Climate Changes and Trends in Rainfall and Temperature of Nablus Meteorological Station

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ABSTRACT

The available water resources in the West Bank, Palestine are limited and insufficient to meet the domestic and agricultural water demands. The climate in the West Bank is dominated by a high temporal and spatial variation. The characterization of climate changes in the West Bank is a preliminary step to assess the status of the water resources in terms of utilizable quantities. This will enable the development of an integrated framework to manage these resources. Rainfall and temperature magnitudes and patterns are of great importance to understand the climatic changes and trends in the West Bank. This characterization enhances the management and development of the water resources under climate change conditions. As a first step, a trend analysis of long-term rainfall and temperature data for Nablus Meteorological Station (NMS) was carried out. Nablus city has a Mediterranean semi-arid climate which characterized as hot and dry in the summer, mild and wet in the winter. This paper employs the fundamental statistical concepts and trend analysis to characterize rainfall and temperature data series for the period from 1975 to 2011 of NMS.

In the analysis of rainfall, it was proved that rainfall of NMS is of high variability where the annual rainfall approximately varies between 335 and 1,400 mm with an average of 654 mm. The overall trend of rainfall is towards a wetter climate, with an estimated increase of about 48 mm in the entire studied period. Two period, averaging 600 mm and 697 mm respectively were detected from fluctuation in rainfall. The trend of the first period (1975-1991) is towards a drier climate, whereas the trend of the second period (1992-2011) is towards a wetter climate. Time series of the SPI depict that in 21 out of 36 years there was a drought in Nablus city while extreme drought did not take place during the last 36 years.

In the analysis of temperature, the temperature variability among years was proved, with a standard deviation of 0.8 ^{o}C and average of 18.4 ^{o}C. The annual mean temperature changes of NMS are characterized by a warming trend. Since 1975, there has been an increase in the annual mean temperature of about 1.8 ^{o}C/36 years (≈ 0.05 ^{o}C/year). The use of cumulative deviations detected two main periods in the temperature of Nablus city. A relatively cool period from 1975 until 1992 has been followed by the warm period on record from 1997 to present.

It was concluded that the changes in climate of NMS are considerable and largely affect the sustainable yield of the water resources in the West Bank.

Keywords: Climate changes; Rainfall; Temperature; Trend Analysis; Semi-arid; Water resources.

1 INTRODUCTION

It is widely accepted that the anthropogenic production of greenhouse gases will cause many changes in the natural environment. The most noticeable of these changes are on the climate, for example increased mean global temperatures and modified precipitation distributions [1]. Climate change and global warming are worldwide recognized as the most significant environmental dilemma the world is experiencing today [2]. Studies have confirmed that global surface warming is occurring at a rate of 0.74 ± 0.18 °C over 1906–2005 [3]. Impact of climate change in future is quite severe as given by IPCC reports which signify that there will be reduction in the freshwater availability because of climate change. This has also been exposed that by the middle of 21st century, annual average rainfall will be decreased by 10–30% [2]. Various researchers have contributed to the study of climate trends and changes [4-8] with long term data. Study of different time series data have proved that trend is either decreasing or increasing, both in case of rainfall and temperature.

For the Middle East, expected higher future temperatures will increase evapotranspiration and changes in climate patterns that might reduce rainfall in the region as a whole [1]. On the other hand, an increase in extreme daily rainfall and a decrease of annual rainfall is a widely accepted prediction for the Eastern Mediterranean region [9]. A climate change study in Israel (Historical Palestine) concluded that by 2020, mean temperature will increase of 0.3-0.4^{o}C and reduction in precipitation by 2% to 1% whereas by 2050, mean temperature will increase of 0.7-0.8^{o}C and reduction in precipitation by 4 % to 2% [10].

In general, the Mediterranean climate is branded by the irregularity of its rainfall, which may intensify water stress in certain periods, together with the existence of a period of water deficit [11]. This deficit is high in arid and semi-arid regions, where precipitation is highly variable in time, space, amount and duration [12]. Drought is a consequence of a reduction over an extended period of time in the amount of rainfall that is received, usually over a season or more in length. However drought has to be perceived as natural part of climate under all climatic regimes. It occurs in high as well as low rainfall areas [13].

Nablus City is the central city in the West Bank, Palestine, in terms of its industrial, commercial and political importance. The city is under semi-arid conditions as characterized by its natural water resources scarcity, low per capita water allocation and conflicting demands on its shared water resources. This scarcity has led to the limited availability of water and the dire need to manage these resources.

