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Research Article

Assessment of Spatial and Temporal Variability of Rainfall Data Using Kriging, Mann Kendall Test and the Sen's Slope Estimates in Jordan from 1980 to 2007

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Abstract: This study aims to examine the spatial and temporal variability of the mean annual rain in Jordan during a 28-year period (1980-2007). The used meteorological datasets are the monthly rainfall amounts (mm) and the annual rainfall recorded at twenty five meteorological stations of the Jordan Meteorological Department. The stations are uniformly distributed over Jordan territory. Various spatial and statistical tools were used to display and analyze the spatial and temporal variability of rainfall data. ArcGIS was used to produce the spatially distributed rainfall data by using Kriging interpolation method. The non-parametric Mann-Kendall test was used to determine whether there is a positive or negative trend in data with their statistical significance. Sen's method was also used to determine the magnitude of the trends. The findings of the analysis show that statistically significant negative trends (95% confidence level) appear mainly in three areas, while no significant trends (95% confidence level) are found in the remnant areas. Further analysis concerning the seasonal Rain Intensity (RI) is needed, because there are different seasonal patterns, taking into account that, convective rain in Jordan occurs mainly within the winter season.

Keywords: Jordan, kriging, mann-kendall, rainfall, sen's method, trend analysis

INTRODUCTION

Rain variability in space and time is one of the most relevant characteristics of Mediterranean climate that is associated with economic, social and ecological implications. Extreme rain events have significant environmental consequences that cause considerable damages in urban as well as in rural areas.

The study of rain intensity trends is a good tool for policy makers, in order to estimate, among other factors, the erosion and the desertification that appear as a consequence of the climatic change in the eastern Mediterranean Sea. The objective of this study is to examine the spatial and temporal distribution of the mean annual rain intensity in Jordan.

Estimating the spatial distribution of climatic data has become an important part of studies helping to understand climate change and its effects throughout the world (Price *et al*., 2000). While many of the studies analyze climatic data in local meteorological stations, spatial distribution of climatic data is produced by estimating data at non monitored locations based on registered values at neighboring sites (Price *et al*., 2000). Different methods were proposed in several studies to estimate spatial distribution of climatic data mainly rainfall and temperatures (Phillips *et al*., 1992; Price *et al*., 2000). The methods which are commonly used to present spatial distribution of climatic data can be classified into three main groups; topographical, graphical and numerical (Daly *et al*., 1994).

Table 1: Coordinates of the meteorological stations used in the study

Station name	Latitude	Longitude
Bakora	35.617	32.667
Deir Alla	35.617	32.217
Gohr Safi	35.467	31.033
Irbid	35.850	32.550
Rabba	35.750	31.267
Shoubak	35.533	30.517
Wadi Dhuleil	36.283	32.150
Wadi Rayyan	35.583	32.400
Suweilih	35.900	32.000
Tafila	35.717	30.783
Oil Refinary	36.117	32.083
Qatranah	36.117	31.250
Ramtha	35.983	32.500
Madaba	35.800	31.717
Wadi Musa	35.467	30.317
Salt	35.733	32.033
Aqaba	35.000	29.550
Ras Munef	35.750	32.367
Amman Civil Airport	35.983	31.983
Ruwaished	38.200	32.500
Mafraq	36.250	32.367
Safawi	38.133	32.200
South Azraq	36.817	31.833
Queen Alia Airport	35.983	31.717
Ma'an	35.783	30.167
Jafer	36.150	30.283

Topographical methods include the correlation of point climate data obtained from topographic and synoptic parameters such as slope, wind speed, elevation, the location of barriers and direction (Houghton, 1979). Graphical methods include isohyets mapping, Thiessen's and rainfall elevation analysis (Peck and

