Journal homepage
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Anbar Journal of Agricultural Sciences
(University of Anbar – Agriculture College)

TREND DETECTION OF AVERAGE ANNUAL RAINFALL AND TEMPERATURE IN SULAYMANIYAH GOVERNORATE, IRAQ

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Article info

Received: 2021-05-18
Accepted: 2021-10-13
Published: 2021-12-31

DOI -Crossref:
10.32649/ajas.2021.175995

Cite as:
Ahmed, G. H., and D. A. M. Al-Manmi. (2021). Trend detection of average annual rainfall and temperature in sulaymaniyah governorate, iraq. Anbar Journal of Agricultural Sciences, 19(2): 221-233.

Abstract

Change in the magnitudes of temperature and rainfall temporally and spatially can be observed, on both regional and global scales, so detecting the trend of their changes is essential to fit the management plans of hydrological, agricultural, and other water-related activities. In this study, the trend of annual temperature and annual rainfall magnitudes within Sulaymaniyah Governorate have been investigated by using the Mann–Kendall trend test and Sen's slope estimator. The recorded data at five stations namely Sulaymaniyah, Dukan, Halabja, Penjwen, and Chamchamal stations across Sulaymaniyah Governorate have been studied. The results showed that the positive increasing trend appeared in the annual temperature values of the data of Sulaymaniyah, Dukan, Penjwen, and Chamchamal stations, while Halbja station didn't reveals any trend in its annual temperature values. Regarding the trend of annual magnitudes of rainfall, the results showed that the trend didn't appears in the rainfall magnitudes of all of the studied stations, based on the calculated value of (Z), the trend has not appeared in average annual rainfall depth in all of the studied stations at the significant level of 95%, however by taking the p-values, slightly trend toward negative was observed in Sulaymaniyah Station, while moderately trend toward negative and positive increase has appeared in Halabja and Chamchamal stations respectively, but at Dukan and Penjwen Stations, the trend has not appeared in the average annual rainfall.

Keywords: Trend detection, Hydrologic variables, Mann–Kendall, Time series, Sulaymaniyah.

كشف الاتجاه لمتوسط هطول الأمطار السنوي ودرجة الحرارة في محافظة السليمانية، العراق

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الخلاصة

يمكن ملاحظة مقدار التغير في درجات الحرارة وهطول الأمطار من الناحيتين الزمانية والمكانية، على المستويين الإقليمي والعالمي، لذا فإن اكتشاف اتجاه تغيراتهما ضروري لملاءمة خطط إدارة الأنشطة الهيدرولوجية والزراعية والأنشطة الأخرى المتعلقة بالمياه. في هذه الدراسة، تم التحقيق في اتجاه درجات الحرارة السنوية ومقادير هطول الأمطار السنوية في محافظة السليمانية باستخدام اختبار اتجاه مان–كيندال ومتخمين منحدرات سين. تمت دراسة البيانات المسجلة في خمس محطات وهي السليمانية ودوكان وحلبجة وبنجوين وجمجمال في محافظة السليمانية. وأظهرت النتائج أن الاتجاه التصاعدي الإيجابي ظهر في قيم درجات الحرارة السنوية لبيانات محطات السليمانية ودوكان وبنجوين وجمجمال، بينما في محطة حلبجة لم تكشف عن أي اتجاه في قيم درجات الحرارة السنوية. بالنسبة لاتجاه المقادير السنوية لهطول الأمطار، أظهرت النتائج عدم ظهور الاتجاه في مقادير هطول الأمطار لجميع المحطات المدروسة، بناءً على القيمة المحسوبة لـ (Z)، لم يظهر الاتجاه في متوسط عمق هطول الأمطار السنوي. في جميع المحطات المدروسة عند مستوى معنوي 95٪، ولكن بأخذ القيم p، لوحظ اتجاه سلبي طفيف في محطة السليمانية، بينما ظهر اتجاه معتدل نحو الزيادة السلبية والإيجابية في محطتي حلبجة وجمجمال على التوالي، ولكن في محطتي دوكان وبنجوين، فان الاتجاه لم يظهر في معدلات المطر السنوية.

كلمات مفتاحية: كشف الاتجاه، المتغيرات الهيدرولوجية، مان–كيندال، السلاسل الزمنية، السليمانية.

Introduction

Rainfall and temperature are the two most important meteorological parameters that affect water resources and many other hydrological processes such as floods and drought. Change in their magnitudes temporally and spatially can be observed, on both regional and global scales, so detecting the trend of their changes is essential to fit the management plans of hydrological and other projects with those changes in their magnitudes, as well to confront the adverse effects of their amounts of change. Rainfall is a principal element of the hydrological cycle, hence understanding its behavior may be of profound social and economic significance. Detection of trends and oscillations in the rainfall time series yields important information for understanding the climate (10).

(20) stated that the changes in precipitation and temperature magnitudes are not globally uniform. Regional variations can be much larger, and considerable spatial and temporal variations may exist between climatically different regions. On the other hand, (1) reported that global climate changes may influence long-term rainfall patterns impacting the availability of water. The global average surface temperature has increased in the 20^{th} century by about (0.6°C), (7). (9) found that all India's mean annual temperature is rising at the rate of 0.05 °C/decade over 1901–2003 which is mostly due to the rise of maximum temperature (0.07 °C/decade) rather than because of the rise of minimum temperature (0.02 °C/decade).

