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RAINFALL TRENDS AS AN INDICATION TO CLIMATE CHANGE SINCE THE 19TH CENTURY IN THE PALESTINIAN CENTRAL MOUNTAINS: JERUSALEM GOVERNORATE AS A CASE STUDY

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Abstract: Climate change is a worldwide problem that is facing the globe in different aspects. To investigate this phenomenon, research has been conducted to check whether climate change is affecting the western part of Jerusalem Governorate or not. Long-term data on annual, seasonal and monthly rainfall were collected from different sources and analyzed for long-term monthly and annual trends. Results showed significant ($p < 0.05$) decrease in the annual rainfall, with about 7.3 mm decadal reduction during 1850-2018. The highest and significant decrease in decadal rainfall occurred during 1890-1939 and 1980-2018, with a decadal decrease of 50.9 mm and 55.9 mm, respectively. The decrease corresponds to 84 mm reduction in annual rainfall since 1850, which could be attributed to the extended effect of the GHG from the industrial revolution on Palestine since the beginning of the 20th century. A significant and increasing trend in drought periods was also obvious, with 1.7 years of drought/decade and an increasing drought recurrence during 1920-1930 and 1998-2018 periods (69% of the drought years occurred in the two periods). Winter season showed highest and significant reduction in rainfall than spring season (1.7 mm/decade and 0.7 mm/decade, respectively), whereas autumn season showed a non-significant decadal decrease in rainfall of about 0.04 mm/decade. The reduction in rainfall and the recurrence of more drought periods, especially the last 20 years, might be the cause for the concurrent reduction in rainfed agricultural areas in Palestine; about 38% reduction in the total rainfed areas (1515 km^2 in 2000 to 929 km^2 in 2017/2018).

Key words: Jerusalem, Climate change, rainfall, rainfed agriculture, drought period.

1. INTRODUCTION

Climate change is a malfunction or a change in normal climate patterns such as wind and its patterns, rain, snow, hail, and changes in temperature that could occur in different regions of the earth, which plays a role in affecting and changing the plant, animal and human life (William et al., 2010).

Debates on both the anthropogenic reasons and degree of agreement on the issue of climate change are obvious. Hence, some people believe that climate change is a natural phenomenon where the globe passed through different phenomena where the Nino & Nina phenomena, the tilt of the axis of the earth between 21.8-24.5 degrees, volcanic eruption and the solar spots, all are combined factors, which lead to a change in the earth's climate every now and then.

Some other people believes that Climate Change is a global environmental problem caused by human activities. Such a problem is obvious in deforestation, natural resource exploitation, extensive use of fossil fuel, fire, industrial pollution, different source and types of pollution, over grazing and fishing, urban sprawl and other related factors. All of the aforementioned factors lead to the increase of the Carbon Dioxide gas emission (CO_2), Chlorofluorocarbons (CFCs) and Methane (CH4) emission (Called the greenhouse gases- GHG) in the air with a rate more than its natural increase. The increase in these gases is supposed to be absorbed by forests and plants during photosynthesis process. However, due to the aforementioned human activities, the percentage of these gases remains above its normal average, which leads to an increase in the earth's temperature and the prevalence of drought and difficulties to different living organisms. Substantial doubt exists about the anthropogenic reasons and degree of agreement on this issue. A large and extensive dataset composed of 1,372 climate specialists and researchers with their publications showed that about 98% of them support the tenets of anthropogenic reasons of climate change, which is supported by the Intergovernmental Panel on Climate Change, whereas the wrest did not support the claim (Johns et al. 2003, William et al., 2010).

The possible effects on temperatures due to GHG increase are of long-term and continuous nature (Jong et al., 2010) compared to the effects that come from volcanic eruption or sunspots. According to the studies of the Intergovernmental Panel on Climate Change, the increase in temperature into the southern and eastern parts of the Mediterranean region during the current century will be more than the average warming up globally, in addition, the mean annual precipitation could also decrease (Trenberth 2019; Yuan 2013). Xoplaki et al., (2003) also reported a gradual decrease in precipitation in the Mediterranean region during the second half of the 20th century with a probability of continuation in this downward trend. The decrease in precipitation could reach up to 20% of the total annual precipitation till the year 2050 (Black 2009).