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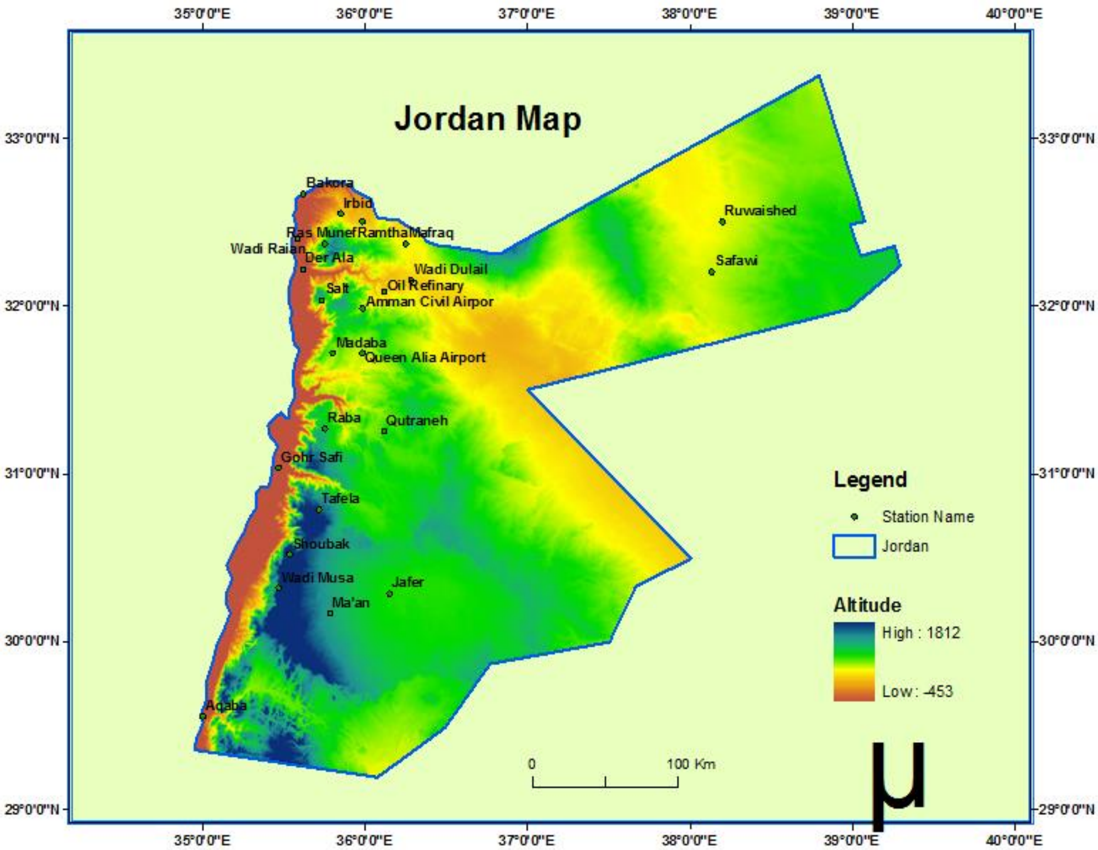

Fig. 1: Location of the twenty five meteorological stations used in the analysis

Brown, 1962). Numerical methods are the most attempted methods in order to estimate spatial distribution of climate data over the last years. Smoothing splines, optimal interpolation and Kriging and its variants are examples in numerical methods (Hutchinson and Bischof, 1983; Phillips *et al*., 1992).

Several spatial and statistical methods were used in the present study to produce spatially distributed rainfall data and to determine the trend of annual and monthly mean rainfall in Jordan for a 28-years period from 1980 to 2007. Monthly rainfall data were obtained from twenty five meteorological stations distributed over all areas of Jordan (Fig. 1). Table 1 displays the location of these meteorological stations.

After Kriging method, spatially distributed data were analyzed by Mann-Kendall test and Sen's Method for trend analysis.

LOCATION OF THE STUDY AREA

Jordan is one of the Middle Eastern countries covers an area of about 91880 sq. km, (Fig. 1). It is located in the northwestern part of the Arabian Peninsula, bordered by Syria in the north, Iraq to the northeast, Saudi Arabia to the east and south and the West Bank to the west.

The elevation of the study area rises from around 750 m below sea level (b.s.l.) at the bottom of the northern part of the Dead Sea to more than 1200 m a.s.l. in the southern part (Salameh and Bannayan, 1993).

Jordan lies among the dry and semi dry climatic zones which are characterized by their low rainfall and high percentage of evaporation, with a mix of a Mediterranean and dry desert climate. The temperature varies from a few degrees below zero in the winter to around 46°C in the summer season. Annual rainfall ranges from 50 mm in the desert to 600 mm in the northwest highlands. Only nine percent of Jordan's area receives more than 200 mm of rainfall annually. Approximately 92% of the rainfall evaporates, 5.4% recharges the groundwater and the remaining 2.4% becomes surface water (Salameh and Bannayan, 1993).

