ORIGINAL ARTICLE

STUDY OF LONG –TERM CLIMATIC CHANGES EFFECTS ON CEDAR OF LEBANON (*Cedrus libani* A. Rich) STANDS (SYRIA) USING REMOTE SENSING TECHNIQUES

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ABSTRACT

Background: Climatic changes have a strong influence on the forest ecology, the eastern coast of Mediterranean is one of the most sensitive regions to climatic change in the world, especially for forests and the distribution of their species. **Objectives:** This research aimed to assess the impact of two climatic factors changes (temperature, rainfall) on *Cedrus libani* on the Syrian coast (Slenfeh, Jaobet_Berkal, Qadmous and Dweer- Ruslan) during the period 1960-2010. **Methods**: The indicators of analysis, range and trend of changes for temperature and rainfall were determined during the period 1960-2010 at the seasonal and annual scales, the drought was also evaluated using the Standardized Precipitation Index (SPI) during the same period. The growth of *Cedrus libani* stands was estimated using the Normalized Difference Vegetation Index (NDVI), which was obtained from the MODIS images during the period 2001-2010. Regression models were established between temperature averages, rainfall amount and (Standardized Precipitation Index) SPI on the one hand, and with NDVI on the other hand, which was calculated for the growth season at different temporal scales. **Results:** The analyses showed a significant increase in the average of annual temperature only in Qadmous and a significant seasonally increase in summer temperature for all sites, however the Autumn, Winter in Qadmous and Spring in Jaobet_Berkal were no significant. The annual rainfall has decreased significantly in Slenfeh and Jaobet_Berkal, while the seasonal analyses have shown a significant rainfall decrease in Spring in all studied sites, and only on winter at Jaobet-Berkal and in Summer at Slenfeh. The results have shown an ascending trend line for annual drought in Slenfeh Jaobet- Berkal and Qadmous. And a negative effect of increasing in temperature average of February and July, January- February, February- March, and January- February- March on natural *C. libani* stands growth in Slenfeh. In the others sites (Jaobet-Berkal, Qadmous and Dweer- Ruslan) there were no significant effects of the temperature change on the artificial *C. libani* stands growth. There was also no significant effect of the rainfall change on *C. libani* stands growth in all studied sites. It was observed that the increasing of humidity in January and December had affected positively the growth in Slenfeh and Jaobet- Borkal, while the increasing of humidity in the Autumn had a positive effect on stands growth in Slenfeh **Conclusion:** It was essential to identify the effect of climatic changes on one of the most important patrimonial species in Syria, so this study represents a key step to determine the difficulties which *C. libani* stands face to survive.

Keywords: *Drought, rainfall, temperature, cedar of Lebanon (Cedrus libani), Normalized Difference Vegetation Index (NDVI), Standardized Precipitation Index (SPI).*

1. INTRODUCTION

The effects of climatic changes on forests vary with geographical zone and the climatic conditions of regions; these affect the distribution of forest types, growth, regeneration and mortality [1]. Recent studies have indicate that there has been a shortage in rainfall between 1960-1990 in the Mediterranean regions, and an increase in temperature between 1.5 and 4 °C over the past 100 years [2]. According to these studies, the rainfall is expected to be about 20-25% below the current average in 2050 in the north Africa, parts of Saudi Arabia, Iran, Syria and Jordan, as well as the temperature would rise between 2 and 2.75°C in the interior areas and about 1.5% in the coastal areas [3].

In the past, cedar of Lebanon (*Cedrus libani* A. Rich) is confined to the eastern Mediterranean basin, it had been forming large forests in Syria, Lebanon and Turkey, which have been an important source of wood for successive human civilizations [4]. After centuries of overexploitation, it remained only small populations [5], which have been isolated since the last fourth ice age [6] to be threatened or on the way to extinction since the 19th century according with National records [7]. The *C. libani* is restricted to high mountainous areas, cedar forests extend over a discontinuous range composed of widely separated regions, generally found at altitudes between 800 and 2100 m, where the annual average temperature ranges from 6 to 12 °C and annual mean precipitation ranges from 600 to 1200 mm with a drought period during summer [8, 9]. Today, Cedar forests constitute 3% of Mediterranean forest in which about 2% are protected, perhaps Climate change can destroy most of the remaining *C. libani* forests [1].

The complex interactions between climate and vegetation at large spatial and temporal scales limit the effectiveness of field methods in studying the impact of climate change [10]. Remote sensing technology have advanced in recent years and increase the accuracy and efficiency of collecting information about forest background and can be used to monitor the terrestrial ecosystems and can help to estimate the effect of climate change on vegetation. Different vegetation indices, as the Normalized Difference Vegetation Index (NDVI), are used to estimate the forest stands growth for a certain time period.