Understanding trends and variations of current and historical hydroclimatic variables is pertinent to the future development and sustainable management of water resources of a particular region, (10). Many parametric and non-parametric methods have been applied for the detection of trends. The most frequently used non-parametric test for identifying trends in hydrologic variables is the Mann- Kendall (MK) test, (5, 6, 7, 8 and 9). The Mann Kendall trend test is used to analyze data collected over time for consistently increasing or decreasing trends (monotonic) in temperature and rainfall values. It is a non-parametric test, which means it works for all distributions, but the data should not correlate.

The minimum number of recommended measurements is therefore at least 8 to 10. Hence, the purpose of this study is to investigate the variability of the rainfall and temperature of Sulaymaniyah Governorate one of the rainiest regions in Iraq. The annual trend of both parameters has been investigated. This includes an understanding of the area's rainfall and temperature trends and variability. Understanding the uncertainties associated with rainfall and temperature patterns will provide a knowledge base for better management of agriculture, irrigation, and other water-related activities in the area under study. The overall objective of this study is to investigate the trend of the annual temperature and annual rainfall within Sulaymaniyah Governorate, by using the Mann–Kendall trend test and Sen's slope estimator.

Material and Methods

The study area: Sulaymaniyah Governorate is one of the largest Governorates in the north of Iraq in terms of area and population. It is bounded by the Iraq-Iran border from the east and north and on the south by Dyala governorate, on the west by Erbil governorate and on the southwest by Kirkuk governorate. Geographically located between the latitudes of °35′00 and °36 ′30 N, and longitudes of °44 ′25 and °46 ′20 E.

The area contains many Meteorological stations and the most considerable ones that possessed sufficient climatic data were Sulaymaniyah, Dukan, Chamchamal, Halabja, and Penjween stations which their elevations respectively are 884.8, 690, 708, 603, and 1284 meters m.a.s.l., Figure 1 shows the location map of the study area.

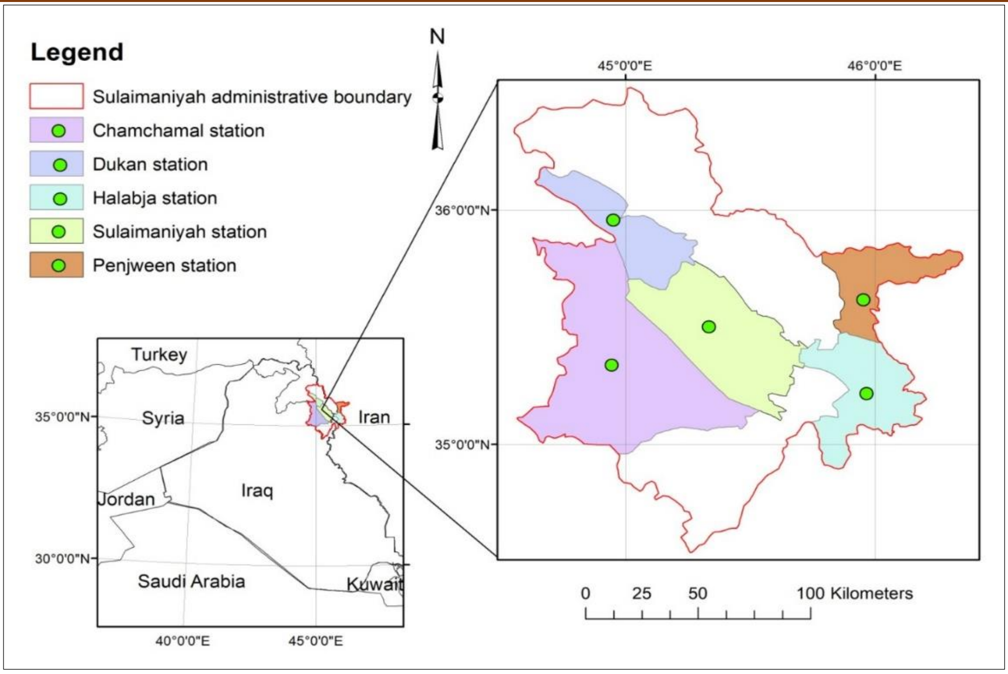

Figure 1 Location map of the study area.

The climate of the study area is under the effects of Mediterranean Sea climate. Minimum temperature recorded in January and the maximum temperature will be at July. The average annual rainfall in the studied area is 678 mm and the average annual temperature is 19.7 ^{o}C.

Approximately 56 % of the annual rainfall is precipitating in winter (from December to February).

Springtime (from March to May) is characterized by shower type of rain accompanied by thunder, hailstorms with precipitation of about 28 % of the annual precipitation. Summer (from June to September) is characterized by a rapid rise in temperature, low humidity, and absence of rainfall (2).

According to Koeppen climatic classification, the climate of the studied area takes the symbol of Csa which indicates to that the area is classified as interior Mediterranean, mild winter, dry and hot summer, (3).