The country can be divided into three main geographical regions. They are namely the Jordan valley Wadi Araba, the high lands and the plateau.

METHODOLOGY AND DATA ANALYSIS

This section is dedicated to giving a brief overview of the methodology used in data analyses. In this study, the spatial and temporal variability of the mean annual rain intensity in Jordan is examined, for the period

1980-2007. The available meteorological data used in this study concern monthly and annual rain amounts, in order to calculate the mean annual Rain Intensity (RI). The monthly data were acquired for twenty five meteorological stations belonging to the Jordan Meteorological Department. The geographical distribution of the meteorological stations is depicted in Fig. 1. The spatial distribution of the mean annual rain intensity is studied using the Kriging interpolation method. Secondly, the temporal variability of the mean annual rainfall trends along with their significance are analyzed using Mann-Kendall test and Sen's method which were applied to the annual spatially distributed rainfall data trends, for a given confidence level in order to detect trends.

The Kriging method: Kriging is a generic name adopted by geostatisticians for a family of generalized least-squares regression algorithms. The basic idea is to estimate the unknown precipitation value at the unsampled location as a linear combination of neighboring observations.

The Kriging techniques is called the best linear unbiased estimator (blue) since it tries to have a mean residual error equal to zero (Clark, 1979), it aims to minimizing the variance of the errors and hence has a strong advantage over other estimation methods like inverse distance weighting or moving average.

Kriging forms weights from surrounding measured values to predict values at unmeasured locations. As with other interpolation methods, the closest measured values usually have the most influence. However, the kriging weights for the surrounding measured points are more sophisticated than other methods. Kriging weights come from a semivariogram that was developed by viewing the spatial structure of the data (ArcGIS Tutorial). To create a continuous surface or map of the phenomenon, predictions are made for locations in the study area based on the semivariogram and the spatial arrangement of measured values that lie nearby.

In kriging the value of a random variable is interpolated as a function of the geographic location *x* at an unobserved location using the measured values of the variable from nearby locations. It computes the best linear unbiased estimator $\check{Z}$ (i) of Z (i) based on a stochastic model of the spatial dependence (Isaake and Srivastava, 1989).

For each month and year, semivariograms were calculated using the following algorithm (Isaaks and Srivastava, 1989):

$$\gamma^*(h) = \frac{1}{2n}\sum_{i=1}^{n} (x(i) - x(i+h))^2 \tag{1}$$

where, $\gamma^*(h)$ is the estimated value of the semivariance for lag h; n is the number of pairs of weather stations whose location are separated by h distance; $x(i)$ and $x(i + h)$ are values of variable x at i and $i+h$, respectively; and i and $i+h$ are position in two dimensions.

Mann-Kendall analysis: The Mann-Kendall test is a non-parametric statistical procedure that is well suited for analyzing trends in data over time. The Mann-Kendall test does not require any assumptions as to the statistical distribution of the data (e.g., normal, lognormal, etc.,) and can be used with data sets which include irregular sampling intervals and missing data (Gilbert, 1987).

The Mann-Kendall Statistic (S) measures the trend in the data. Positive values indicate an increase in constituent concentrations over time, whereas negative values indicate a decrease in constituent concentrations over time. The strength of the trend is proportional to the magnitude of the Mann-Kendall Statistic (i.e., large magnitudes indicate a strong trend).

The data used for the Mann-Kendall Analysis should be in time sequential order. The first step is to determine the sign of the difference between consecutive sample results.

Sign (x_j-x_k) is an indicator function that results in the values -1, 0, or 1 according to the sign of x_j-x_k where j>k, the function is calculated as follows:

$$\text{Sign (xj - xk)} = \begin{bmatrix} 1 & \text{if xj - xk} & >0 \\ 0 & \text{if xj - xk} & =0 \\ -1 & \text{if xj - xk} & <0 \end{bmatrix}$$

The Mann-Kendall statistic (S) is defined as the sum of the number of positive differences minus the number of negative differences as follows:

$$S = \sum_{k=1}^{n-1}\sum_{j=k+1}^{n} \text{sign (xj - xk)}$$

Sen's estimator analysis: If a linear trend is present in a time series, then the true slope (change per unit time) can be estimated by using a simple non-parametric procedure developed by Sen (1968a and b). The slope estimates of N pairs of data are first computed by:

$$\text{Qi} = \frac{\text{Xj - Xk}}{j-k} \text{ for I} = 1,\ldots, \text{N}$$

where, x_j and x_k are data values at times j and k (j > k), respectively. The median of these N values of Q_i is Sen's estimator of slope. The Sen's estimator is computed by:

$$Q_{med} = Q\,(n+1)/2 \qquad \text{if N is odd}$$

Q_{med} = [Qn/2 + Q (n+2)/2)]/2   if N is even

Finally, Q_{med} is tested by a two-sided test at the 100 (1_α ͅ) % confidence interval and the true slope may be obtained by the non-parametric test.