This paper carries out a trend analysis of the long-term rainfall and temperature data for the NMS. The major objective of this work is to study rainfall and temperature change in Nablus from data set for the period 1975-2011. It is aimed to give detailed information on rainfall and temperature data of Nablus, to reveal the nature and magnitude of trends and the change points and significant wet/dry periods and warming/cooling in data series of NMS.

2 STUDY AREA

Nablus city is located in the northern part of the West Bank, approximately 52 km east of the Mediterranean Sea and 60 km north of Jerusalem with an elevation of 570 m above mean sea level (see Error! Reference source not found.). More than 135,000 inhabitants live in Nablus City [14]. In Nablus governorate which has a total area of 158,022 hectares, there are different major land use classes including built-up areas, settlements, military areas, natural reserves, forests, cultivated areas, industrial and commercial. The city has a Mediterranean semi-arid climate which characterized as hot and dry in the summer, mild and wet in the winter. The winter rainy season is from October to April in the city. Rainfall events predominantly occur in autumn and winter and account for 90% of the total annual rainfall events. The average annual rainfall is 654 mm. The average mean daily temperature ranges from 24.4 ^{o}C in summer to about 9.6 ^{o}C in winter. The monthly average relative humidity ranges between 51% and 67%. The evaporation rate is particularly high in the summer due to strong insulation. Evaporation greatly exceeds the rainfall in the period from April to October [15].

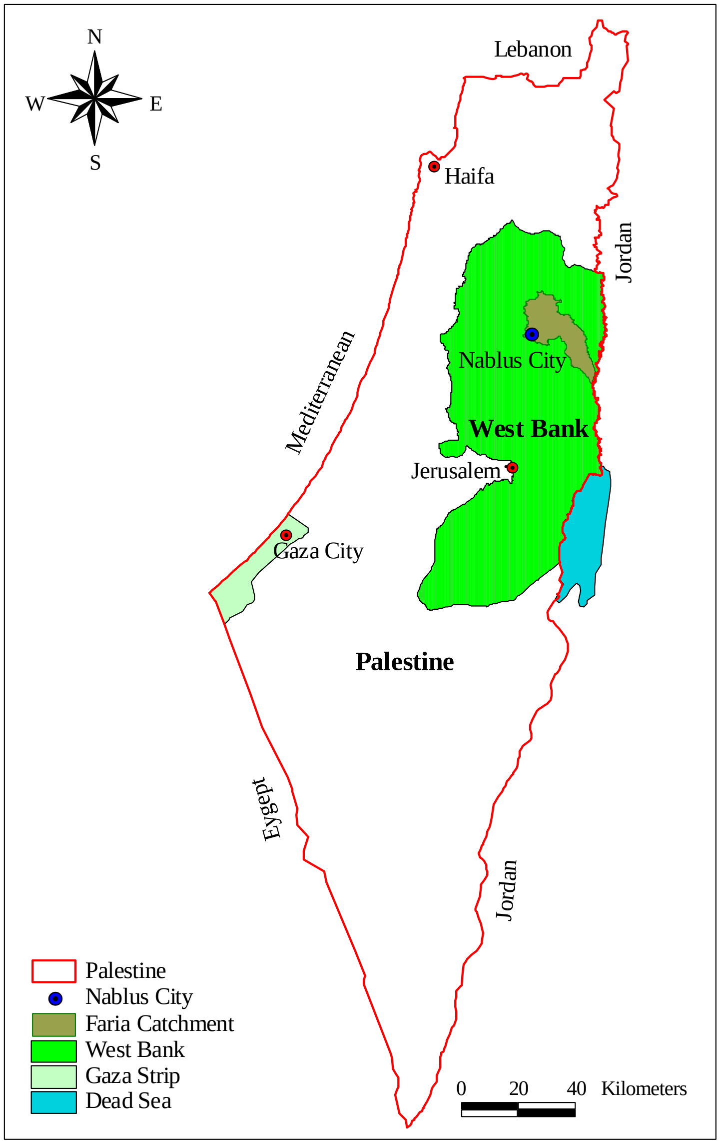

Figure 1: Regional location map of Nablus city

3 METHODS AND DATA ANALYSIS

3.1 Data Collection and Methods

The rainfall and temperature data used in this study for NMS were obtained from the Palestinian meteorology office (PalMet). NMS is a standard weather station in which most climatic data are measured. Continuous daily rainfall and temperature data for this station is available since 1975. Temperature data is missing for the period from 1992-1996. Annual and seasonal rainfall and temperature data were computed from the available daily data. Rainfall and temperature data analyses were made for the hydrological year from the 1st of September to 31st of August [16]. The database was maintained in a spreadsheet format that is accessible by MS Excel for ease of analysis and manipulation.