Trend analysis: Trend analysis can be defined as the use of an empirical approach to quantify and explain changes in a system over a period of time. The purpose of trend testing is to determine if the values of a random variable generally increase (or decrease) over some period of time in statistical terms, (14).

Mann-Kendall trend test: The non-parametric Mann Kendall trend test was used for trend analysis of annual temperature and annual precipitation, (8 and 11). The Mann Kendall test is a statistical test widely used for the analysis of the trend in climatologic and hydrologic time series (19).

There are two advantages of using this test. First, it is a non-parametric test and does not require the data to be normally distributed. Second, the test has low sensitivity to abrupt breaks due to inhomogeneous time series (18). According to this test, the null hypothesis H0 assumes that there is no trend (the data is independent and randomly ordered) and this is tested against the alternative hypothesis Ha, which assumes that there is a trend, (12).

The Mann-Kendall test statistic S is given by:

$$S = \sum_{k=1}^{n-1} \sum_{i=k+1}^{n} \text{sgn}(X_i - X_k) \qquad (1)$$

X_j and X_k represents the annual values in years *j* and *k*, *j* >*k*, respectively, and

$$\text{sgn}(X_j - X_k) = \begin{cases} 1 & \text{if } x_j - x_k > 0 \\ 0 & \text{if } x_j - x_k = 0 \\ -1 & \text{if } x_j - x_k < 0 \end{cases} \qquad 2$$

And the *tau* (**τ**) is estimated as:

$$\tau = \frac{2S}{n(n-1)} \qquad (3)$$

Modified Mann-Kendall test which was suggested by (18) has used in this study, and the adjusted variance is given by:

$$\text{Variance } (\partial 2) = \frac{1}{18} \left[n(n-1)(2n+5) - \sum_{ti=1}^{m} ti(ti-1)(2ti+5) \right] \qquad 4$$

Where,
m: is the number of tied groups in the data set and
ti: is the number of data points in the i^{th} tied group.
In case of no ties (e.g., no multiple values for the same sampling time) the variance of S given by:

$$\partial^2 s = \frac{[n(n-1)(2n+5)]}{18} \qquad (5)$$

$$Z = \begin{cases} S-1/\partial_s & \text{if } S > 0 \\ 0 & \text{if } S = 0 \\ S+1/\partial_s & \text{if } S < 0 \end{cases} \qquad 6$$

And, 95% confidence corresponds to α = 0.05, where the null hypothesis of no trend is rejected when |Zcal. > 1.96. A positive (negative) value of Z_{mk} indicates that the data tend to increase (decrease) with time.

Sen's slope estimator: The magnitude of the trend is predicted by the Sen's estimator (19). Where the slope Ti of all data pairs was estimated according to the following relationship:

$$Ti = \frac{(X_i - X_k)}{j-k} \quad \text{for } i = 1, 2, 3, ... \qquad (7)$$

Where; Xj and Xk are considered as data value at time j and k (j > k).
The median of n values of Ti is computed by Sen's slope estimator and as follow:

$$Qi = \begin{cases} \dfrac{Tn+1}{2} & \text{if, n is odd} \\ \dfrac{\left[\dfrac{Tn}{2} + \dfrac{Tn+2}{2}\right]}{2} & \text{if, n is even} \end{cases} \quad (8)$$

Sen's nonparametric method is used and the test has been performed using XLSTAT software. Positive value of Qi indicates an upward or increasing trend and a negative value of Qi gives a downward or decreasing trend in the time series.

Moving average: The annual precipitation values for the selected meteorological stations are plotted versus time with 5 years moving average. It is used to damp and smooth out the random component leaving the effects of longer wet and dry cycles in the records of the long-term annual precipitation (2). The wet period can be recognized by comparing the five-year moving line with the average annual precipitation of the selected stations. This line fluctuated around the long-term mean. However, during drought period the five-year moving average line is located below the long-term average, while during the wet period it is located above the long-term average line.

Results and Discussion

Data analysis for 28,15,15,17, and 18 years of average annual temperature and rainfall were recorded at Stations of Sulaymaniyah, Dukan, Chamchamal, Halabja, and Penjween respectively were carried out. The results of the Mann Kendal trend test in Table 1 and the figures of 2,3,4,5 and 6 showed that at the significance level of 95%, the trend has detected in average annual temperature at the Stations of Sulaymaniyah, Dukan, and Penjween, where the trend was toward positive increasing in average annual temperature for each of the mentioned three stations. Furthermore, and according to the value of significance *p*-value (Two-tailed), a moderate level of the trend toward positive increase can be observed in the temperature of Chamchamal Station, since the value of (*p*) is more than 5% and equal or less than 30% (5), while at the rest of the studied stations the trend has not appeared in average annual temperature. The positive increase of the annual temperature in the mentioned stations was mainly due to growing population, urbanization, deforestation, overcrowding, and frequent human activities.