Evans (2009) predicted the future climate changes in the Middle East using 18 global climate models. The models expected an increase in temperature of about 4 K with a decrease in the precipitation by the end of the 21st century. Such changes are most probably to occur in the Eastern Mediterranean including Turkey, Syria and the northern part of Iraq. An 170,000 km^2 in rainfed areas as a result of the reduction in precipitation was also detected. The MM5 climate hydrology model found similar results, where the model predicted an increase in the mean annual temperature of about 4.5℃, with a decrease in the mean annual precipitation of about 25% and a consequent decrease in the runoff water of about 23%, which will be more obvious in the mountainous part of the Eastern Mediterranean (Kunstmann et al., 2007). Water resources are also a potential element to be affected due to climate change. For example, the General Circulation Model found an increase in the annual temperature of 0.6 to 2.1 ℃ in Lebanon but no decrease in the annual precipitation. The increase in temperature would have an impact on the water balance with potential reduction of the available water resources (Bou-Zeid & El- Fadel 2002). In a model to predict temperature and precipitation for the Middle East and North Africa region (MENA) during 2020-2050, a 15-20% decrease in precipitation was found with a simultaneous increase in the annual vegetation reference evapotranspiration (ETp). This climatic change is distinctive in Syria and other surrounding countries of the Middle East (Terinlk et al., 2013).

From a geomorphologic point of view, the Middle East has diverse topography with different associated climatic conditions, which was reflected by a model depicting its climate during the 21st century. The modelling suggested disproportional changes in some climatic parameters in accordance to the spatial and the topographic features of each area. The model also found a continuous increase in temperature of about 3.5 to 7℃ up to 2099 with a decrease in the annual rainfall in the Levant area (Middle East and the Eastern Mediterranean). The projected climatic change could has an effect on the regional availability of fresh water in the Levant (Lelieveld et al., 2012). Zhang et al., (2005) found statistical and spatial coherent increase in the annual maximum of the daily maximum and minimum temperature in different countries of the Middle East and Arab Gulf area, but the annual precipitation and the precipitation intensities were not significantly affected with no spatial coherence.

Kutiel (1996) analyzed the dry and wet years and sequences in the eastern Mediterranean. He found some common sequences at the four stations included into the study (Thessaloniki, Athens, Nicosia, and Jerusalem). Kutiel (1996) found that dry years and sequences are more frequent during recent years whereas wet years and sequences were more frequent at the beginning of the century. The author found also that the extremely dry years were obvious during the recent years. The inferences are that the eastern Mediterranean has a changing tendency toward a dryer period recently. The dry episode started in the southern station of Jerusalem and has expanded slowly northward the eastern Mediterranean. Almost similar results were obtained by Oikonomou et al., (2008).

In conclusion, most of the analysis presented in the aforementioned literature provides modelling of climate change based on mathematical models and simulation techniques, the resultant scenarios of the simulation could have large uncertainties and discrepancies, especially in its precision, its spatial and temporal extent. In addition, a specific change in climate will produce different consequences in the targeted area of the Middle East, depending on its hydrologic, political, and social characteristics. Finally, lack of real climatic data about the study areas and the lack of accurate water balance data hinder the use of advanced hydrologic models (Bou-Zeid & El- Fadel 2002; Terinlk et al., 2013).

Although Palestine is situated in the Eastern Mediterranean coast and in a moderately climatic region, but it is considered one of the Middle Eastern countries with high threats and damage to water resources and with water shortage. The inevitable change of the globe's climate will further decrease its available water resources, making Palestine one of the thirstiest societies (Mimi et al., 2009). Such a shortage will lead to a rise in water cost and though gives the priority to people who can pay more for water as a social scenario. In addition, rainfall will decrease, drought will prevail, and consequently the agricultural sector and associated food security will be threaten (Mimi et al., 2009). Based on this, the current research intends to answer whether Palestine in general and the study area in particular is subjected to climate change. The main objectives of this research are to: (i) study the rainfall characteristic in the study area and its relation to climate change; (ii) analyze the annual and monthly pattern of rainfall and identify any changes in them since 1850; and (iii) to analyze and correlate changes in land use with climate change.

2. METHODOLOGY

2.1 Study area

Jerusalem Governorate is located in the middle of Palestine, with an average distance of about 45 km east of the Mediterranean Sea. It is located on top of the Central Palestinian Mountain chain that is extending from the north to the South (Figure 1). The Governorate has an area of about 353 km² with total population of about 879700 (Choshen 2019). The topography of the Governorate includes many mountains within its borders, some of the most important are: The Mount of Olives, Al-Masharef and Al-Mukabber mountains, also surrounded by a number of valleys, some of which are: Silwan valley, Al-Joz valley and Im Al-Daraj valley. Jerusalem was surrounded with forests of walnut, olive and pine trees since long time, nevertheless, the continuous war and severe human exploitation resulted in the destruction of these forests, affecting soil stability, forcing the farmers to construct agricultural terraces, canals, ponds and wells for water conservation.