2. MATERIALS AND METHODS

2.1 Study site: Cedar of Lebanon does not constitute pure forests in Syria, but it forms small scattered populations in the Syrian coast. The study was carried out in four of the most important sites (Fire and cedar reserve, Jaobet_Berkal, Mawla Hasan and AL-Nabi Matta) (Figure 1). These sites are situated at altitudes between 750 and 1100m, the annual mean precipitation ranges from 1200- 1500mm with a drought period during summer, the annual average temperature ranges from 12 to 14°C, and the average minimum temperature ranges 4 to 7 °C, while the average high temperature ranges from 20 to 22 °C. The *C. libani* stands were found on brown soil placed on calcareous or basaltic rocks. The Mean Annual Increment (MAI) of theses stands varies from 11 to 14 m^3 /year. The presence of *C. libani* varies according to studied site (Table 1).

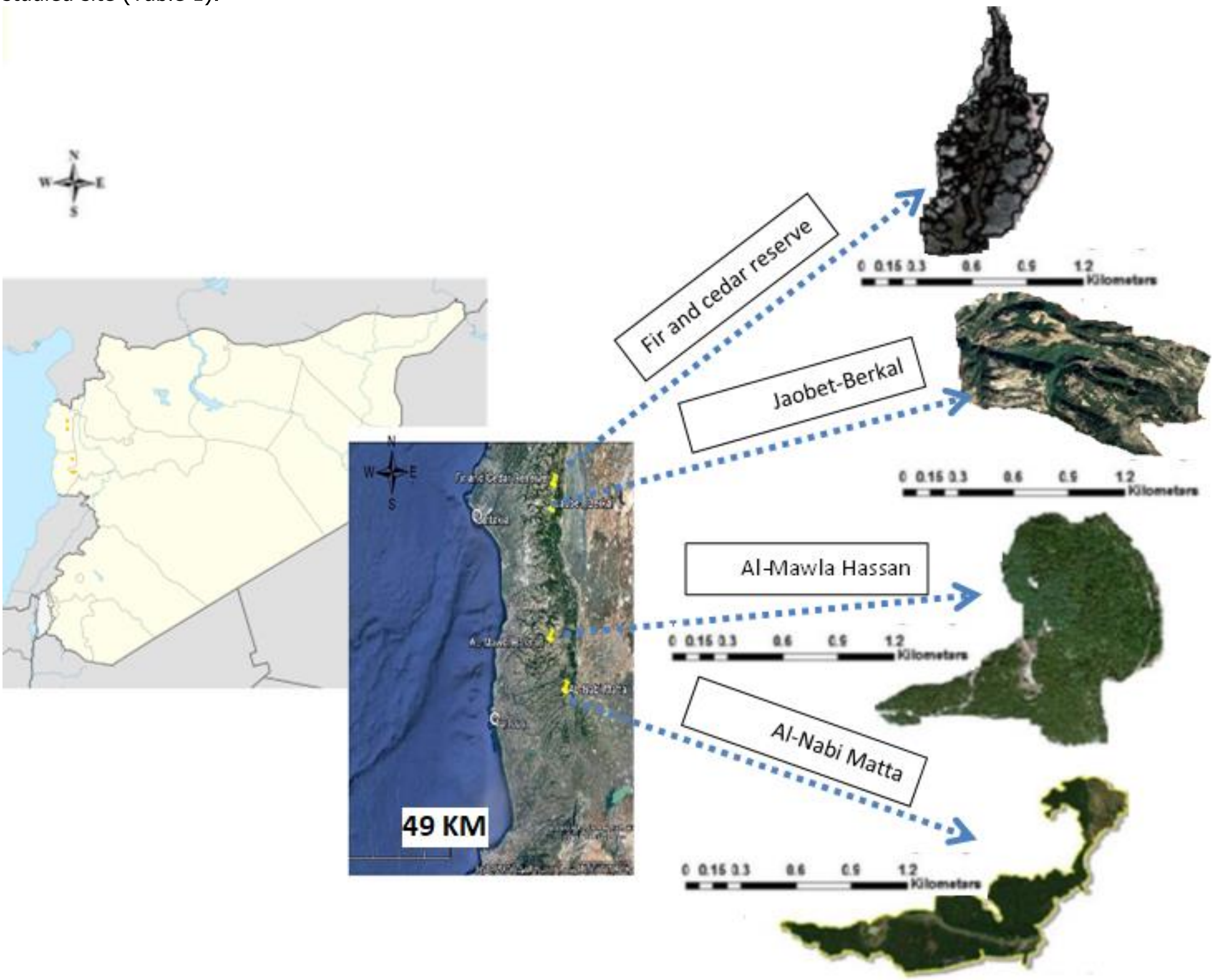

Figure 1: The figure presents most important sites of *C. libani* in the Syrian cost.