Calculation of probability associated with the Mann Kendall statistic: To deal with the non-monotonic character of trends in the data, the method described by Kendall (1975) was used Kendall describes a normal-approximation test that could be used for datasets with more than 10 values; the test procedure is as follows:

- Calculate S as described above
- Calculate the variance of S, VAR(S), by the following equation:

$$VAR(S) = \frac{1}{18} = [n\ (n-1)\ (2n+5) - \Sigma\ t(t-1)\ (2t+5)]$$

where, n is the length of data set and t is the extent of any given tie or the number of data value in a group of determination.

- Compute a normalized test statistic Z as follows:

$$Z = \frac{S-1}{\sqrt{VAR(S}} \quad \text{if } S > 0$$

$$Z = 0 \text{ if } S = 0$$

$$Z = \frac{S+1}{\sqrt{VAR(S}} \text{ if } S < 0$$

Compute the probability associated with this normalized test statistic. The probability density function for a normal distribution is given by the following equation:

$$f\ (z) = \frac{1}{\sqrt{2\pi}} e^{-\frac{z^2}{2}}$$

Decide on a probability level of significance (95% typically).

- The trend is said to be decreasing if Z is negative and the computed probability is greater than the level of significance.
  The trend is said to be increasing if the Z is positive and the computed probability is greater than the level of significance.
  If the computed probability is less than the level of significance, there is no trend.

RESULTS AND DISCUSSION

Spatial variability of the mean annual rain intensity: Rainfall in Jordan usually occurs in winter (December to February), with some in autumn and spring (September to November and March to May) but