The Western part of Jerusalem Governorate has been chosen as the focus of the current study because of the homogeneity in its climatic conditions where Mediterranean climate prevails, whereas dry and very hot conditions prevail into the eastern part of the governorate with limited amount of data and scarce rainfall events. The Western part is located on a mountainous area with an elevation of 750 meters above sea level, and 1150 meters above the Dead Sea level (Isaac & Khalilieh 2008). The prevailing climate is Mediterranean, with a hot and dry summer, moderate temperatures during the winter season and fluctuating rainy seasons. The month of January is the coldest month of the year where the mean annual temperature is 9.1ºC. On the other hand, July and August are the hottest months of the year with an annual average of 24.2ºC. The mean annual rainfall is 537 mm (Palestinian Central Bureau of Statistics PCBS, 2008)

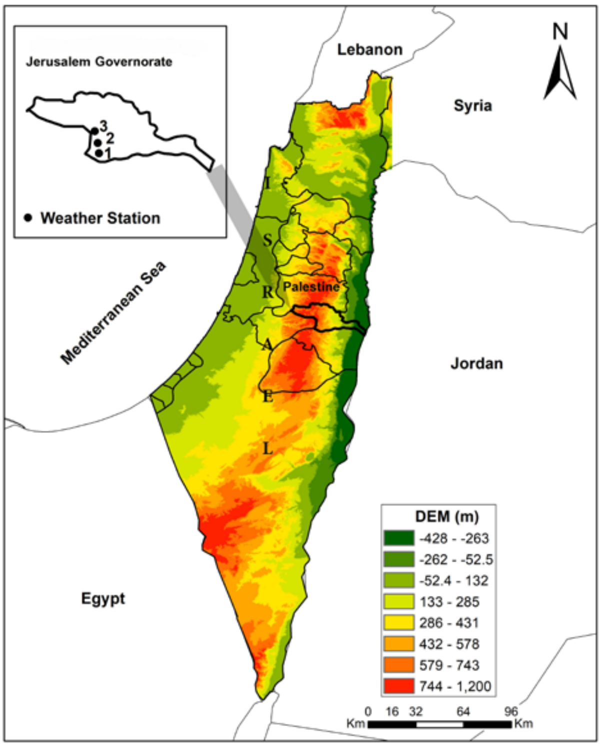

Figure 1. Geographic location of Jerusalem governorate.

2.2. Data collection and Data quality control

Monthly precipitation total for three stations distributed in the Western part of Jerusalem Governorate, specifically into the boundary of Jerusalem city and its surroundings (Fig. 1, Table 1), were obtained from Israel and Palestinian meteorological departments as well as from Ottoman and British records. The temporal coverage of these monthly time series extended for 169 years (from 1850-2018).

To ensure data accuracy and precision, the available monthly rainfall time series were subjected to quality control process where they scanned and plotted to detect any systematic errors, missing data and outliers. The total missing data detected in the whole-time series was 6 monthly values. These values

Table 1. Weather stations that were used in the study and its locations (shown in Figure 1).

	Name	Longitude	Latitude	elevation
	JERUSALEM old City HOSP	35.2308º	31.7780º	760
	JERUSALEM AM. COL. Hotel	35.2298º	31.7900º	760
	JERUSALEM St Anne	35.2360º	31.7808º	740

were replaced by the long-term averages of their respective months. Furthermore, all months with a total of zero rainfall or with unusual values from September to May were marked as suspected monthly values, and these values were evaluated based on the nearest stations (distance <20Km) (Qiryat Avanim, Ramallah, Bethlehem and Ma'ale Adumim stations).

For outliers, the thresholds were determined within the range of ±5 standard deviations for monthly precipitation total (Peterson et al., 1998). After that, the outliers detected were spatially evaluated by comparison with the nearest stations. Five outliers were detected (1 in December/1991, 2 in April/1856 and April/1971, 2 in February/1992 and February/1857).

It is also important to investigate whether the climatic series exhibits a normal distribution in order to determine whether parametric or non-parametric tests could be used for assessing homogeneities, trends, and variability tests. Four normality tests namely, Shapiro-Wilk (SW), Jarque-Bera (JB), Anderson Darling (AD) and Lilliefors (LF) were applied to the monthly, seasonal and annual rainfall data sets. The results indicated that not all monthly and seasonal time series followed the normal distribution whereas the annual totals followed.