Table 1: The presence percentage of *C. libani* in studies sites

***C. libani* site**	**Presence percentage of *C. libani* in the site**
Fir and cedar reserve	60-90 %
Jaobet_Berkal	40-70 %
AL-Nabi Matta	65 %
AL-Mawla Hassan	40 %

2.2 Estimating the temperature and rainfall changes: The average monthly temperature and monthly rainfall data for the period 1960-2010 for the meteorological stations of Slenfeh, Jaobet-Berkal and Qadmous, which represent the Fire and cedar reserve, Jaobet_Berkal and AL-Mawla Hasan sites were used, while only the monthly rainfall data for Dweer-Ruslin meteorological station (represent Al-Nabi Matta site) was available for the period 1984-2012. The tends and ranges of change in average temperature and rainfall were estimated at seasonally and annual scales for the studied periods using the simple linear regression.

2.3 Estimating drought index: The monitoring of the meteorological drought was performed by the analyze of Standardized Precipitation Index (SPI) at the base of rainfall data. The SPI can be defined as the number of standard deviations by which a normally distributed random variable deviates from its long-term mean and can gives a better representation of abnormal wetness and dryness periods. The term drought is not related only with low rainfall, as well as the term humidity is not related only with high rainfall but also related with the distribution of rainfall in the accumulation periods [11]. The SPI can be used to characterize meteorological drought on a range of timescales, on short timescales, the SPI is closely related to soil moisture, while at longer timescales, the SPI can be related to groundwater and reservoir storage. The SPI values show the characteristics of succession of the drought and humidity periods in a station, thus, any abnormal change in the rainfall characteristics of this station, will give a conclusion that there is or is no drought in that area [11]. The SPI index is used to determine the number of dry years on a given time scale, and to identify anomalous dry periods. It is also used to compare different stations with different locations at the same time. This index allows to estimate drought intensities at different temporal scales (1,3 ,6 ,9 ,12 and 24) months according to the Table 2:

Table 2: Values of the Standardized Precipitation Index (SPI) index and correspondent drought intensities [11].

SPI Values	Drought tolerances
2 ≤	Extreme Moisture
1.5 -1.99	Very wet
1-1.49	Average humidity
(-0.99)-0.99	Close to normal
(-1)-(-1.49)	Moderate dryness
(-1.99)-(-1.5)	Severe drought
-2 ≥	Extreme dryness

SPI: Standardized Precipitation Index.

2.4 Estimating growth of *C. libani* stands: the normalized difference vegetation index (NDVI), which is calculated using satellites images, is recently used to represent the forest stands growth in many studies [12, 13]. It is computed by the Eq. (1).

$$NDVI = \frac{NIR - R}{NIR + R} \quad (1)$$

Where: NIR is the near infrared spectral wavelength, and R is the red spectral wavelength.

The NDVI values for the studied sites were obtained from MODIS images (250m) for the period 2001-2010. The mean of annually, seasonally and monthly NDVI values were calculated.

2.5 The effect of changes in temperature, rainfall and drought on *C. libani* stands: Regression models were established between the mean NDVI index calculated for the studied *C. libani* stands, in the growing season (up May to July), during the period 2001-2010. The average temperature, total rainfall and SPI at different temporal scales (monthly, seasonally, annually and at 2 to 5 month) were computed for the studied sites for the same period.

3. RESULTS AND DISCCUSION

Estimating of temperature and rainfall changes: The Result have shown an increase in average annual temperature in Slenfeh and Jaobet_Berkal, and a significant increase in Qadmous during the studied period. The amount of change was 0.03, 0.004, and 0.027 °C per year for Slenfeh, Jaobet_Berkal and Qadmous, respectively (Figure 2, Table 3). At seasonally scale, average temperature has significantly increased in winter, spring and has insignificantly deceased in autumn in Slenfeh. In Jaobet berkal average temperature has significantly increased in winter and has significantly decreased in summer, while there was a significant increase in average temperature during Spring and Summer in Qadmous. Jalab et al. (2014) showed that there is an increase in average annual temperature of 1.98 °C in Slenfeh during the period 1978-2011, this confirm the warming which has happened in Slenfeh in the last three decades [14].