To understand temporal climatic variability or change of rainfall and temperature in Nablus City, basic statistical analyses were firstly conducted on the annual and seasonal rainfall and temperature data including the annual and seasonal mean, median, standard deviation, minimum and maximum measurements. To test whether the annual rainfall and temperature data follow a normal distribution, the skewness and kurtosis were computed.

Trend analysis was conducted for detecting climate change for both rainfall and temperature. The cumulative sums of deviations were calculated over the 36 years period, in order to analyze non-abrupt changes in the rainfall and temperature series and differentiate wet/dry or warming/cooling periods. The t-test was used to check whether decreasing or increasing trend (climate change) significant or not.

Finally, drought analysis was conducted on rainfall data by utilizing the Standardized Precipitation Index (SPI). Accordingly, drought severity was classified into mild drought, moderate drought, severe drought and extreme drought. The frequency of drought, dry, normal and wet years was also estimated.

3.2 Annual and Seasonal Rainfall

3.2.1 Basic Statistical Analysis

Basic statistical analyses were conducted on the annual and seasonal rainfall data including the annual and seasonal mean, median, standard deviation, skewness, kurtosis, minimum, maximum and range measurements. **Table 1** summarizes the basic descriptive statistical measures of annual and seasonal rainfall data.

Table 1: Descriptive statistics of annual and seasonal rainfall data

Parameter	Annual	Fall	Winter	Spring	Summer
Mean (mm)	653.7	90.7	435.9	127.0	0.1
Median (mm)	623.5	72.9	372.3	118.6	0.0
Standard Deviation (mm)	205.0	66.2	180.2	81.9	0.2
Skewness	1.5	1.5	2.1	0.5	5.0
Kurtosis	4.1	2.8	6.4	-0.6	26.6
Minimum (mm)	335.4	5.3	240.7	0.0	0.0
Maximum (mm)	1402.4	289.8	1161.1	302.4	1.4
Range (mm)	1067.0	284.5	920.4	302.4	1.4

From the table, it can be inferred that the mean annual rainfall of NMS is 654 mm and the median is 624 mm. This indicates that the annual rainfall values are skewed to the right. Skewness and kurtosis indicate that the rainfall data do not follow a normal distribution. The high standard deviation values can be easily correlated with the high rainfall range. The rainfall range signifies the difference between the maximum and minimum annual rainfall. The standard deviation and the range indicate the temporal variability of annual rainfall and hence denote how reliable the rainfall is in terms of its persistence as a constant and stable replenishing source.

3.2.2 Trend Analysis

Error! Reference source not found. depict the annual and seasonal time series of rainfall data. Apparently, high oscillation in the annual and seasonal rainfall values can be observed which in turn reflects the temporal variability and uncertainty in the replenishment of local water resources. From Error! Reference source not found. **(a)** it can be inferred that more than twice of the average annual rainfall was occurred in the year 1992 where 1402 mm was recorded. This is the maximum rainfall that occurred during the last 36 years. From Error! Reference source not found.**2** it can be seen that, over the entire period, winter has the highest amount of rainfall. It is worthwhile to note that the winter rainfall (see Error! Reference source not found., **c**) correlates well with the annual rainfall (see Error! Reference source not found., **a**). For instance, more than 80% of the rainfall for the year 1992 (1402 mm) occurred in the winter time. On average, winter rainfalls accounts for around 70% of annual rainfalls whereas rare rainfall events occurred in summer.

The trend of annual rainfall (see Error! Reference source not found., **a**) is towards a wetter climate, with an estimated increase of about 48 mm in the entire studied period (36 years). The winter series (see Error! Reference source not found., **c**) showed a similar increasing trend of annual rainfall, whereas decreasing trend was observed for fall and spring rainfalls (see Error! Reference source not found., **b** and **d**). The t-test confirmed that the positive trend observed is significant with a 95 % confidence limit for all seasons.