The homogeneity of the decadal and the monthly time series was examined by using the Standard Normal Homogeneity Test (SNHT) for a single break (Alexandersson, 1986) and von Neumann ratio test (von Neumann, 1941) at 0.05 significance level. The tests revealed no changing points in all the checked time series from September to May.

The magnitude of the increasing or decreasing trends of (annual and seasonal) precipitation were derived by applying the parametric least squares linear regression for the annual total rainfall and Sen's estimator (Sen 1968) for the seasonal averages. The statistical significance of the trend in seasonal series was analyzed using the non-parametric Mann-Kendall (MK) test (Mann 1945). The MK test has been widely employed by many researchers in the hydrological studies to ascertain the presence of statistical significance trend (Douglas et al., 2000; Yu et al., 1993).

The significant differences of the means between different periods were examined at 0.05 significance level by parametric independent sample T-test and the non-parametric Mann-Whitney U test for two samples, respectively for the annual and seasonal levels.

Sigma plot software and RStudio V. 3.4.3 were used to produce charts and to perform all calculations that related to outliers, normality, homogeneity, trends and drought index.

3. RESULTS AND DISCUSSION

3.1 Annual level

Analysis of the annual rainfall since the mid-19th century until 2018 indicated that the total annual rainfall decreased significantly ($p<0.05$) in the Western part of Jerusalem Governorate by 7.3 mm/decade (Fig. 2A). During the period (1850-1899), the variations in total annual rainfall obviously followed an increasing trend by 23.8 mm/decade but the increase is not significant (Fig. 2B), and its decadal averages are totally above the long-term average (537 mm) (Fig. 2A). An increasing but not significant trend is also obvious during the period 1950-1989 and equals to 32.8 mm/decade but mostly with variations of decadal averages below the long-term average (Fig. 2A).

After the last decade of the 19th century until 2018, the total annual rainfall showed a significant and decreasing trend by 8.9 mm/decade, with the highest and significant decreasing trend between the years 1890-1939 and 1980-2018; 50.9 mm and 55.9 mm/decade respectively (Figs. 2A and, 2C for the period 1980-2018).

The last decade of 2010-2018 has the lowest decadal rainfall average (444. 1 mm) and the decade 1890-1899 has the highest decadal average with an average of 678.5 mm (Fig. 2A). The results also showed that the rainy year 2017 was the driest year since 1850 (207.7 mm) whereas 1992 was the wettest with exceptional total rainfall (1016.1 mm) (Fig. 2C). It could be hypothesized that the highest decreasing trend during 1980-2018 is due to the unusual drought season 2017. However, when this exceptional rainy season was removed from the time-series, the trend was not significantly changed, and though the hypothesis is not true, hence the decreasing trend of rainfall might be attributed to the changes in the prevailing climate.

The industrial revolution started in mid-19th century in Britain and extend to all Europe lately.