Regarding the trends of average annual rainfall for the studied recorded years, it can be observed from the results represented by Table 2 and the figures 7, 8, 9, 10, and 11 and based on the calculated value of (Z), the trend not appeared in average annual rainfall depth in all of the studied stations, so the null hypothesis is accepted at the significance level of 95%, however by taking the *p*-value, slightly trend toward negative was observed in Sulaymaniyah Station, where the value of(*p)* was greater than 30% and equal or less than 50%. While moderately trend toward negative and positive increase has appeared in Halabja and Chamchamal Stations respectively, Figures 8 and 9, but at Dukan and Penjwen Stations, the trend has not appeared in the average annual rainfall.

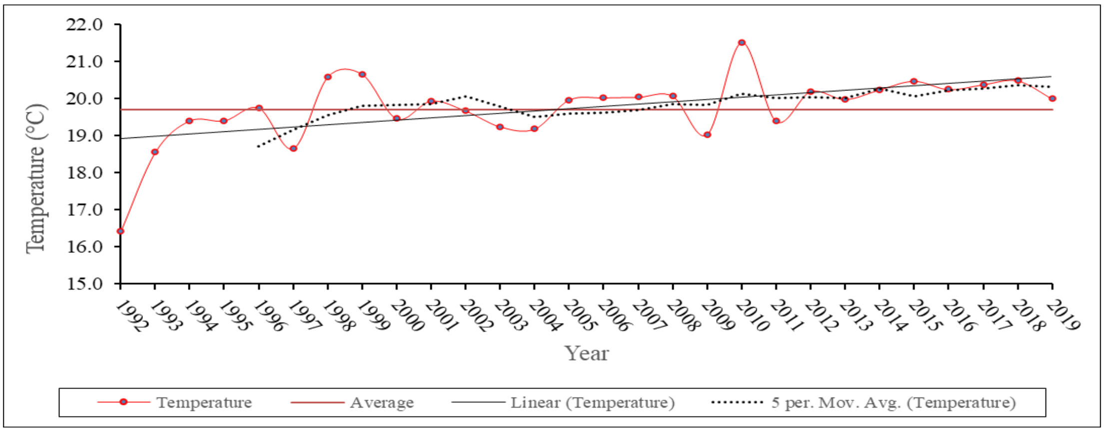

Figure 2 Plot of average annual temperature versus 28 years of record at Sulaymaniyah Station.

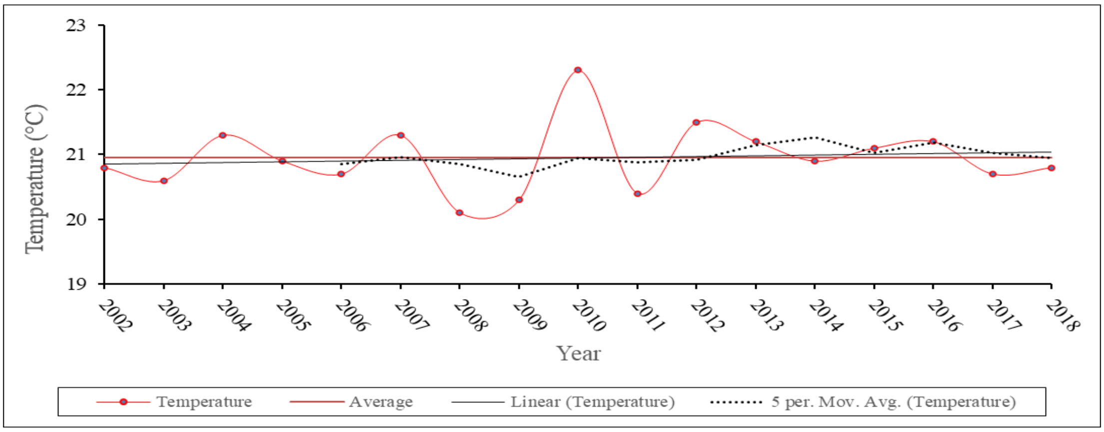

Figure 3 Plot of Average annual temperature versus 17 years of record at Halabja Station.

Table 1 Mann-Kendall trend test analysis of average annual temperature for the stations of the studied area.

Station	Years of record, (n)	S	Var.(S)	Kendall's Tau	Z value	Sen's value Q	*p*-value
Sulaymaniyah	28	171	2561	0.453	3.33	0.046	0.001
Dukan	15	74	404.33	0.722	3.63	0.1	0.0002
Chamchamal	15	35	404.33	0.34	1.69	0.057	0.091
Halabja	17	7	584.33	0.052	0.24	0.008	0.804
Penjwen	18	65	583.667	0.487	2.43	0.17	0.008

Table 2 Mann-Kendall trend test analysis of average annual rainfall (mm), for the stations of the studied area.