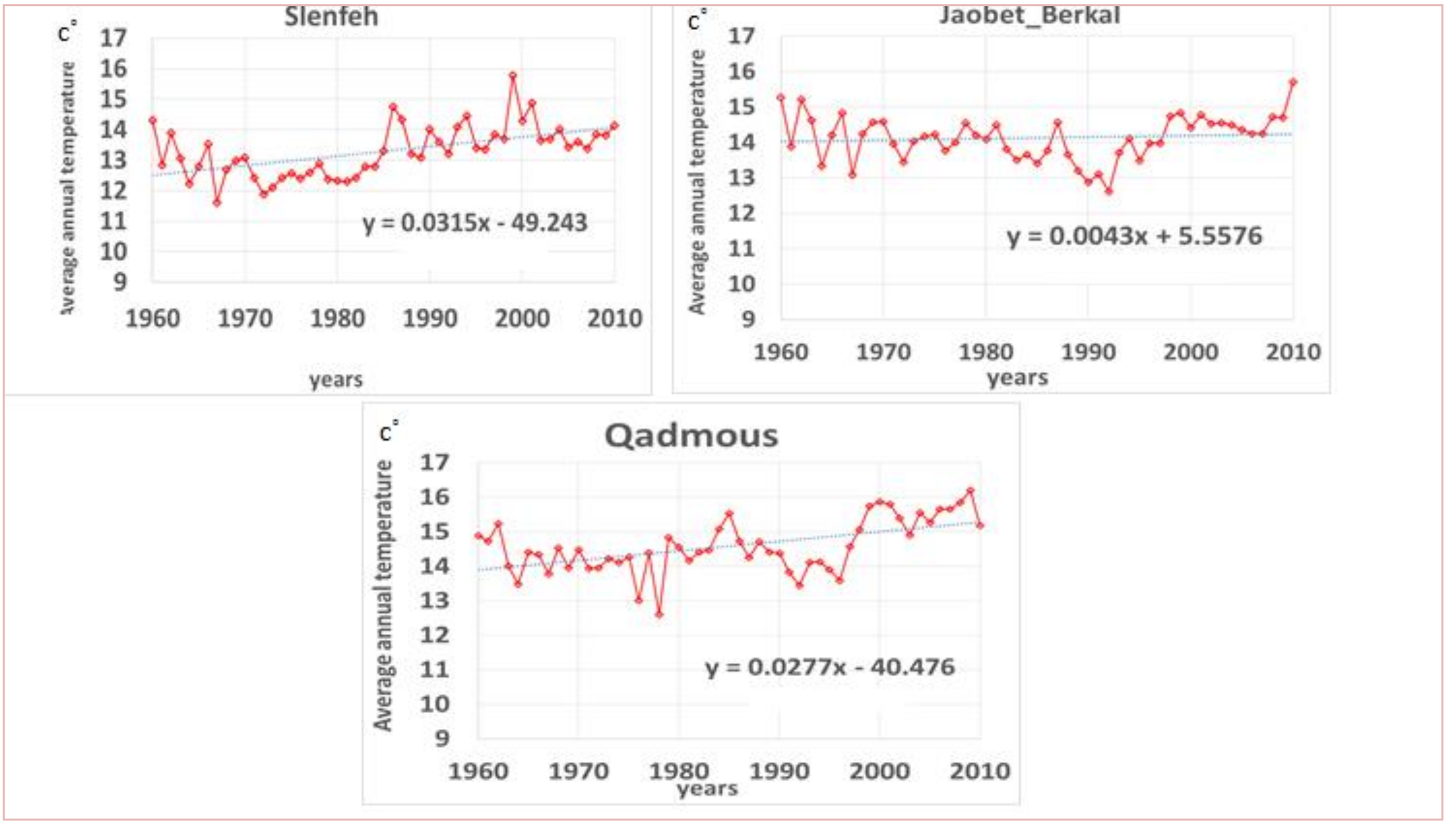

Figure 2: The figure presents the trends and ranges of change in the mean annual temperature in Slenfeh, Jaobet_Berkal and Qadmous stations during the period (1960-2010).

Table 3: Trends and ranges of change in average temperature at seasonal and annual scales in studied stations.

Meteorological station	Winter	Spring	Summer	Autumn	Annual
Slenfeh	0.05*	0.02*	0.02*	-0.13	0.03
Jaobet berkal	0.07*	0.01	-0.05*	-0.01	0.00
Qadmous	0.02	0.02*	0.04*	0.02	0.03*
Dwer-rislan	-	-	-	-	-

* Significant at P = 0.05

Albert et al. (2008) indicate a dominant negative rainfall tendency in the Mediterranean region over the past 50 years [15]. This corresponds to our results, which show a remarkable decrease in average annual precipitation in all studied stations (Figure 3), this decrease is significant in both Slenfeh and Jaobet- Berkal, it is about 7.93 mm and 9.73 mm per year respectively (Table 4). It was noted that the precipitation of Winter has significantly decreased in only Jaobet-Berkal, whereas the precipitation of Spring has significantly decreased about 3.39, 4.03 and 3.44 mm per year in Slenfeh, Jaobet-Berkal and Qadmous respectively. in Autumn, the decrease in rainfall was not significant at all stations. Conversely to Jalab et al., (2014) that showed an annual insignificant increase in rainfall about 3.28 mm/year, and significant increase in Winter in Slenfeh during the period 1978-2011 [14].