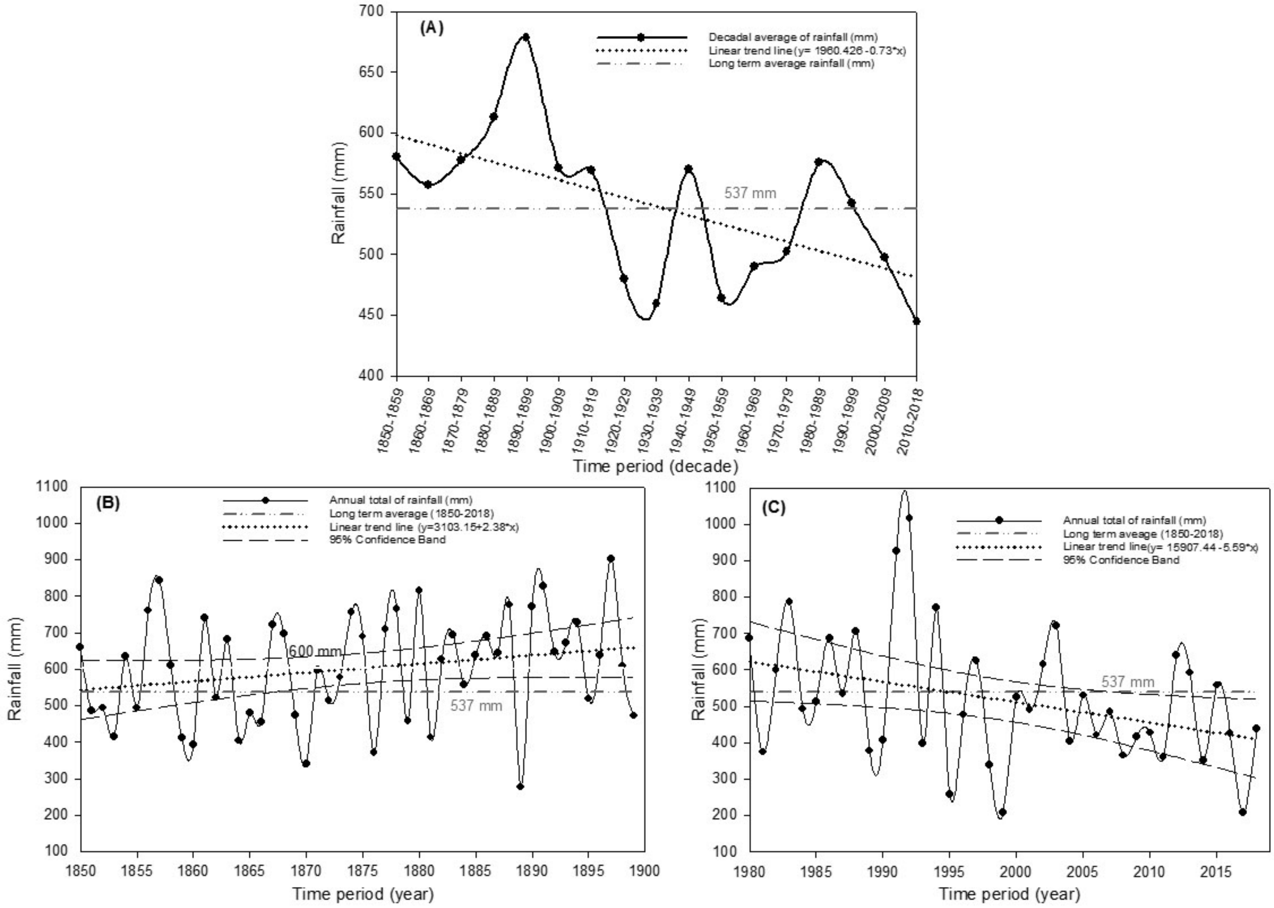

Figure 2. (A) Decadal rainfall averages for 1850-2018, (B) Total annual rainfall for the period 1850-1900, and (C) is the total annual rainfall for 1980-2018

During this period, the use of new energy sources such as petroleum and coal allowed for a high and elevated concentration of CO_2, which is now agreed upon as a main greenhouse gas (GHG), resulting in global warming and climate change (Martinez 2005). The results of Figure 2 show that the consequences of the global climate change because of the early industrial revolution have begun and showed its effect early in the 20th century in the Western part of Jerusalem Governorate, about (50-60) years after the beginning of the industrial revolution all over Europe (Fig. 2 A). As a result, the mean annual rainfall for the 1850-1900 has significantly decreased from 600 mm to 516 mm for the 1980-2018 period, about 84 mm reduction; about 15.6% of the long-term annual rainfall (537 mm) (Figures 2B and 2C). Figures 2A and 2B also show that the effect of industrial revolution and its related GHG has significantly decreased the annual rainfall in the study area from 600 mm during (1850-1900) to 516 mm since the beginning of the 20th century. This means that the cumulative effect of climate change started to be obvious and quantified since the first decade of the 20th century onward, although the causes of such phenomena started long time ago.

This result indicates the unforeseen effect of the GHG during that period, although the industrial revolution has already begun long time ago, but the effect did not show up yet in the study area, which is similar to what has been found in 2003 (Johns et al. 2003) on a global range investigation of modelling climate change since 1860. John (2003), in his model, found that the mean annual temperature of the Northern hemisphere started to diverge from the long-term average temperature since 1915, which is almost consistent with the current finding.

During (1850-2018) the total number of dry years per decade showed a significant and increasing trend by 1.7 year/decade (Figure 3C). Based on the Z-score test, the recurrence of drought period showed an increasing pattern since the second decade of the 20th century (Figure 3C), with the highest level from 1920 to the mid-1930s and from 1998 to 2018, where the longest period of drought continuously extended from 1922 to 1935 and from 2003 to 2011 (Figure 3A). Figure 3A also revealed that the period extended from 1880-1899 was the wettest period with only 3 years that were classified as a slight drought and one year as a severe drought (Fig. 3A).