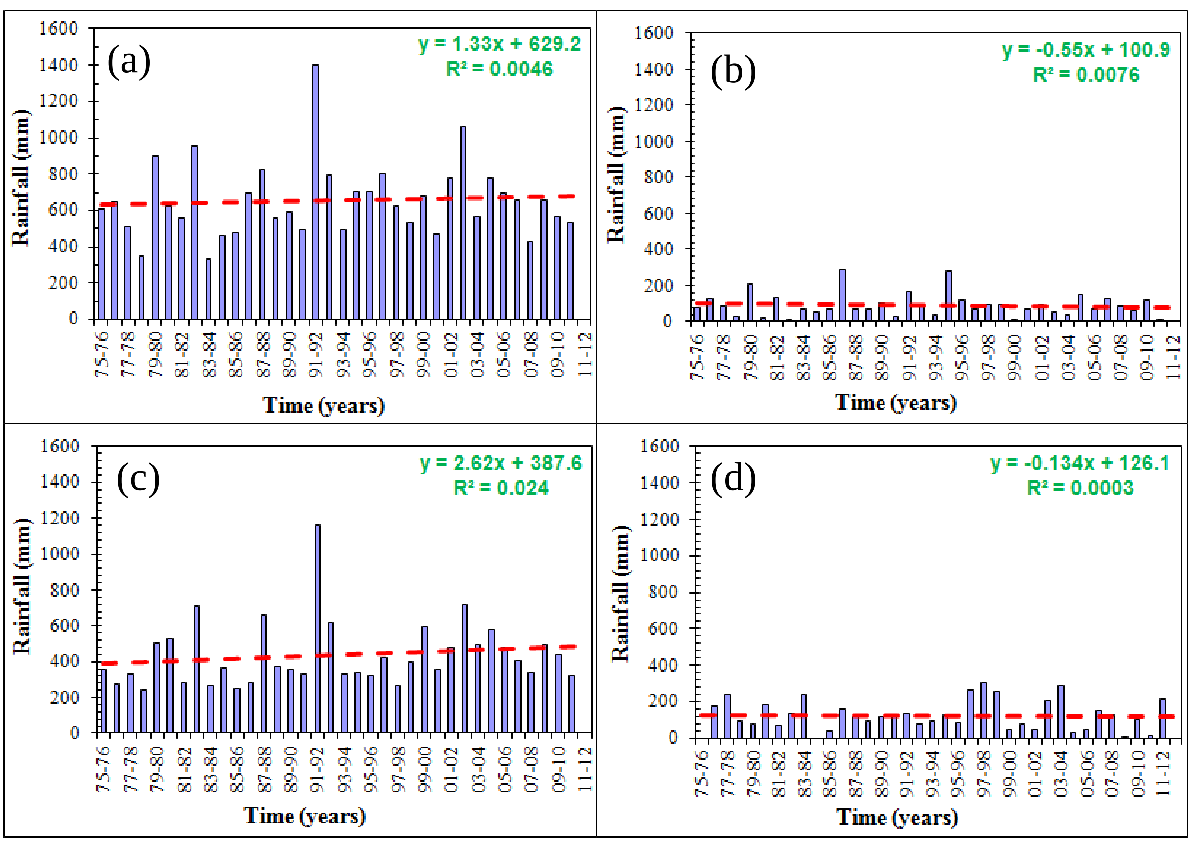

Figure 2: Linear trends over the annual and seasonal rainfall; (a) Annual; (b) Fall; (c) Winter; and (d) Spring

For a better understanding of inter-annual variability, the cumulative sums of annual rainfall deviations are plotted as depicted in Error! Reference source not found.. From the figure, two periods are detected: 1975-1991 and 1992-2011. The trend of the first period is toward a drier climate, whereas the trend of the second period is towards a wetter climate. This means that Nablus rainfall is periodic in the essence that dry period are followed by wet period. A t-test found significant (α = 0.05) decrease and increase for the two periods respectively.

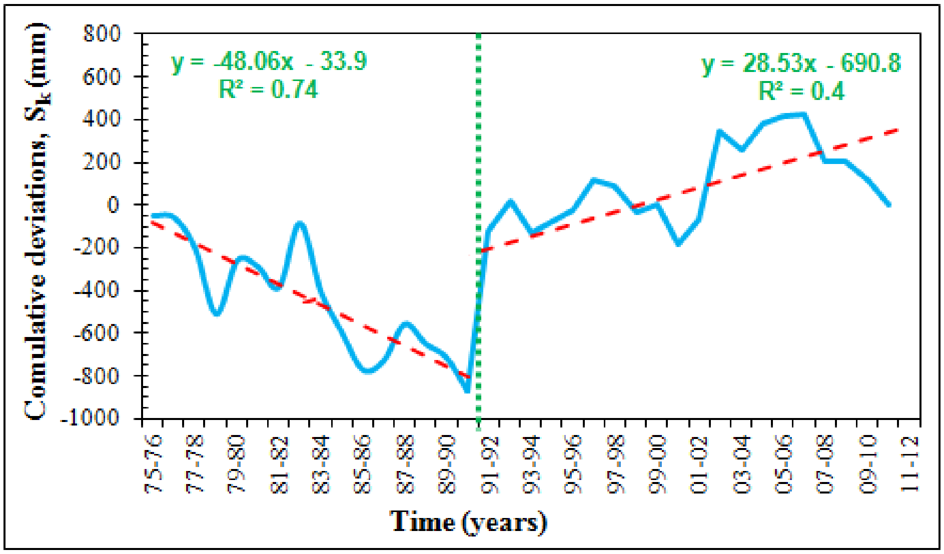

Figure 3: Cumulative sum of deviations from mean annual rainfall

3.2.3 Drought Analysis

Rainfall was used in drought index calculations where rainfall variability indices were used to identify droughts and to establish some arbitrary values for drought identification. These simple indices with rainfall as the only input perform comparatively well compared to more complicated indices in depicting periods and density of droughts [17].