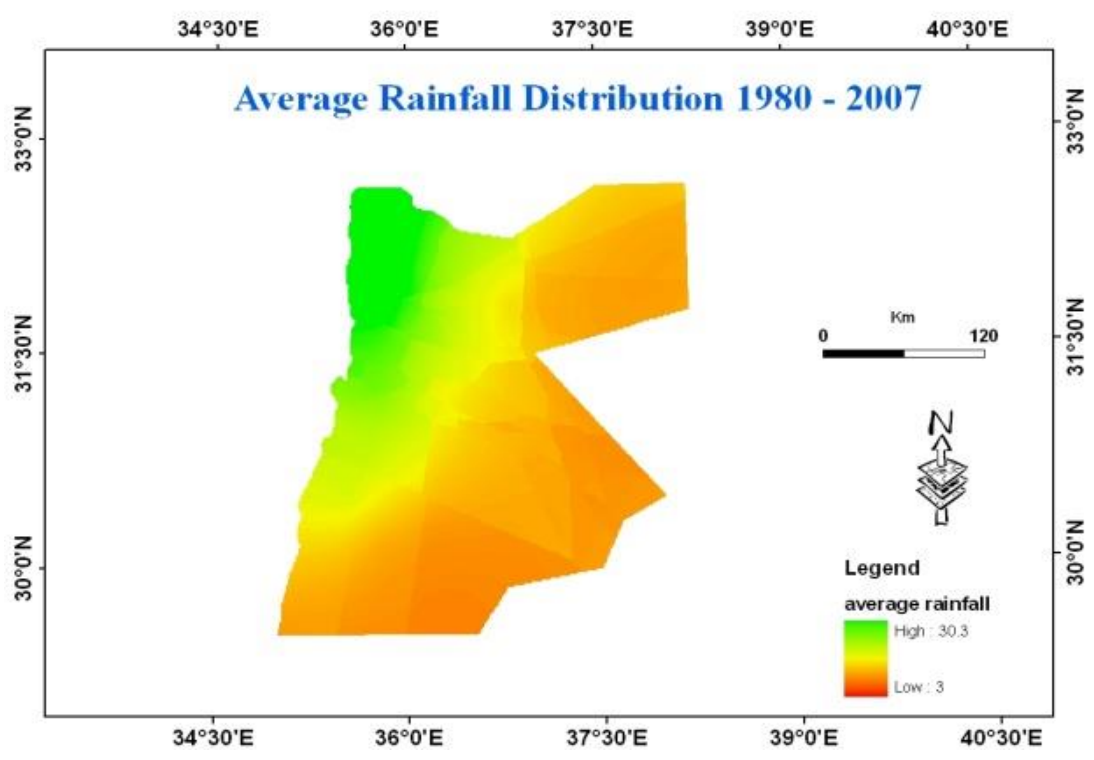

Fig. 2: Spatial distribution of the mean annual rainfall (mm/y), in Jordan, during the period 1980-2007

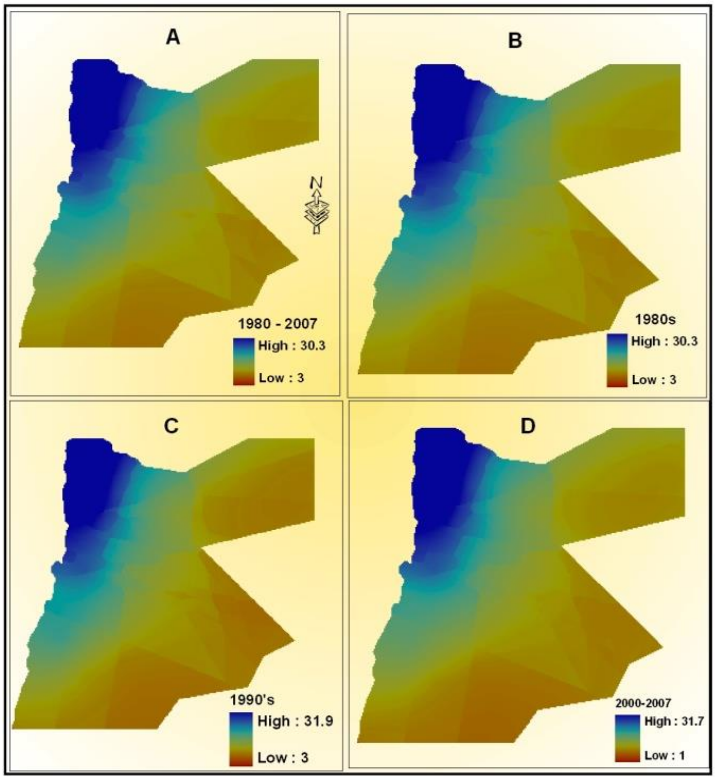

Fig. 3: Spatial distribution of the mean annual rainfall (mm/y), in Jordan, A: During the period 1980–2007, B in 1980's. C in 1990's, D during 2000- 2007

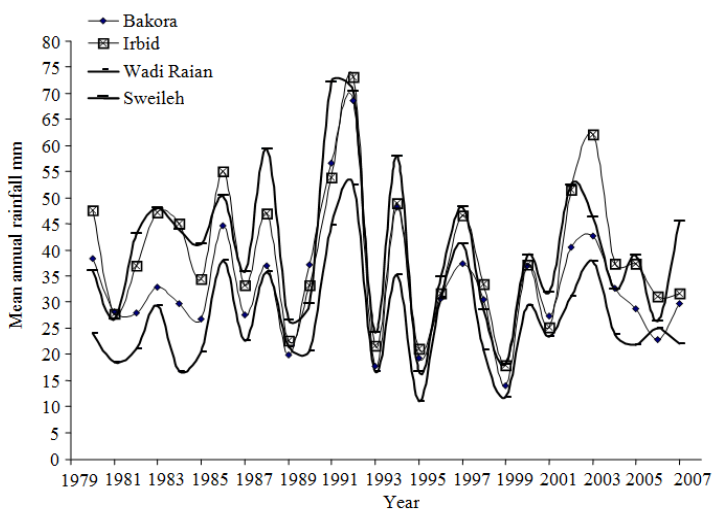

Fig. 4: Mean annual rainfall of 28 years in selected rainfall stations

the summers (June to August) are always very dry. As is common in dry land regions, rainfall is not only low, but also highly variable and unpredictable over time and space.