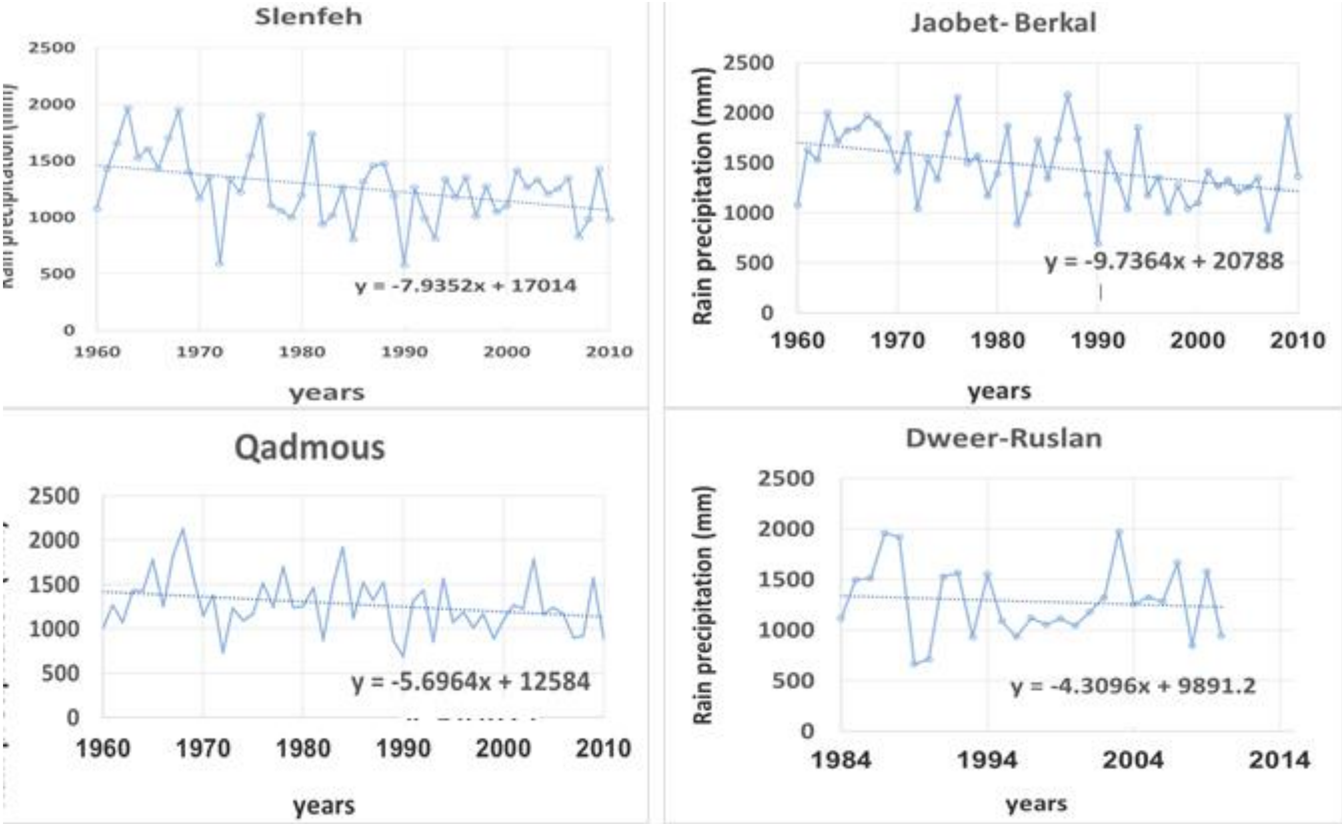

Figure 3: The figure presents the annual precipitation time series and corresponding interpolated regression lines in Slenfeh, Jaobet_Berkal, Qadmous during the period (1960-2010), and Dweer-Ruslan during the period (1984-2012).

Table 4: Trends and ranges of change in rainfall at seasonal and annual scales in Slenfeh, Jaobet_Berkal, Qadmous during the period (1960-2010), and Dweer-Ruslan during the period (1984-2012).

Meteorological station	Winter	Spring	Summer	Autumn	Annual
Slenfeh	-3.23	-3.39*	-0.42*	-0.89	-7.93*
Jaobet berkal	-5.48*	-4.03*	-0.13	0.01	-9.73*
Qadmous	-2.63	-3.44*	0.10	0.27	-5.69
Dwer-rislan	1.99	-0.02	0.48	1.81	- 4.31

* Significant at P= 0.05

Seasonal and annual drought frequency: Rainfall quantity and its temporal variability, as well as temperature changes, affect the drought intensity and frequency, which greatly affect the forest growth and species distribution [14]. Drought coefficients were calculated on the basis of SPI and then characteristics of drought (intensity, duration and frequency) were analyzed. The result showed that the relative frequency of drought - in Jaobet-Berkal- was the highest among the studied stations, where it was 20 % during 50 years, while it was 16%, 12% in Slenfeh, Qadmous respectively (Table 5). In Dwer-Ruslan the drought frequency was calculated for 28 hydrological years and it was 14% (Table 5). Figure 4 shows a positive trend of annual drought in the four meterological stations, the decreasing rate of the SPI values was the highest in Jaobet-Berkal (0.0297), then in Qadmous (0.0263), and (0.0236) in Slenfeh and finally 0.014 in Dweer-Ruslan .

Table 5: The Drought frequency according to SPI index in studied stations during the period 1960-2010.

