. Rainfall, which was measured at the Sarsink site, is the same as what was mentioned, which linked the warmth index to the daily growth temperature of trees. By using the mathematical model prepared by(Kira 1977), which estimates the degree of warmth, the degree of warmth was estimated for the sites (Dohuk-Sarsink) and the different periods extending from the year 1900 to 2022 AD. Thus, we can measure the Growing Degree Days (GDD) throughout the study period for years for a century. From this, the relationship between the GDD for the sites (Dohuk-Sarsink) and the years was prepared, as in Figures(4) and (5) [13].

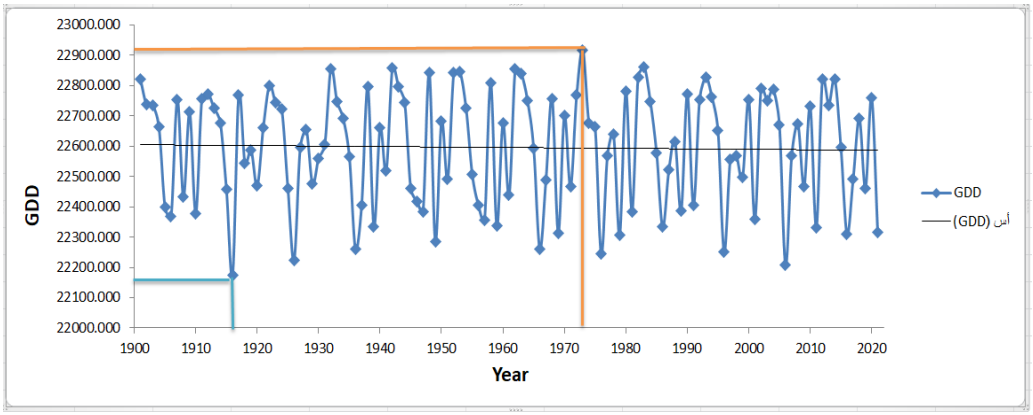

Figure 4. The relationship between Growing Degree Days (GDD) and the years (1900-2022) AD for the Dohuk region.

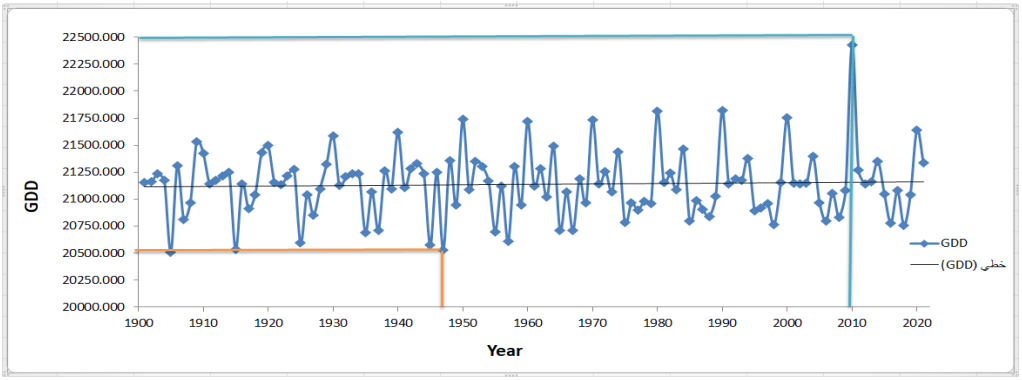

Figure 5. The relationship between Growing Degree Days (GDD) and the years (1900-2022) AD for the Sarsink region

From Figure (4) we learn about (GDD) for *Quercus eagilops.* and *Pistacia khinjuk* trees growing on the site, which shows that the maximum daily thermal range was (22920.000) which was in the year (1972) AD, while the lowest daily thermal range was in the year (1916) AD (22160.000) and we notice that there is a fluctuation in (GDD) between these two ranges throughout the years from (1900-2022) AD and that the general trend line of the data is almost straight and located in the middle and notice from the general trend an increase and decrease in the trend, which indicates that this site is their continuous in terms of (GDD) and therefore it meets the requirements of these two types within the acceptable thermal range that they need for growth and development [14].

Figure (5) shows the relationship between (GDD) and the years from 1900-2022 AD for both types, *Pistacia khinjuk* and *Quercus eagilops*, which can be observed that (GDD) ranges in The site has a minimum value of (22175.3-22500.0) in the year 1948 AD and a maximum (GDD) of (22915.7-22950.0) in the year 2010 AD. We notice that the temperature fluctuations are more stable in this site and for a narrow or small temperature range around the axis of the general trend of the growth requirements for this site and that there is a limited fluctuation in specific years such as (2010-1990-1980-1970-1960-1950-1940) AD, where it is represented by an increase in (GDD). We also notice in other years temperature ranges below the average and for almost the same periods and an increase in the fluctuation in the stability of (GDD) as the number of years increases, which indicates that temperatures are taking on increases, but slightly around the general trend of temperatures.

4. Conclusion

The study reached many graphs and tables to estimate the changes in temperatures, and it was shown to us from Growing Degree Days (GDD) that they meet the requirements of these two species within the acceptable thermal range for growth, but it was noted that the Sarsink site was less fluctuating during the study years and more stable in the thermal range than the Dohuk site, and it also indicates that there is a negative effect of high temperatures on the growth of trees in that site, which is far from optimal.

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