According to the performed analysis, high rainfall patterns are found in the western and north western sub-regions (Ras Munef ~50.2 mm/y, Suweilih ~40.2 mm/y and Irbid ~39 mm/y) followed by the Central sub-regions (Madaba ~27.5mm/y, Amman Airport ~21.4 mm/y), while low rainfall (~2.7 and 2.1 mm/y) dominate at south and eastern sub-regions (Aqaba ~2.1, Jafer ~2.7 and South Azraq ~5, respectively). The western and the north western sub-regions depict relatively higher rainfall patterns (Fig. 2). As it has been mentioned previously, the monthly rain total is divided by the respective monthly duration having as a result the mean monthly rain intensity and thereafter the mean annual.

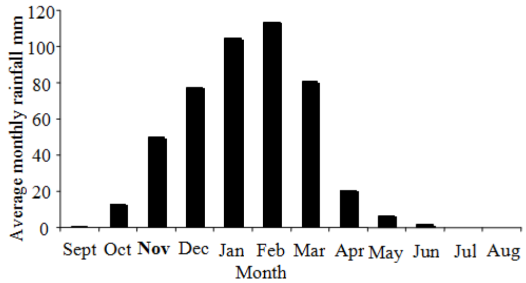

Fig. 5: The monthly mean rainfall distribution of Irbid station for 28 years

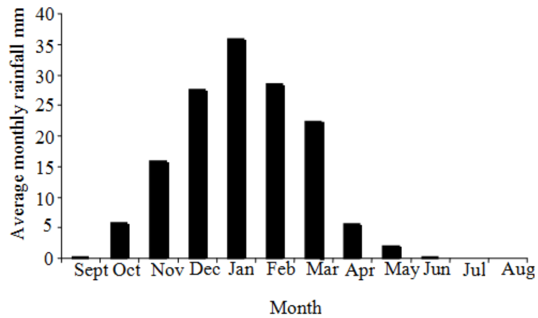

Fig. 6: The monthly mean rainfall distribution of Wadi Duhlail station for 28 years

The high mean annual rain intensity pattern is mainly attributed to the winter thunder storms appearing along the long mountainous range in the west and North West of Jordan and in the central part of Jordan Fig. 3. The winter rainfall is also of high intensity especially in west and north-west Jordan, with the appearance of thunder storms. These rainfalls are mainly attributed to the cold fronts or unstable air masses.

In summary, the climate of the study area is classified as semi-arid with mild, cold winters and hot, dry summers.

Temporal variability of the mean annual rain intensity: Trend analysis for rainfall in Jordan has been carried out in the present study with 28 years of rainfall data from 1980 to 2007. Mann-Kendall and Sen's Slope Estimator were used for the determination of the trends. Figure 4 represents the annual rainfall for 28 years with minimum rainfall occurrences in the years 1995 and 1999 and maximum rainfall in the years 1991 and 1992.

Monthly average is least for the month of June, July, August and September for all these 28 years (~0 mm) while maximum rainfall occurs in the month of January (98.1mm) followed by February (83.7 mm) and December (78.1mm). Figure 5 and 6 show the monthly average rainfall distribution of 28 years of individual months.

Mann-Kendall tests this section presents the results of the non-parametric Mann-Kendall test at 95% significance. The annual mean rainfall is subjected to the Mann-Kendall test at each station. Table 2 summarizes the total numbers of significant serial correlations, as well as the significant decreasing and increasing trends, during the study period 1980-2007. Detailed interpretations will be made in the following sections.

In the non parametric Mann-Kendall test, trend of rainfall has been calculated for each station individually together with the Sen's magnitude of slope (Q). In the Mann-Kendall test the Zc statistics revealed the trend of the series for 28 years for individual 25 stations.

The trend analysis revealed that statistically insignificant (95% confidence level) negative trends of the mean annual rain intensity appear in the wider area of Jordan.

The rainfall exhibits a decreasing trend in twenty stations investigated; only three stations of these (Aqaba, Wadi Dhuleil and Mafraq) showed a statistically significant decrease trend at least 5% level, while the rest showed insignificant decrease trend.