Staion	Temporal scale	Drought class			Frequency drought	Relative Frequency (%)
		Moderate	severe	extreme		
Slenfeh	Annual	5	2	1	8	16
	Autumn	6	2	1	9	18
	Winter	2	2	1	5	10
	Spring	4	1	2	7	14
Jaobet-Berkal	Annual	7	2	1	10	20
	Autumn	5	5	0	10	20
	Winter	5	1	3	9	18
	Spring	6	1	1	8	16
Qadmous	Annual	3	2	1	6	12
	Autumn	6	1	2	9	18
	Winter	3	4	0	7	14
	Spring	5	3	1	9	18
Dweer-Ruslan	Annual	3	1	0	4	14
	Autumn	7	1	0	8	29
	Winter	1	0	2	3	11
	Spring	2	2	1	5	18

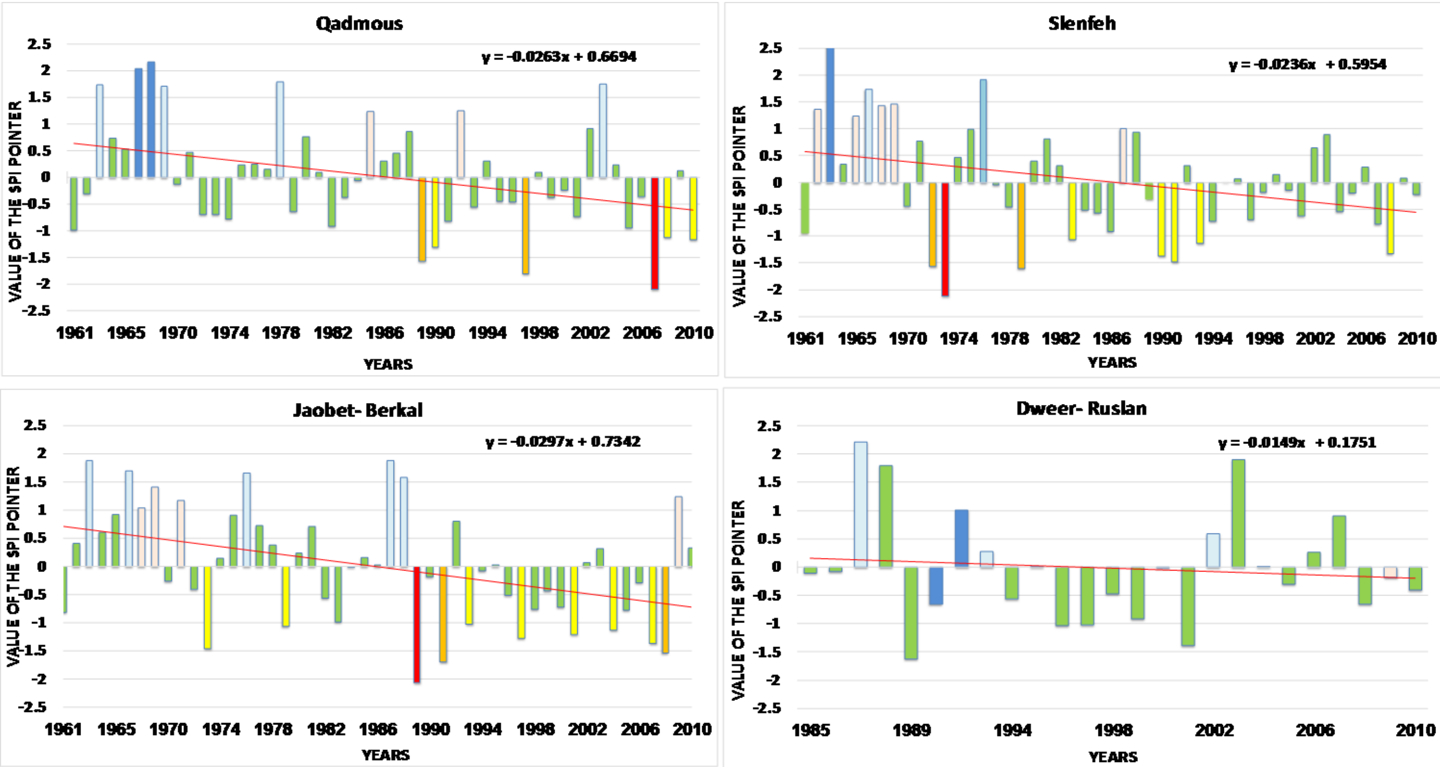

Figure 4: The figure presents the trend of annual drought change in the study stations (Slenfeh, Jaobet-Berkal, Qadmous), during the period (1960-2010) and Dweer- Ruslan during the period (1960-2010) at. (Green: the years close to the natural, Yellow :the years with moderate drought, Orange: the years of severe drought, Red: years of extreme drought)

The Growth of studied *C. libani* stands during the period 2001-2010: to study the growth of *C. libani* stands**,** the NDVI index was calculated during the period 2001-2010. Our results indicate that the values of NDVI for all studied sites have annually changed but insignificantly. They have decreased in the both of the AL-Nabi Matta and AL-Mawla Hassan during the studied period, when it has increased in Jaobet_Berkal and Slenfeh (Table 6).