Meteorological drought is frequently described in terms of drought indices, which are convenient and relatively simple to use. One of them is the Standardized Precipitation Index (SPI) which we utilized in this study. The SPI is a dimensionless index where negative values indicate drought and the positive values indicate wet conditions. SPI is calculated by taking the difference of the precipitation from the mean for a particular time step, and then dividing it by the standard deviation as in the following equation [18]:

$$SPI = \frac{x_i - \bar{x}}{\sigma} \quad (1)$$

The SPI was calculated for annual rainfall data and the result is depicted in Error! Reference source not found.**4**. From the figure it is clear that the annual rainfall of Nablus city varies with time, whereas the upward and downward movement of the graph corresponds, respectively, with those of the above and below average rainfall. Moreover the dry and wet years are related to this variation. However, the figure indicates that in 21 out of 36 years there was a drought in Nablus city.

Drought severity was classified to four intervals of SPI values as follows: less than -0.99 is mild drought, between -1 and -1.49 is moderate drought, between -1.5 and -1.99 is sever drought and greater than -2 is extreme drought [18]. According to this classifications it was found that mild drought occurs in 18 out 36 years, in 2 out of 36 years there was a moderate drought, and in 1 out of

36 years there was a sever drought. Extreme drought did not occur during the last 36 years in Nablus.

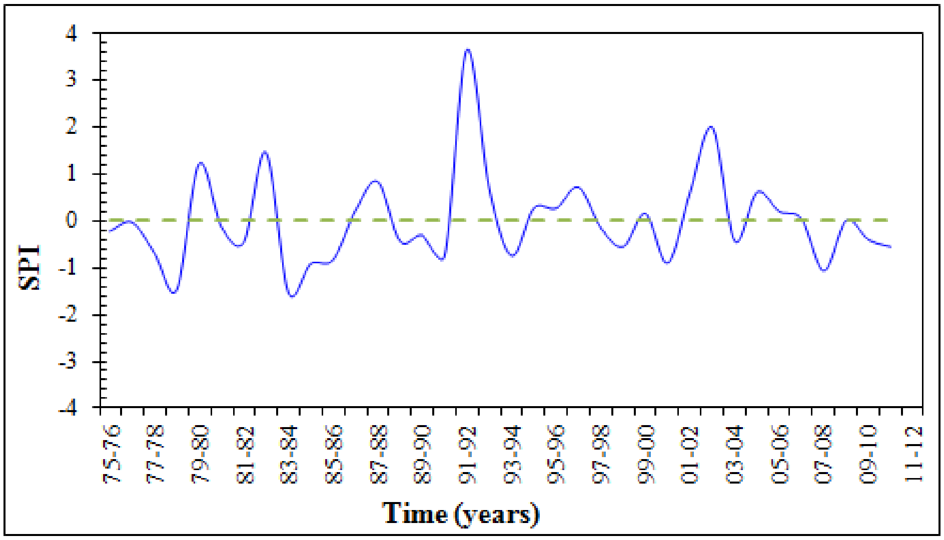

Figure 4: Time series of SPI for annual rainfall

The frequency of drought, dry, normal and wet years was estimated as follows: the first (P_{25}) and third (P_{75}) quartiles of annual rainfall were calculated. A year with annual rainfall above P_{75} was considered a wet year, while a year with annual rainfall less than the P_{25} was considered a dry year. A year with annual rainfall in between P_{25} and P_{75} was considered as a normal year. The 10^{th} (P_{10}) and 90^{th} (P_{90}) percentiles were considered thresholds for extreme values [12] and a year was considered as a drought year when the annual rainfall is of less than P_{10} [19]. The occurrences of drought, dry, normal and wet years were then counted and expressed as a percentage from the total number of years. Error! Reference source not found.**5** depicts the distribution of drought, dry, normal and wet years for the 1975–2011 period. Apparently, around 44% of the years were normal years in the past 36 years while 10% of the years were drought ones.