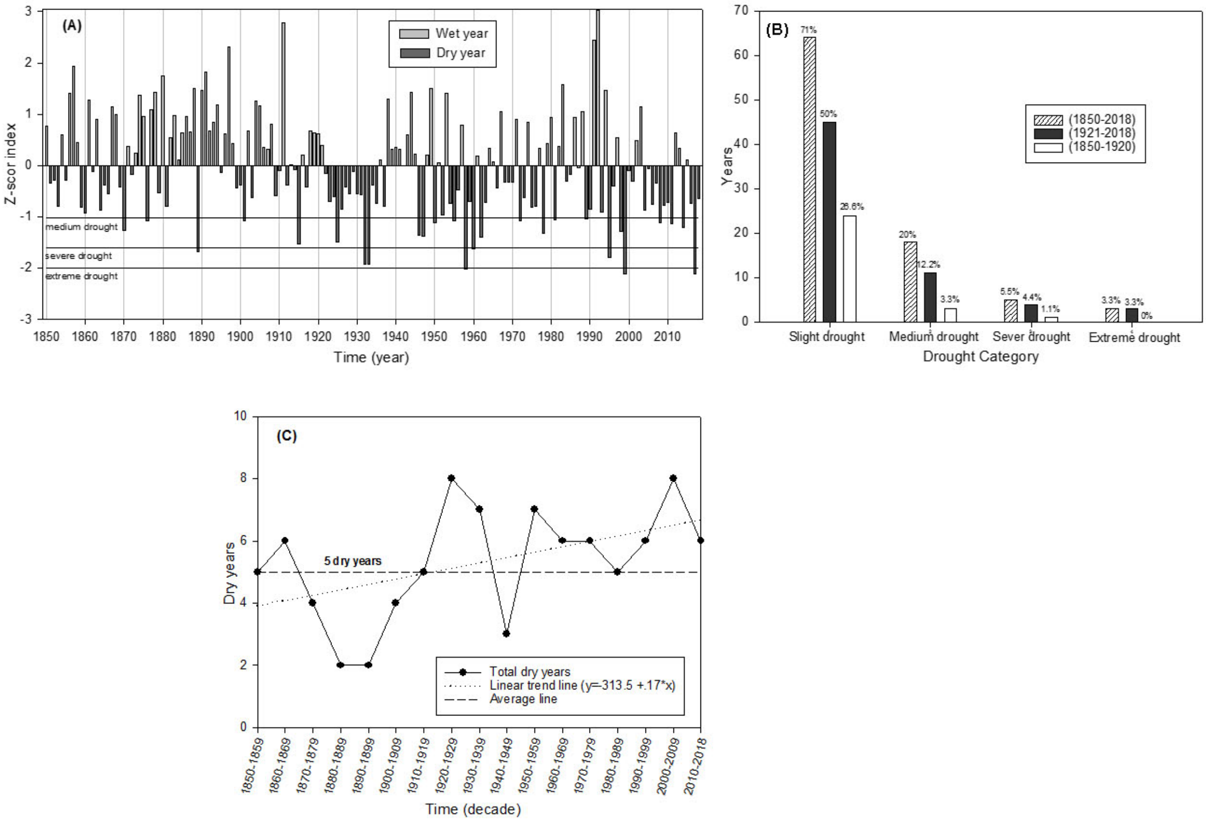

Figure 3. (A). Annual Z-score test along the period under investigation. (B). Drought categories between (1850-2018) and (C) is the dry years with the linear trend from 1850 to 2018.

Furthermore, 31% (28 years) from the total dry years (90 years along the period 1850-2018) occurred during 1850-1920, while 69% (62 years) of the total dry years occurred during the period 1921-2018 (Fig. 3B). About 25% of the total dry years during the 1921-2018 period (62 years) occurred in 1998-2018, where 16 out of 21 years were classified as dry years (Fig. 3A). In addition, two out of three events for the extreme drought category were in 1999 and 2017 which is an indicator to increase the probability of occurrence in the extreme drought category (Fig. 3A). Over the 169-year period, 64 years (71%) experienced slight drought, 18 years (20%) medium drought, 5 years (5.5%) (1891, 1932, 1933, 1960 and 1995) severe drought and 3 years (3.3%) (1958, 1999 and 2017) extreme drought (Fig. 3B).

