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TREND ANALYSIS USING MANN-KENDALL AND SEN'S SLOPE ESTIMATOR TEST FOR ANNUAL AND MONTHLY RAINFALL FOR SINJAR DISTRICT, IRAQ

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ABSTRACT

The time series rainfall data of 70 years (1940 – 2010) of Sinjar District used to identify the trend and slope magnitude of this series. To analyze the trend, the non-parametric test (Mann-Kendall test) and Sen's slope estimator were used. For developing a functional relationship between variables, a linear trend of rainfall data for the studied area evaluated using the linear regression. The annual trend analysis showed decreasing trend because the value of Mann- Kendall's tau and the magnitude of Sen's slope estimator were both negative and was found to be - 0.06501 and -0.7283, respectively. Also for the slope of the linear regression was negative and equal to −0.916 mm/year, which represents the rate of decreasing in trend for yearly annual rainfall. In addition, the results showed that the trend analysis of monthly rainfall has a varied trend of rainfall in the rainy months. Finally, the results showed a positive trend (increasing) for the months of October and April and negative trend (decreasing) for the other months.

KEYWORDS: Rainfall; Mann- Kendall (MK); Estimator of Sen's slope; Trend Analysis; Linear Regression.

1. INTRODUCTION

Rainfall is one of the vital climatic factors that can indicate climate change. The variation of rainfall would affect the hydrological properties and soil characteristics. The trend analysis of rainfall data is important in studying the influences of climate change for planning and management of water resources. Agriculture of Sinjar district in the north of Iraq primarily depends on rainfall and its distribution. Analysis of the precipitation pattern is considered to be of great importance over varies spaces over the past century, because it brings the scientific community exposure to global climate change (IPCC, 1996).

The key more efficiency directions in the management of water resources and flood management will increase by focus on hydro-meteorological conditions (Mondal et al., 2012). Rainfall patterns decide the cropping pattern sustainability and productivity of agriculture plan. The intensity and frequency of rainfall can be considered a condition for standard of human living. The knowledge about rainfall probability allows us to manage with the severe conditions faced during the season (Kumar et al. 2015). While the subject of climate change is a wide area, the change in rainfall characteristics (i.e. intensity and frequency) deserves urgent and systematic attention because it affects both clean water availability and food production (Dore, 2005). In many countries worldwide, the agriculture continues depends to

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the chance of occurring of rainfall, and nearly 70% of the net sown area is still depending on the rain (Narain et al. 2006). According to the IPCC (Intergovernmental Panel on Climate Change, 2007), in the future, climate change will affect the agricultural sector, and the risk of hunger and water scarcity will rise. Many studies have conducted in recent years to study trends around the world, see (Khan et al., 2000; Shrestha et al., 2000; Mirza, 2002), finding that the frequency of intense rainfall has increased in many parts of Asia, but the number of rainy days and total annual rainfall has decreased. From the studies of different types of time series data, it has been found that, the trend of time series of hydrological parameters is varying significantly (i.e. increasing, decreasing and remain as the origin). In case of rainfall, the human intervention by shifting land use from the effects of agriculture and irrigation activities is also another factor influencing climate change (Kalnay and Cai, 2003). In this study, the analysis of the long-term data series was processed to predict the influence of climate change. With the growing awareness of the potential adverse effects of global climate change on water supplies. The changes in rainfall were studied to assess the spatial pattern of rainfall trends over Sinjar district, located in northern of Iraq.

Study Area

The area of study (district of Sinjar) is located within the province of Nineveh in northwestern Iraq about 84 km from the center of Mosul at Latitude: 36° 18' 55" & Longitude: 41° 58' 42", as shown in Figure 1. It is surrounded by Al-Jazeera irrigation project from the north, the western Iraq desert to the south, Sinjar Mountain's highest peak elevation of 1400 meters from the sea level to the west, and Tallafar governorate to the east. The average annual rainfall obtained from meteorological station of Sinjar is about 400 mm for the studied period 1940-2010. The rainy season starts in October and ends in May. During this season, the excess rain water (runoff) flows north and east into the valleys from the hills. Maximum monthly evaporation usually occurs in July, reaching 563.4 mm. In December the value fell to 57.4 mm (Zakaria et al. 2015).