Station	Years of record, (n)	S	Var.(S)	Kendall's Tau	Z value	Sen's value Q	*p*-value
Sulaymaniyah	28	-40	2562	-0.106	-0.77	-5.189	0.445
Dukan	15	11	408.333	0.105	0.49	15.75	0.626
Chamchamal	15	33	408.3	0.314	1.58	32.517	0.114
Halabja	17	-42	589.333	-0.309	-1.68	-18.452	0.09
Penjwen	18	-4	589.333	-0.029	-0.12	-2.029	0.904

The results of Table 1 refer to that the highest increase in Q (°C/Year) was 0.17 where noticed in Penjwen station, and the lowest increase was (0.008) appeared in Halabja station. As well

from the figures 2, 3, 4, 5 and 6 appeared that the mean annual temperature was 19.474, 21.147, 13,405, 20.947, and 20.22 °C for Sulaymaniyah, Dukan, Penjween, Halabja, and Chamchamal stations respectively, whereas the figures 7, 8, 9, 10 and 11 showed that the mean annual rainfall was 700.789, 573.573, 1052.105, 657.252, and 466.4 mm for Sulaymaniyah, Dukan, Penjween, Halabja, and Chamchamal stations respectively,

It is worthy to mention that the magnitudes of average annual rainfall did not match with the changes in the values of temperature; this can be returned to that the average annual rainfall at the studied area governed by the climate of the Mediterranean Sea more than was affected by the changes in the local climate.

In general and in the case of these limited data, it can be said that the temperature trend is toward positive increase over the studied area, and the rainfall has not emerged any clear trend.

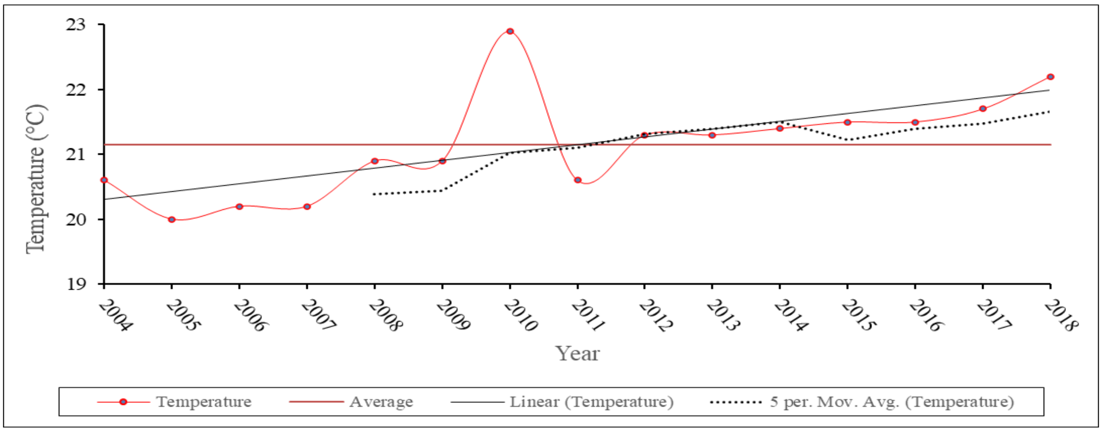

Figure 4 Plot of average annual temperature versus years of record at Dukan Station.

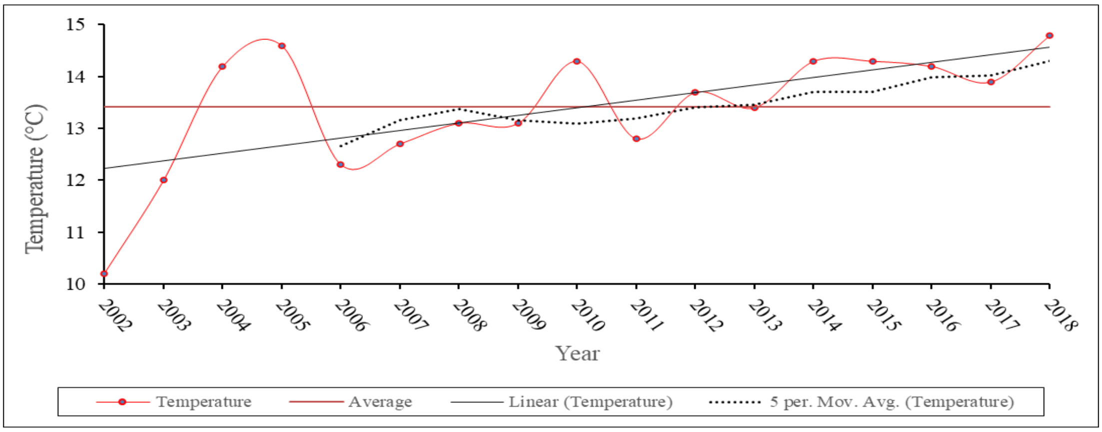

Figure 5 Plot of average annual temperature versus years of record at Penjwen Station.