De Pauw & Wu (2010) studied the climate change, drought and possibility for water harvesting in Palestine. The authors calculated the annual Standardized Precipitation Index (SPI) based on rainfall dfor the period 1901 to 2007. Authors specified droughts during 1915, 1925, 1932, 1933, 1946, 1947, 1952, 1958, 1960, 1962, 1978, 1981, 1993, 1995, 1998, 1999. They also specified 1915 and 1999 as the most extreme drought years. Semawi (2012) studied the occurrence of drought for the period 1923-2007 in Jourdan. Semawi suggested 10 years severe drought occurrence and another 10 years with mild drought occurrence over the 84-year period. The severe drought occurred during 1932, 1933, 1947, 1958, 1960, 1962, 1981, 1989, 1995, and 1999; whereas the mild drought years occurred during 1925, 1952, 1955, 1970, 1976, 1978, 1998, 2004, 2006, and 2008. Skaf & Mathbout (2010) computed the annual Standardized Precipitation Index (SPI) depending on rainfall data during the period 1958-59 to 2007-08 and for 15 stations covering different climatic zones in Syria. The authors found that years 1972-73, 1998-99, 1999-00, and 2007-08 were the most extreme drought years. A drier trend conditions in larger parts of the Mediterranean region have also been observed, which could have similar or nearly similar trend as that found in Jerusalem Governorate. Sousa et al., (2011) investigated patterns and extremes of drought indices in the 20th century in the Mediterranean region and found a clear trend towards drier conditions in most of the western and central Mediterranean regions. These results are fully in consistent with what has been found in the current study.

3.2 Seasonal level

Figure 4A shows the decadal winter rainfall averages for the period 1850-2018. During this period, rainfall significantly decreased by 1.7 mm/decade. The period from 1980 onward exhibited a highly decrease trend of 9 mm/decade, although not significant but nearly five times than the whole period of 1850-2018. The temporal behavior for winter rainfall notably showed decreasing pattern since the first decade of the 20th century and mostly below the seasonal long-term average (120.9 mm). Furthermore, the rainfall average for the period (1911-2018) significantly decreased by 19 mm compared with the average for the period (1850-2018) (Fig. 4A).

Spring rainfall showed similar trend to winter with a general decline pattern from 1850 to 2018, which is more distinct since 1970 and onward (Figure 4B). A significant decrease of spring rainfall by about 0.7 mm/decade during 1850-2018, and by 5.4 mm/decade since 1970 onward; eight times than the whole period.

For autumn, figure 4C shows different pattern as compared to those of winter and spring, especially during the period (1850-1979) where it displayed significant increase trend above the long-term average (21.8 mm) by 0.047 mm/decade. In addition, it showed very weak and non-significant decrease trend by 0.04 mm/decade during the whole period (1850-2018). On the other hand, autumn behavior was similar to winter and spring in the last five decades where it showed significant decrease trend by 2.4 mm/decade in the same period.

The land use changes, especially the agricultural land use has a strong relation with rainfall of the area. Land use area, especially agricultural areas decreased dramatically the last 17 years; which is an important indicator for the changes in climate. The cultivated area was 1,515 km^2 in 2000 and decreased to 1,491 km2 in 2006, and in 2017 it became 929 km2; a reduction of about 38% of the total cultivated land within a short span of time (Table 2). This reduction could be partly attributed to the concurrent changes in the quantity as well as the spatio-temporal distribution of rainfall during the last 20 years (Palestinian Central Bureau of Statistics PCBS, 2019).

In addition, the annual spring flow rate could also give a clear indication of the concurrent climate change in the study area with a decrease in rainfall. The spring annual flow rate has decrease by about 50%, where the annual spring flow rate was 60 million m^3 per year in 2003 and reached to 31 million m^3 per year in 2017. This reduction might also be attributed to the decrease in the annual rainfall during the last 15 years, which affected negatively the spring annual recharge (Applied Research Institute of Jerusalem ARIJ 2015).