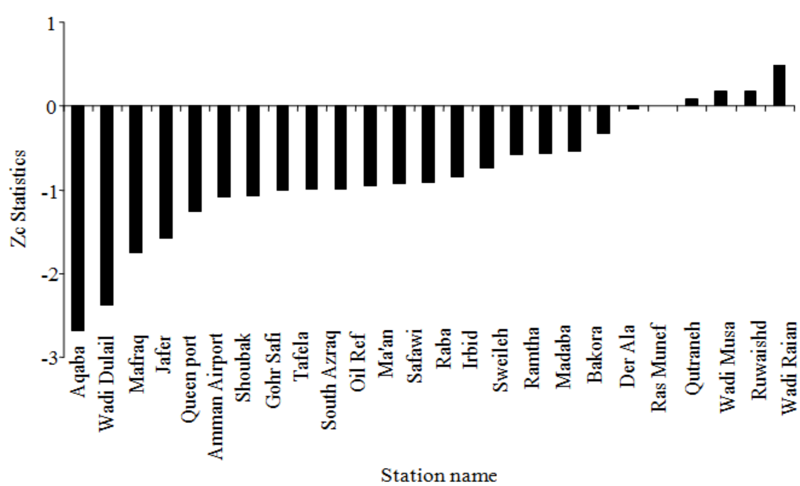

Fig. 7: Trend of Zc for individual stations for 28 years

Table 2: Annual rainfall trends in Jordan country over the 28 -year period using the Mann-Kendall test and Sen's slope methods

Time series station name	Mann-Kendall trend First year	Last year	n	Test Z	Sen's slope Q	Prop.	Trend (At 95% level of significance
Aqaba	1980	2007	28	-2.69	-0.112	0.99643	Decreasing
Wadi Dhuleil	1980	2007	28	-2.39	-0.236	0.99158	Decreasing
Mafraq	1980	2007	28	-1.76	-0.206	0.96080	Decreasing
Jafer	1980	2007	28	-1.58	-0.079	0.94295	No trend
Queen port	1980	2007	28	-1.25	-0.125	0.89435	No trend
Amman Airport	1980	2007	28	-1.09	-0.17	0.86214	No trend
Shoubak	1980	2007	28	-1.07	-0.265	0.85769	No trend
Gohr Safi	1980	2007	28	-1.01	-0.061	0.84375	No trend
Tafila	1980	2007	28	-0.99	-0.214	0.83891	No trend
South Azraq	1980	2007	28	-0.99	-0.058	0.83891	No trend
Oil Ref	1980	2007	28	-0.95	-0.103	0.82894	No trend
Ma'an	1980	2007	28	-0.93	-0.04	0.82381	No trend
Safawi	1980	2007	28	-0.91	-0.057	0.81859	No trend
Rabba	1980	2007	28	-0.85	-0.207	0.80234	No trend
Irbid	1980	2007	28	-0.75	-0.205	0.77337	No trend
Suweilih	1980	2007	28	-0.59	-0.20	0.72240	No trend
Ramtha	1980	2007	28	-0.57	-0.10	0.71566	No trend
Madaba	1980	2007	28	-0.55	-0.131	0.70884	No trend
Bakora	1980	2007	28	-0.32	-0.062	0.62552	No trend
Deir Alla	1980	2007	28	-0.04	-0.006	0.51595	No trend
Ras Munef	1980	2007	28	0	0.019	0.50000	No trend
Qatranah	1980	2007	28	0.08	0.003	0.53188	No trend
Wadi Musa	1980	2007	28	0.18	0.039	0.57142	No trend
Ruwaishd	1980	2007	28	0.18	0.009	0.57142	No trend
Wadi Rayyan	1980	2007	28	0.49	0.066	0.68793	No trend