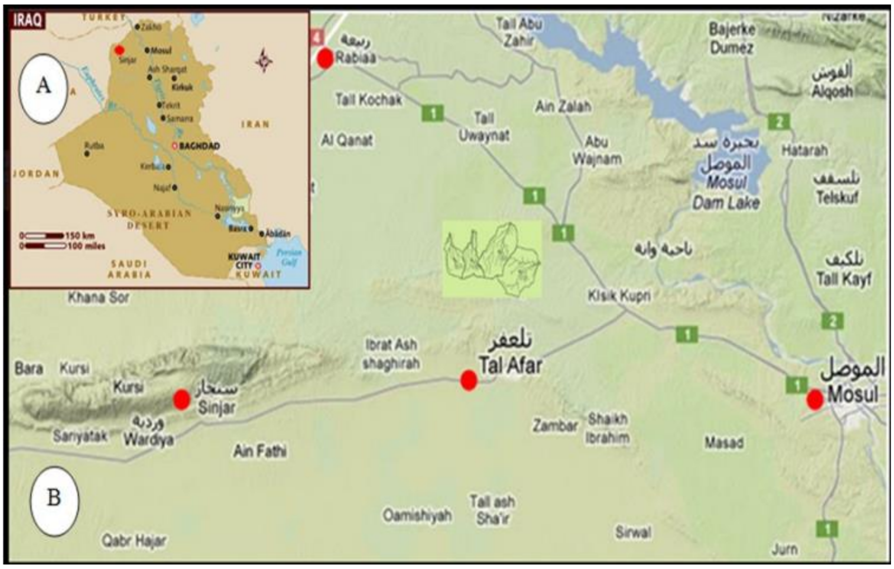

Fig. (1): Location of study area

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2. MATERIAL AND METHODS

3.1 Data collection

The average of monthly and annual data of rainfall for the Sinjar District has been collected from Mosul Directorate of Irrigation for 70 years period of from 1940 – 1941 to 2009 – 2010.

3.2 Rainfall Analysis Trend

For several years, the researchers and hydrologists are interested in trend analysis of meteorological variables (rainfall, temperature, relative humidity, wind velocity, and streamflow). The preceding studies suggested the non-parametric Mann-Kendall test is the most widely used method. Trend analysis of the selected area for rainfall is carried out in this study, firstly by checking the trend whether the Mann-Kendall (non-parametric) test for both annual and monthly average rainfall data series decreases, increases or no trends. Secondly, estimating the magnitude of trend using the Sen's slope estimator. Finally, in the third step a regression model was developed for the observation rainfall data. Below the details of the three steps for trend analysis:

3.2.1 Test of Mann-Kendall trend:

The non-parametric (Mann-Kendall) test (Kendall, 1975; Mann, 1945), due to its insensitivity to the normal distribution of data time series and outliers, this statistical model is mostly used for patterns identifying in hydro-meteorological data time series. The statistics of the Mann-Kendall test (S) are given below:

$$S = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} sign(X_j - X_i) \qquad (1)$$

Where:

n: numbers of data points

X_j and X_i are annual values in years j and i, j > 1 and Sign (X_j – X_i) calculated using the equation:

$$Sign(X_j - X_i) = \begin{cases} -1 \; for \; (X_j - X_i) < 0 \\ 0 \; for \; (X_j - X_i) = 0 \\ +1 \; for \; (X_j - X_i) > 0 \end{cases} \qquad (2)$$

Sign (X_j – X_i) means the individual sign capability that takes on the values [1, 0, or -1]. A positive S value indicates an ever-increasing trend, and a negative value indicates a downward trend. Nevertheless, the statistical analysis for the validity of the phenomenon needs to be carried out. The test procedure using the normal approximation test is described by Kendall (1975). This test assumed that the data set does not contain many connected values. The variance (S) is calculated with the following equation:

$$Var(S) = \frac{1}{18}\left[n(n-1)(2n+5) - \sum_{p=1}^{g} t_p(t_p - 1)(2t_p + 5) \right] \qquad (3)$$

Where:

n is the data points number,

g is the zero difference between compared values number,

tp is the number of data points in the p^{th} group.