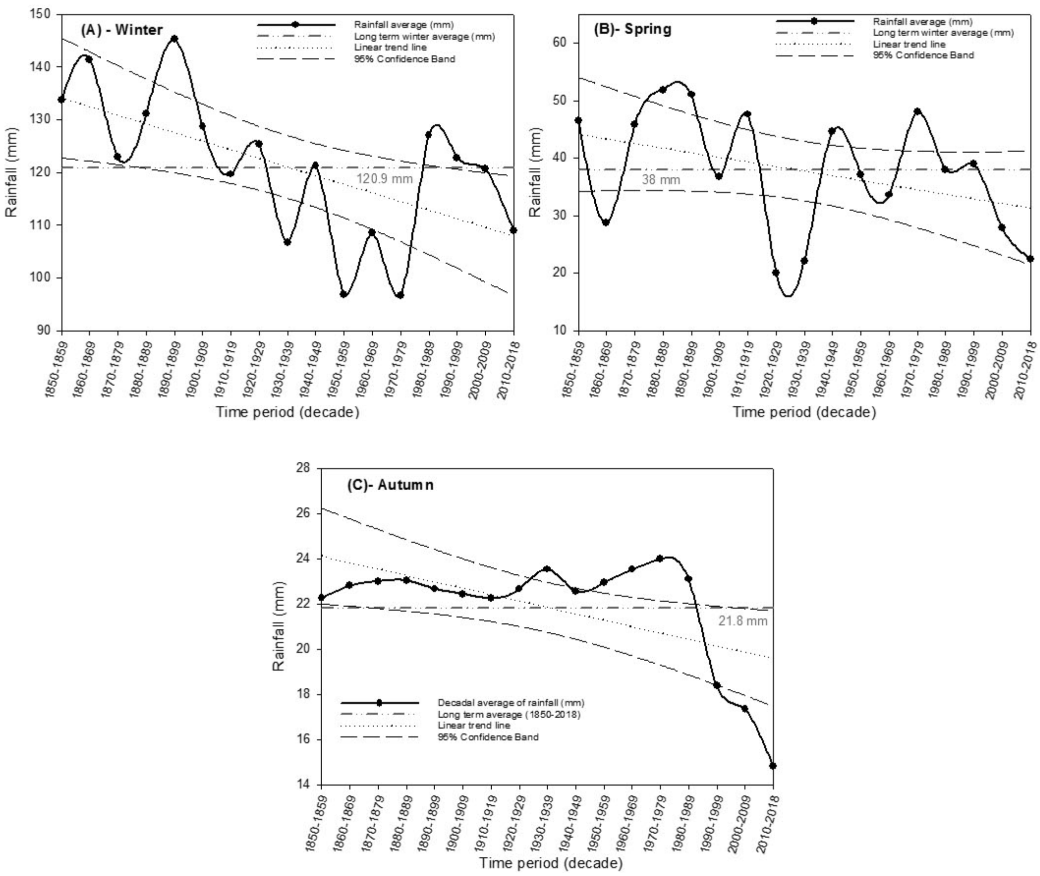

Figure 4. Seasonal rainfall averages for the period 1850-2018, (A) winter (B) spring (C) autumn.

Table 2. Cultivation types and patterns in the Central Palestinian Mountain.

Indicator	Year			
	2000	2006	2010	2017
Cultivated Land (km^2) (1)	**1,514.8**	**1,490.6**	**1,029.3**	**929.4**
Area of Permanent Cultivated Land (km^2)	1,192.6	1,147.6	542.4	658.9
Area of Temporary Cultivated Land (km^2)	322.2	343.0	268.3	270.5
Area of Irrigated Cultivated Land (km^2)	161.6	153.8	128.0	144.3
Area of Rain-fed Cultivated Land (km^2)	1,353.2	1,336.8	682.7	787.2
Area of Permanent Cultivated Land Per Capita (m^2)	407.9	305.1	139.8	156.0

A study on the Palestinian climate change has ensured an increase of temperature in Palestine by about 0.74 degrees Celsius during the period 1905-2010, which provides a further indication of the existing change in climatic condition; including the changes in rainfall and temperature (Abu Hammad & Salameh 2019, Salameh et al., 2019).

In addition, the accelerated population growth, where it is estimated that the annual population growth rate reaches 4.24%, putting more pressure on existing resources, such as: energy, food and farmlands, accompanied by an extensive urban expansion and air, water and soil contamination (Palestinian Central Bureau of Statistics PCBS, 2017a). All of these facts support debate of climate change in Palestine in general, and the study area in particular.

4. CONCLUSIONS

Palestine in general, and the study area in specific, cannot be considered as one of the principal industrial areas, which could affect the world's climate. Rather, Palestine and the study area was and still being affected by the causes of climate change, which can be supported by the following results of the current research:

- A decrease in the annual rainfall of about 84 mm (15.6% of the long-term annual average).
- The study area is subjected to more consecutive drought periods than rainy periods, especially during the 2000-2018 period.
- Winter rainfall showed decreasing pattern since the first decade of the 20th century and mostly below the seasonal long average with similar trends for spring season.
- The changes in rainfall signals the changing in temporal pattern of rain in the study area, which can be strongly connected with an elevated temperature.
- Changing in rainfall amounts and patterns started early in 1911 and onward, about 100 years after the beginning of the industrial revolution in Europe.
- About 38% of the agricultural and green areas disappeared the last 17 years, with a possible deterioration of the environment. This warrant the importance of developing the green areas, including agricultural, pastoral, and forested areas to decrease the effect of climate change on rainfall and other climatic parameters.

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