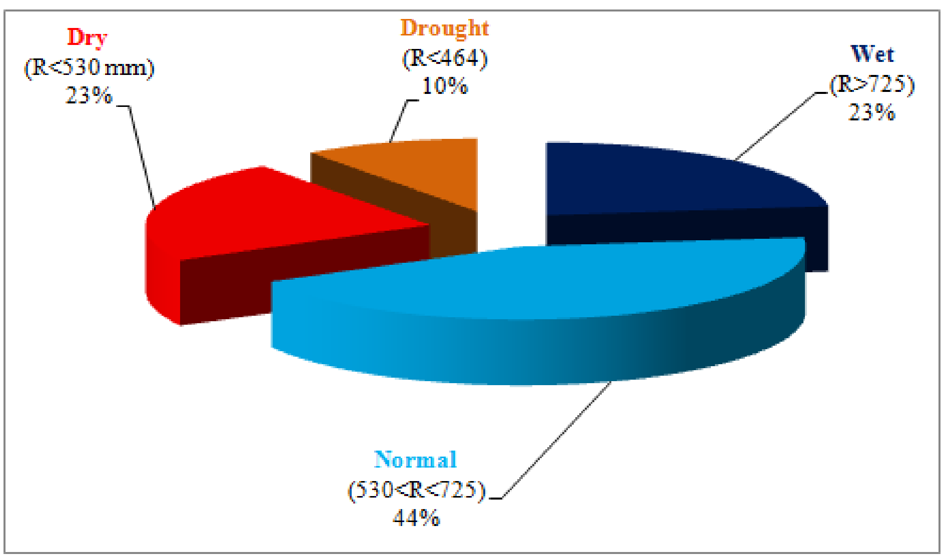

Figure 5: Distribution of wet, normal, drought and dry years

3.3 Annual and Seasonal Temperature

3.3.1 Basic Statistical Analysis

Basic statistical analyses were conducted on the mean annual and seasonal temperature data including the annual and seasonal mean, median, standard deviation, skewness, kurtosis, minimum, maximum and range measurements. **Table 2** summarizes the basic descriptive statistical measures of mean annual and seasonal temperature data.

Table 2: Descriptive statistics of mean annual and seasonal temperature data

Parameter	Annual	Fall	Winter	Spring	Summer
Mean (^{o}C)	18.4	20.7	11.0	17.2	24.6
Median (^{o}C)	18.3	20.5	11.1	17.2	24.7
Standard Deviation (^{o}C)	0.8	0.9	1.4	1.0	0.7
Skewness	0.5	1.3	-0.5	0.4	-0.4
Kurtosis	0.6	3.7	0.3	0.6	-0.7
Minimum (^{o}C)	16.8	19.3	7.5	15.2	23.3
Maximum (^{o}C)	20.2	23.7	13.4	19.5	25.7
Range (^{o}C)	3.4	4.4	5.9	4.3	2.4

From the table it can be inferred that there was variability among years, with a standard deviation of 0.8 ^{o}C and average of 18.4 ^{o}C. Skewness and kurtosis indicate that the temperature data do not follow a normal distribution. Summer has the highest average temperature (24.6 ^{o}C) whereas the minimum average temperature has companied with winter season (11 ^{o}C). The temperature range signifies the difference between the maximum and minimum annual temperature which was the maximum for winter season (5.9 ^{o}C). This indicates the temporal variability of annual and seasonal temperature.

3.3.2 Trend Analysis

Figure 6 (a) shows the inter-annual variations of mean annual temperature and its trend in the studied period. The t- test confirmed that the positive trend is significant with a 95 % confidence limit. There was variability among years, with a standard deviation of 0.8 ^{o}C where the average for 36 years period is 18.4 ^{o}C. The trend is towards a warmer climate, with an estimated increase of about 1.8 ^{o}C/36 years ($\approx$ 0.05 ^{o}C/year). For a better understanding of changes in the temperature series, the cumulative sums of deviations were plotted in **Figure 6 (b)**. Given that, data for the period from 1992 to 1997 were unavailable; two periods were detected by the cumulative sums of deviations: 1975-1992 and 1997-2010, which had average annual temperature of 17.9 ^{o}C and 18.9 ^{o}C, respectively. The trend of the first period is towards a cooler climate (decreasing trend), whereas the trend of the second period is towards a warmer climate (increasing trend). The decreasing and increasing trends are statistically significant. Similar to the increasing trend of mean annual temperature, maximum and minimum time series indicates increasing trend over the studied period (**Figure 6**, **c** and **d**).