Table 6: Trend and significance of Normalized Difference Vegetation Index (NDVI) values change in the studied sites during 2001-2010.

Studied Site	a	Signification
Slenfeh	0.0038	Not significant
Jaobet berkal	0.0012	Not significant
AL- Nabi Matta	-0.0017	Not significant
AL -Mawla Hassan	-0.0056	Not significant

a: Regression slope coefficient.

Effect of temperature and rainfall change on *C. libani* stands growth in studied sites: Regression models were established between mean NDVI calculated for studied *C. libani* stands in growth season, two factors of climate change (temperature and rainfall) at different temporal scales (monthly, seasonally, annually and at 2 to 5 months). The results showed a significant negative regression between NDVI and average temperature change in Slenfeh in February, July and October, also in January- February, February- March and January- February- March in Slenfeh (Table 7), this indicate that the augmentation of average temperature of February during the period 2001-2010 has a negative effect on growth of *C. libani* stands, that can be explained by the fact that the cold weather in February and October is very important for the growth of theses stands. Conversely the rise of monthly average temperature in July will expose *C. libani* stands to hydric stress, and thus affect their growth. In Slenfeh we found a significant negative affect of temperature increase on the growth of studied stands at annual and seasonally scales for Winter and Autumn (Table 7), this corresponds to other studies that confirm the need of *C. libani* to cold Winter [1, 16]. In the others sites (Jaobet-Berkal, Al-Mawla Hassan and Al-Nabi Matta) there were no significant effect of temperature change on *C. libani* growth (Table 7). This is due to the low biomass of these stands, where it was previously observed a decrease in NDVI value in both Al-Mawla Hassan and Al-Nabi-Matta during the studied period, and the growth of Jaobet-Berkal stands was three times lower than Slenfeh (Table 6). In addition, the area where *C. libani* is spread and the percentage of its canopy cover was greater in Slenefeh than the other sites. The results showed also no significant effect of the rainfall change on *C. libani* growth in Slenfeh, or in the other sites except Al-Mawla-hassan; where there was a significant positive effect of rainfall in August (Table 7).

Table 7: The significance of regression model between temperature, rainfall and NDVI in studied sites during 2001-2010**.**

Temporal Scale	Slenfeh		Jaobet-Berkal		Al-Nabi-Matta		Al- Mawla - Hassan	
	T	R	T	R	T	R	T	R
January	0.02	0.00	0.00	0.00	-	0.00	0.00	0.00
February	**-0.01***	0.00	0.00	0.00	-	0.00	0.01	0.00
March	0.00	0.00	0.00	0.00	-	0.00	0.02	0.00
April	0.01	0.00	0.00	0.00	-	0.00	0.01	0.00
May	0.02	0.00	0.00	0.00	-	0.00	-0.03	0.00
June	0.00	0.00	0.00	0.00	-	0.00	0.02	0.00
July	**-0.03***	0.01	0.00	0.00	-	0.00	0.00	0.00
August	0.006	-0.001	0.004	0.001	-	-0.001	-0.008	**0.001***
September	-0.01	0.001	0.006	0.00	-	0.00	-0.006	0.00
October	**-0.017***	0.00	0.001	0.00	-	0.00	-0.001	0.00
November	-0.005	0.00	0.003	0.00	-	0.00	0.003	0.00
December	0.015	-0.001	-0.001	0.00	-	0.00	-0.009	0.00
January-February	**-0.02***	0.00	0.00	0.00	-	0.00	0.01	0.00
February-March	**-0.01***	0.00	0.00	0.00	-	0.00	0.02	0.00
March-April	0.00	0.00	0.00	0.00	-	0.00	0.02	0.00
April-May	0.04	0.00	0.00	0.00	-	0.00	-0.03	0.00
May-June	0.01	0.00	0.00	0.00	-	0.00	0.00	0.00
June-July	-0.02	0.01	0.00	0.00	-	0.00	0.02	0.00
January-February-March	**-0.02***	0.00	0.00	0.00	-	0.00	0.03	0.00
February-March- April	-0.02	0.00	0.00	0.00	-	0.00	0.02	0.00
March-April-May	0.06	0.00	0.00	0.00	-	0.00	0.02	0.00
April-May-June	0.02	0.00	0.00	0.00	-	0.00	0.00	0.00
May-June-July	-0.01	0.00	0.00	0.00	-	0.00	0.00	0.00
January-February-March-April	-0.03	0.00	0.00	0.00	-	0.00	0.03	0.00
February-March-April-May	-0.03	0.00	0.00	0.00	-	0.00	0.02	0.00
March-April-May-June	0.03	0.00	0.00	0.00	-	0.00	0.02	0.00
April-May-June-July	-0.01	0.00	0.00	0.00	-	0.00	0.00	0.00
January-February-March-April- May	-0.04	0.00	2.00	0.00	-	0.00	0.03	0.00
February- March-April-May-June	-0.03	0.00	0.00	0.00	-	0.00	0.02	0.00
March-April-May-June-July	-0.02	0.00	0.00	0.00	-	0.00	0.02	0.00
Winter	**-0.033***	0.00	-0.001	0.00	-	0.00	-0.002	0.00
Spring	0.062	0.00	0.004	0.00	-	0.00	0.017	0.00
Summer	-0.004	0.00	0.001	0.00	-	0.00	0.017	0.00
Autumn	**-0.027***	0.00	0.005	0.00	-	0.00	0.0022	0.00
Annual	**-0.074***	0.00	0.004	0.00	-	0.00	0.015	0.00