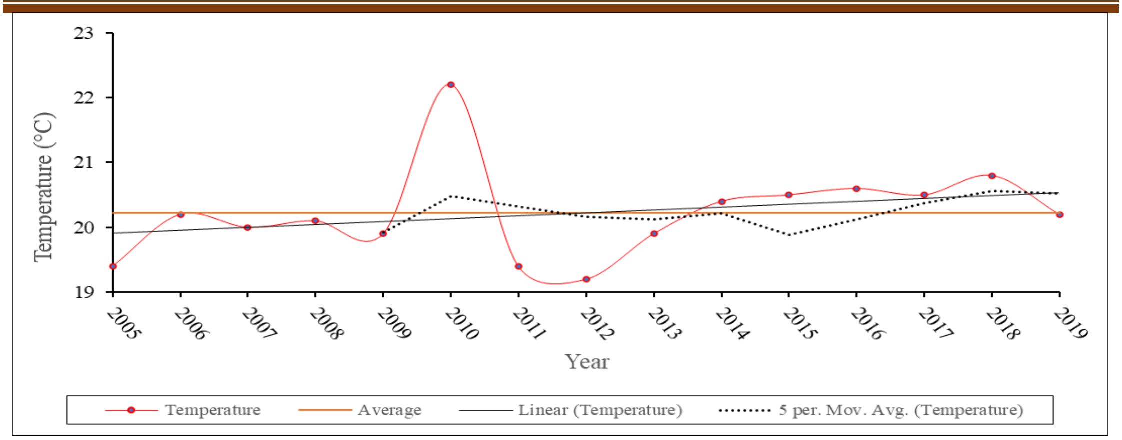

Figure 6 Plot of average annual temperature versus years of record at Chamchamal Station.

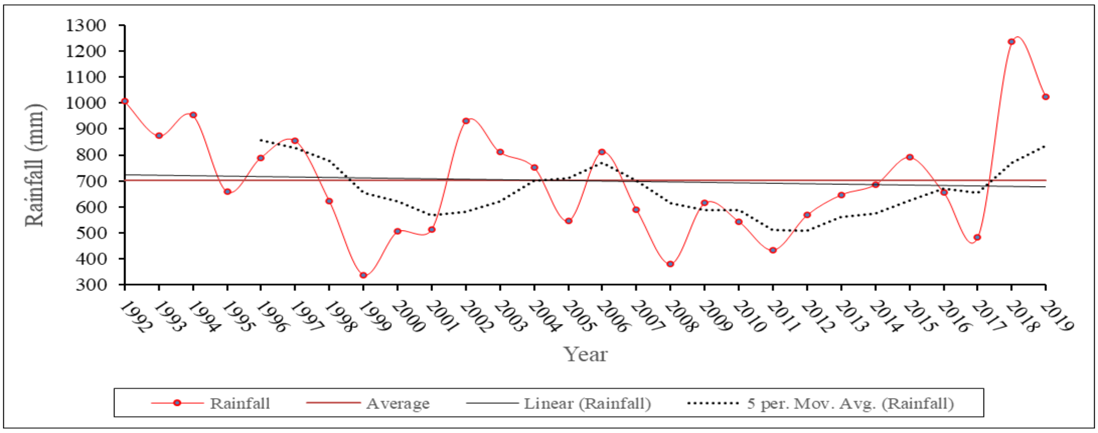

Figure 7 Plot of average annual Rainfall (mm) versus years of record at Sulaymaniyah Station.

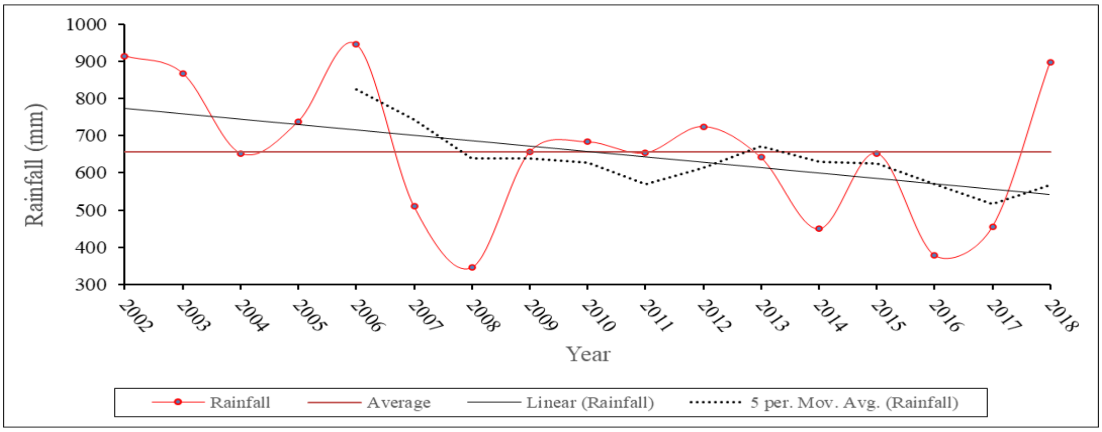

Figure 8 Plot of average annual Rainfall (mm) versus years of record at Halabja Station.