The seasonal time series (**Figure 7**) showed a similar trend of mean annual temperature. The t-test confirmed that the positive trend observed is significant with a 95 % confidence limit for all seasons. For all seasons, a general warming is noticed over the entire period, with a trend rate of 0.054 ^{o}C/ year for fall, 0.045 ^{o}C/ year for winter, 0.041 ^{o}C/ year for spring, and 0.055 ^{o}C/ year for summer. The highest significant warming season is summer, with a trend rate of about 2 ^{o}C/36 years. This trend rate is the highest warming among seasons.

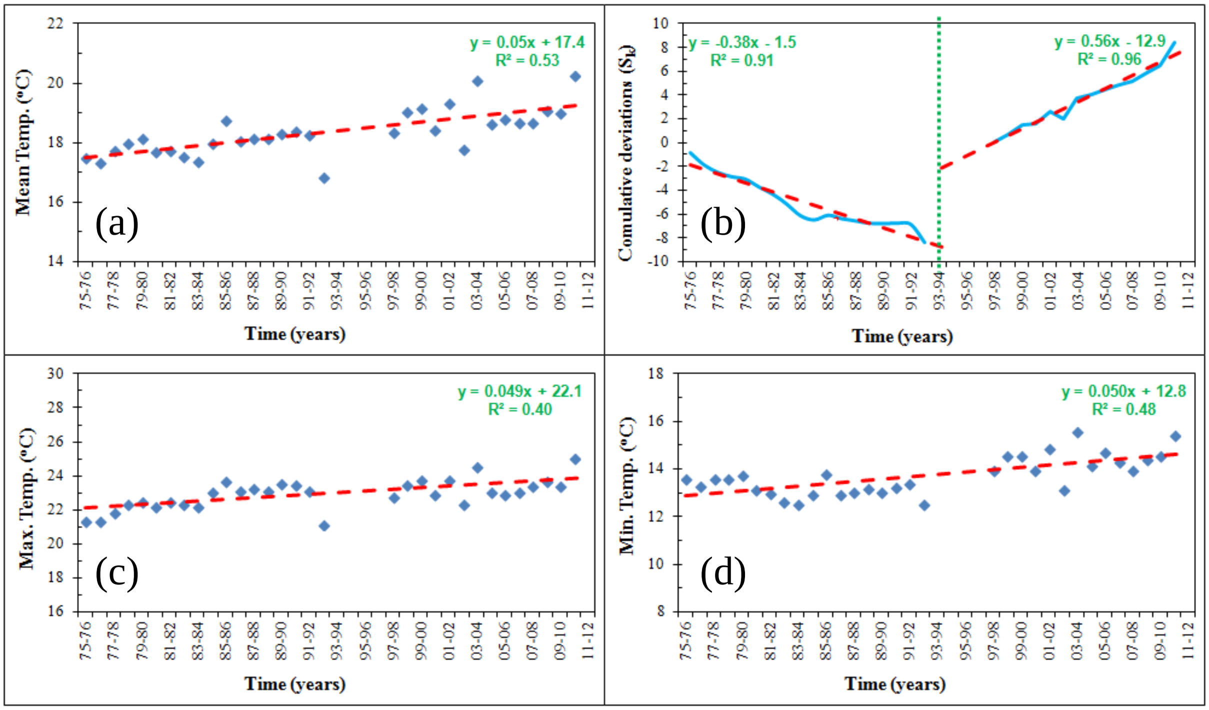

Figure 6: Inter-annual variations of annual temperature records. (a) Annual mean temperature and its trend, (b) Cumulative sums of deviations from the average of annual mean temperature, (c) Annual maximum temperature and its trend, (d) Annual minimum temperature and its trend