* Significant at P= 0.05; **T**= Temperature; **R**= Rainfall.

Effect of drought on *C. libani* stands growth: Results showed a significant regression between SPI and NDVI in January and May at monthly scale, and in Autumn at seasonally level in Slenfeh (Table 8), this means that the higher the humidity in January, and in Autumn, the higher the growth is positively affected in studied stands. In May the relationship between SPI and NDVI was reversed, high humidity in May had a negative impact on growth. For other sites, there was non-significant regression between the two indices at all temporal scales, except in December in Jaobet-Berkal (Table 8), some studies have explained that when precipitation is abundance to grow at some time, and increase in precipitation will decrease temperature, which is not good for vegetation growth, especially during the growth season [17].

Table 8: Significance of regression model between SPI and NDVI in studied sites during 2001-2010.

Temporal Scale	Slenfeh	Jaobet-Berkal	Al-Nabi-Matta	Al-Mawla - Hassan
January	**0.03***	0.00	0.035-	0.00
February	-0.013	-0.001	0.02	0.01
March	0.01	-0.005	-0.003	0.00
April	-0.013	0.00	-0.018	0.00
May	**-0.038***	0.00	0.02	-0.004
June	0.02	0.00	-0.048	-0.019
July	0.11	-0.028	-0.041	0.00
August	-0.006	-0.004	-0.004	0.015
September	0.008	-0.001	0.005	0.003
October	-0.006	0.002	0.009	0.004
November	0.021	0.004	0.011	-0.004
December	0.023	**0.006***	-0.005	-0.01
January- February	0.03	-0.004	-0.001	0.02
February- March	-0.007	-0.005	0.01	0.01
March- April	-0.000	-0.004	-0.009	0.00
April- May	-0.032	0.00	-0.004	0.00
May- June	-0.021	0.00	0.01	-0.007
June- July	0.04	0.00	-0.110	-0.021
January- February- March	0.04	-0.008	-0.003	0.02
February- March- April	-0.013	-0.004	0.00	0.01
March- April- May	-0.021	-0.003	-0.005	0.00
April- May- June	-0.023	0.01	-0.024	-0.001
May- June- July	-0.030	-0.006	0.01	-0.011
January- February- March- April	-0.026	-0.006	-0.010	0.01
February- March- April- May	-0.032	0.005	0.01	0.01
March- April- May- June	-0.012	-0.001	-0.013	0.00
April- May- June- July	-0.029	0.01	-0.038	-0.002
January- February- March- April- May	-0.006	-0.007	-0.016	0.01
February- March- April- May- June	-0.026	-0.004	-0.022	0.01
March- April- May- June- July	-0.013	-0.002	-0.018	0.00
Winter	-0.008	0.0002	0.016	-0.007
Spring	-0.022	-0.003	0.002	-0.007
Summer	0.007	0.00	-0.015	0.025
Autumn	**0.032***	-0.004	-0.002	0.001
Annual	0.016	0.001	0.007	0.032

* Significant at P= 0.05

4. CONCLUSION

Regression models between NDVI and climate variables are effective tools to explore forest ecosystem response to climate change. This study analyzed NDVI, temperature, rainfall and drought changes and examined the effects of these variables on growth of *C. libani* for 3 different sites in Syrian coast during the growing seasons (May to July) of the period 1960-2010, and for fourth site during the period 1984 -2012 at monthly, seasonally, annually and at 2 to 5 months. In Slenfeh, the average temperature increasing was not significant at annual scale, but significant in seasonal scale, of Spring, Summer and winter. In the other hand, the annual precipitations decreased significantly, and there was a significant decrease in rainfall in Spring and summer, there was also a significative effect of temperature changes on the studied *C. libani* stands growth, while there was no impact of rainfall change on growth stands. In the other sites, no effect of temperature and rainfall changes on the growth index was observed due to the low coverage and density of the *C. libani* trees. Finally, this study was a key step to identify the difficulties that the Lebanese cedar in Syria confronts to survive.

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