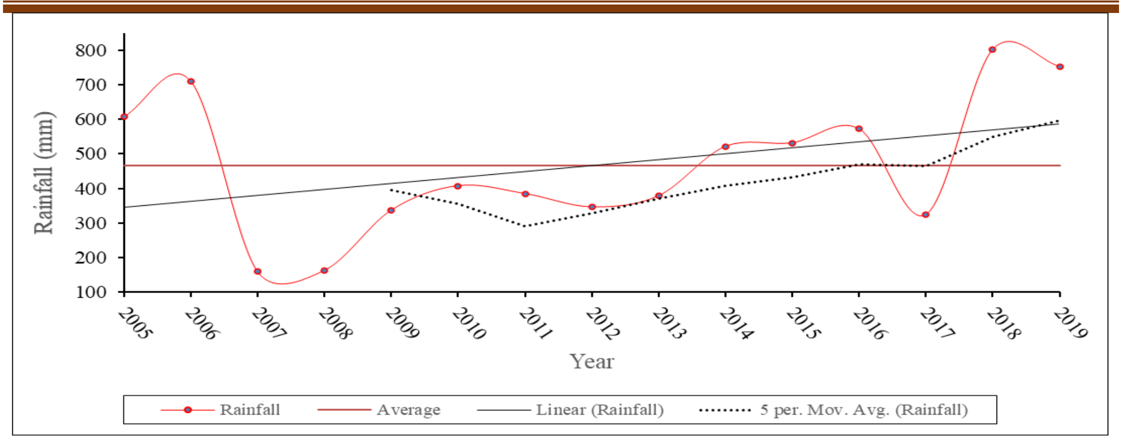

Figure 9 Plot of average annual Rainfall (mm) versus years of record at Chamchamal Station.

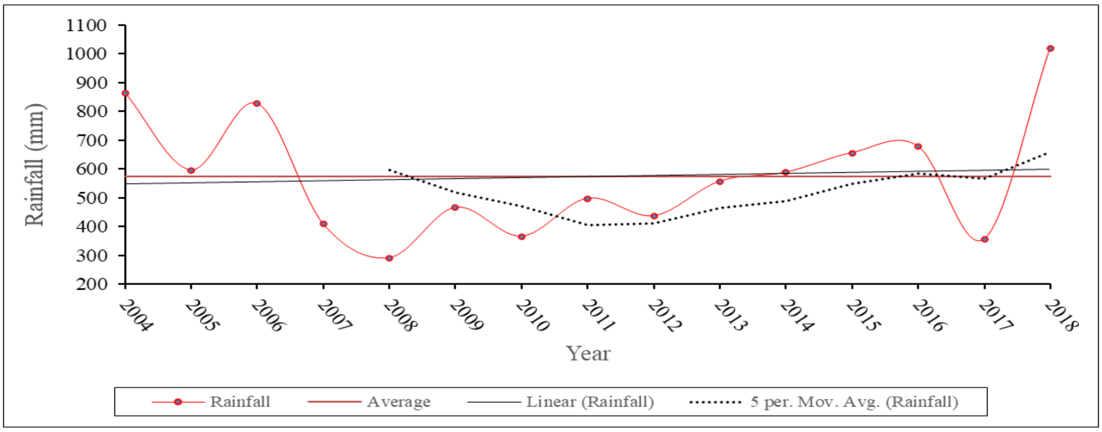

Figure 10 Plot of average annual Rainfall (mm) versus years of record at Dukan Station.

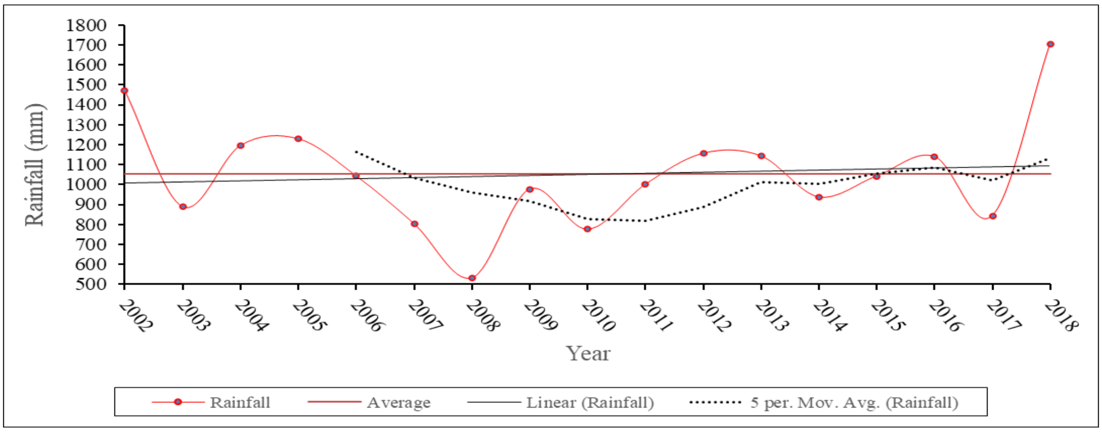

Figure 11 Plot of average annual Rainfall (mm) versus years of record at Penjwen Station.