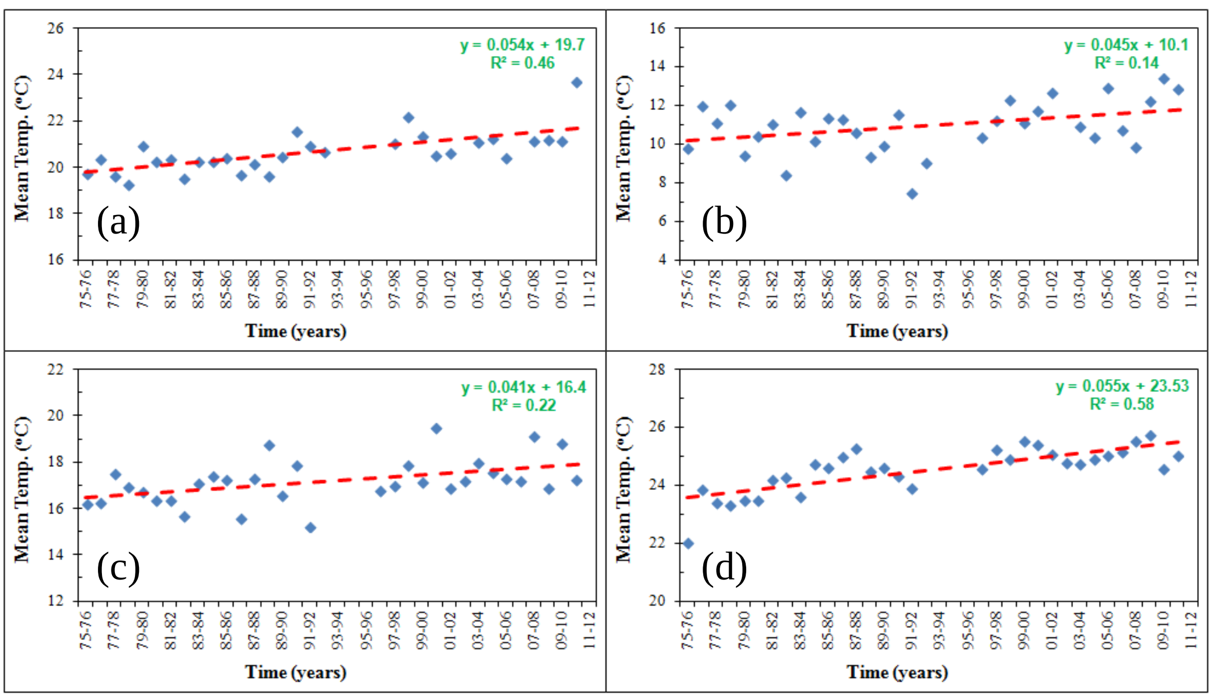

Figure 7: Linear trends over the seasonal mean temperature. (a) Fall, (b) Winter, (c) Spring, and (d) Summer

4 SUMMARY AND CONCLUSIONS

Nablus city is one of the Mediterranean semi-arid areas. The winter rainy season is from October to April with an average annual rainfall of 654 mm. The average mean daily temperature ranges from 24.4 ^{o}C in summer to about 9.6 ^{o}C in winter. The analysis conducted in this paper focused on the climate changes of rainfall and temperature. Time series of rainfall and temperature data were studied and annual and seasonal trends were reported. Drought analysis was conducted on annual rainfall and the frequency of wet, normal, dry and drought was figured out. Quantitatively, the general conclusions are summarized as follows:

- The mean and median annual rainfall for Nablus City is 654 and 625 mm, respectively with high oscillation in the annual rainfall values;
- The winter season has the highest amount of rainfall. On average, winter rainfalls accounts for around 70% of annual rainfalls whereas rare rainfall events occurred in summer;
- The trend of annual rainfall is towards a wetter climate. Since 1975, there has been an increase in the annual rainfall of about 7% (48mm). This result is inconsistent with the analysis of the climate done by Pe’er, G. and Safriel for entire historical Palestine;
- The use of inter-annual variability (cumulative deviations) showed that drier period occurred over the period from 1975 to 1991 has been followed by a wetter period on record from 1992 to present. This means that Nablus rainfall is periodic in the essence that dry period are followed by wet period.
- A significant increasing trend observed in winter, whereas decreasing trend was observed for fall and spring rainfalls;
- Time series of the SPI depict that in 21 out of 36 years there was a drought in Nablus city while extreme drought did not take place during the last 36 years;
- In the past 36 years, annual rainfall of around 44% of the years were normal while 10% of the years were drought ones;
- The summer season has the highest average temperature (24.6 ^{o}C) whereas the minimum average temperature has companied with winter season (11 ^{o}C);
- Annual mean temperature changes of Nablus are characterized by a warming trend. Since 1975, there has been an increase in the annual mean temperature of about 1.8 ^{o}C/36 years (≈ 0.05 ^{o}C/year);
- The use of cumulative deviations detected two main periods in the temperature of Nablus city. A relatively cool period from 1975 until 1992 has been followed by the warm period on record from 1997 to present;
- A general warming is noticed for all seasons, over the studied period, with a trend rate of 0.054 ^{o}C/ year for fall, 0.045 ^{o}C/ year for winter, 0.041 ^{o}C/ year for spring, and 0.055 ^{o}C/ year for summer. The highest significant warming season is summer, with a trend rate of about 2 ^{o}C/36 years.
- Generally, NMS has an increasing rainfall trend accompanied with an increasing trend in temperature. This is a very important result which tackled results of the predicted climate change scenarios for the region (e.g. [10]) which concluded that a decreasing trend of rainfall will be accompanied by an increasing trend of temperature.

5 ACKNOWLEDGEMENT

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