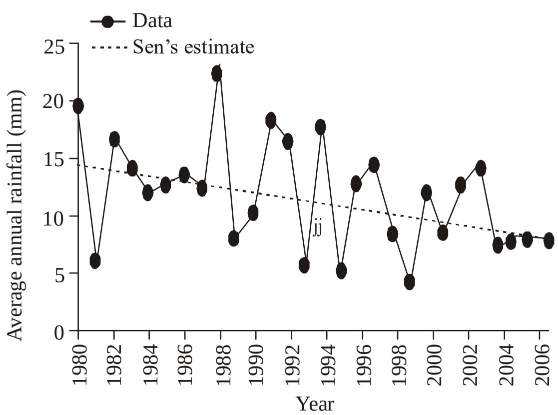

Fig. 8: Annual rainfall trends using Sen's slope method for Wadi Dhuleil station

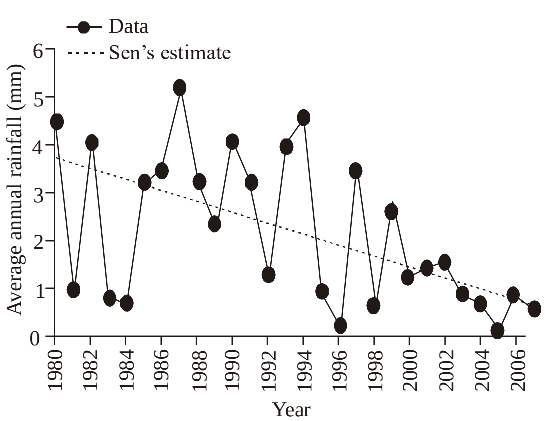

Fig. 9: Annual rainfall trends using Sen's slope method for Aqaba station

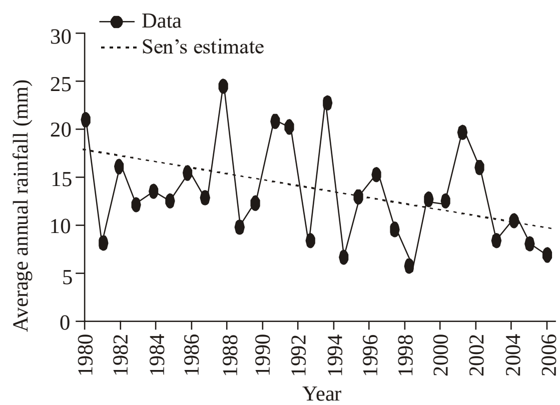

Fig. 10: Annual rainfall trends using Sen's slope method for Mafraq station

Thus Zc values for Qatranah, Wadi Musa, Ruwaishd and Ruwaishd stations showed an insignificant increasing trend while one station (Ras Munef) showed no trend (Fig. 7).

Sen's estimator of slope, following the Mann Kendall test, was employed to figure out the change per unit time of trends observed in all rainfall time series. Outputs are presented in Table 2, where a positive sign indicates an upward slope and a negative sign represents a downward one.

Table 2 demonstrates the results of change per unit time of the trends detected for each station for 28 years using Sen's Slope method which also indicates the slope magnitude for each station. For the negative trends, the highest (lowest) slope value was computed for Shoubak (Deir Alla) station, with a value of -0.265

mm/year (-0.006 mm/year). On the other hand, Sen's estimator value ranges from 0.066 mm/year at Wadi Rayyan station to 0.003 mm/year at Qatranah station for the positive trends.

The estimated Sen's slope (Q) has been calculated for 25 stations showing descending slope magnitude in twenty stations. Only the five stations (Qatranah, Ras Munef, Wadi Musa, Ruwaishd and Wadi Rayyan), showing an increasing trend in Sen's slope method. Figure 8 to 10 show the annual rainfall trends using Sen's Slope method for the three stations that shown a significant decreasing trend in Mann Kendall method.

The results of the Sen's Slope test seems to be fairly similar to those obtained from the Mann-Kendall test.

CONCLUSION

In this study, trends of annual rainfall in Jordan, for the period 1980-2007, were investigated with the use of two statistical tests.

The main conclusions of the performed analysis could be summarized in the following:

- The rainfall data at 25 sites were analyzed using non-parametric tests, Mann Kendall and Sen's methods. Analysis of the Mann Kendall test showed that most of the data did not reveal a significant trend. Statistically significant decreasing trends were observed at three stations while seventeen stations showed an insignificant decreasing trend. The remaining, one station has no statistically significant trend, while four stations have an insignificant increasing trend.
- Sen's Slope also indicates decreasing magnitude of slope in correspondence with the Mann-Kendall Test values. Therefore, it can be concluded that there is a decreasing trend of rainfall of the area in these 28 years.
- The results of the Sen's slope test seemed to be fairly similar to those obtained from the Mann-Kendall test.
- Rainfall varies in the different months and the different years as evidenced in the graphs. The spatial mean annual rain intensity pattern (period 1980- 2007) showed that high values are depicted at the western and north western mountainous sub-regions followed by those in the central and north eastern sub-regions of Jordan, while low values appeared in the majority of the eastern and southern regions of the Kingdom.
- Rainfall usually occurs in winter (December to February), with some in autumn and spring (September to November and March to May) but the summers (June to August) are always very dry.
- As is common in dry land regions, rainfall is not only low, but also highly variable and unpredictable over time and space.
- In summary, the climate of the study area is classified as semi-arid with mild, cold winters and hot, dry summers.

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