From Figure 12, noticed that the average annual temperature for the studied area located between the highest value recorded at Dukan station and the lowest value for Penjwen station, while the highest value of annual rainfall depth observed at Penjwen Station and the lowest value recorded at Chamchamal station, and the rainfall values for the rest stations lies between the mentioned two extremes, see Fig 13. The highest value of the annual temperature at Dukan station can be attributed to the existence of Dukan Lake which absorb tremendous amount of solar radiation at the day and

release it as the form of heat to the surrounded air due to the difference in temperature of land and the water of lake, beside to the existence of wide urban area of Dukan and Raniya Districts which cause to the increase of the temperature. While the lowest value of annual temperature at Penjwen station return to the existence of high mountains and extensive vegetation area at that location. On the other hand the low rainfall magnitudes at Chamchamal station attributable to its latitude location and less vegetation cover, in compare to the other stations. But the highest value of rainfall at Penjwen station was due to its mountains and dense vegetation cover which are leaded to convenient the air condition to form the precipitation.
It is worthy to mention that the global warming and the world wide climate change are other reasons of overall changes in the values of both annual temperature and annual rainfall, whereas the climate of the studied area is under the effects of the Mediterranean seas and regional climates.

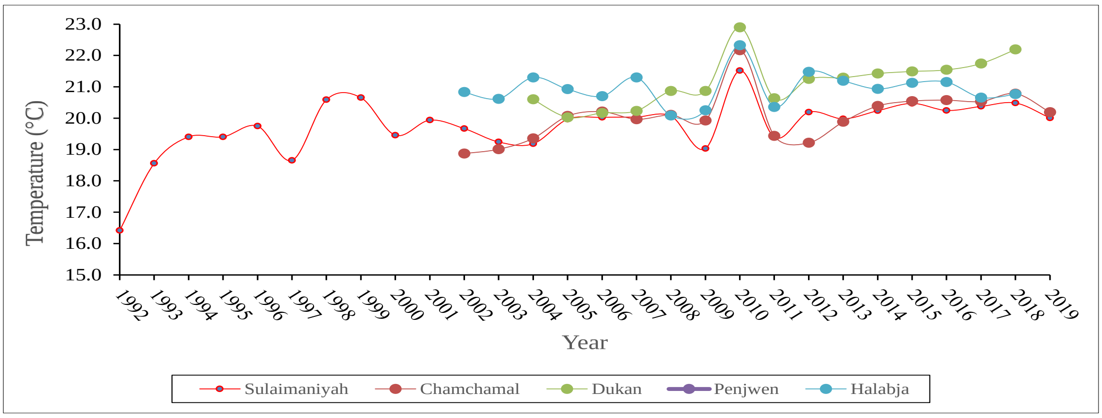

Figure 12 Average annual temperature for the recorded years at the studied stations.

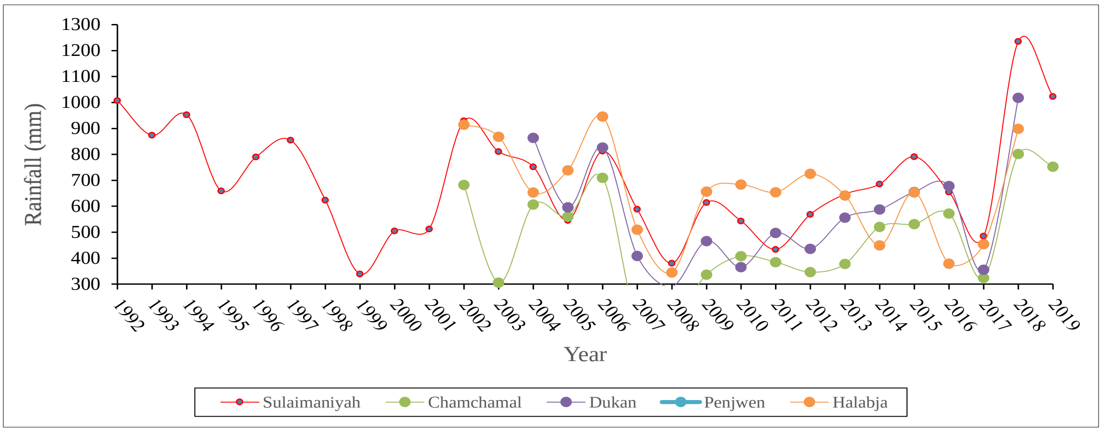

Figure 13 Annual rainfall depth for the recorded years at the studied stations.

Under the light of this study can be concluded that the trend patterns as discussed in the results lead to the confirmation of climate change in the studied area mainly due to growing population, urbanization, deforestation, overcrowding, and frequent human activities. The Z values of the MK Test revealed an upward increasing trend in temperature of Sulaymaniyah, Dukan, and Penjwen stations. Likewise, Sen's Slope Estimator has also estimated to detect the magnitude of slope for the studied data. According to the value of significance (P-two tailed), a moderate level of the trend toward positive increase can be observed in the temperature of Chamchamal station, while at the rest of the studied stations the trend has not appeared in average annual temperature. The trend has not appeared in the annual temperature values of Halabja, station.

Regarding the trends of average annual rainfall for the studied years, and based on the calculated value of (Z), the trend not appeared in average annual rainfall depth in all of the studied stations, at the significant level of 95%. However by taking the (P) values, slightly trend toward negative

was observed in Sulaymaniyah station, while moderately trend toward negative and positive increase has appeared in Halabja and Chamchamal stations respectively, but at Dukan and Penjwen stations the trend has not appeared in the average annual rainfall. Overall the temperature trend is toward positive increase over the studied area, and the rainfall showed no clear trend.

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