A standardized measure of test statistics (Z_{mk}), determined using the following equation:

$$Z_{mk} = \begin{cases} \frac{S-1}{\sqrt{Var(S)}}, \; if \; S < 0 \\ 0 \quad if \; S = 0 \\ \frac{S+1}{\sqrt{Var(S)}}, \; if \; S > 0 \end{cases} \qquad (4)$$

The determined standardized Z_{mk} values follow distribution normal with variance normal "0"and "1" , it is utilized a measure of trend significance. In fact, this test measurement is utilized to null hypothesis test, H_0 if Z_{mk} is more than $Z_{\alpha/2}$. This value of Z_{mk} is contrasted and standard distribution normal table of two followed test at certainty levels of α=1 %, α=5 % and α=10 %. In a two-followed test, null hypothesis (H_0) is accepted for no trend if the determined value of Z_{mk} between – $Z_{1-\alpha/2}$ and $Z_{1-\alpha/2}$, and in this way, H_1 is rejected.

3.2.2 Test of Sen's Slope Estimator:

Simple linear regression is one of the most frequently used model for the linear trend identification. This method requires however the

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assumption of residual normality (McBean and Motiee, 2008). Viessman et al. (1989) stated that, due to the influence of natural phenomena, many hydrological variables show a pronounced right skewedness and do not adopt a normal distribution. Thus the Sen (1968) slope estimator is found to be a powerful tool to develop the linear relationships. Sen’s slope has the advantage over the slope of regression, in the sense that gross data series errors and outliers do not affect in much. The slope of the Sen was determined to be the mean of all pair-wise slopes for any pair of points in the dataset. The following equation is used to estimate each individual slope (m_{ij}):

$$m_{ij} = \frac{Y_j - Y_i}{j-1} \qquad (5)$$

Where,

i = 1 to n - 1,

j = 2 to n,

Y_j and Y_i are data values at time j and i (j > i), respectively.

If in the time series there are n values of Y_j, estimates of the slope will be N= n(n-2)/2. The slope of the Sen Estimator is the mean slope of such slopes N values. The Sen's slope is:

$$m = \begin{cases} m_{\left[\frac{N+1}{2}\right]} & \text{if } n \text{ is odd} \\ \frac{1}{2}\left(m_{\frac{N}{2}} + m_{\left[\frac{N+2}{2}\right]}\right) & \text{if } n \text{ is even} \end{cases} \qquad (6)$$

Positive Sen's slope reveals an upward trend while negative Sen’s slope suggests a downward trend.

3.2.3 Linear regression analysis

Linear regression analysis is a parametric model and one of the most common methods to detect a pattern in data series. By fitting a linear equation to the observed data, this model establishes a relationship between two variables (dependent and independent). Next, the data is tested there is to find out whether there is a relationship between the interest variables or not. This is possible with the scatter plot. If no relationship between the two exists variables, the linear regression model does not prove to be a useful model. The correlation coefficient which ranges from -1 to +1 is a numerical measure of this correlation between the variables. A coefficient value ± 1 for correlation indicates a good match. A value close to zero implies that the two variables have a random, non-linear relation. The linear regression model is generally described by the following equation:

$$Y = m * X + C \qquad (7)$$

Where, Y and X are the dependent variable (rainfall) and the independent variable (time in months or years), respectively, m is the line slope (mm/year) and C is the intercept constant coefficient. The coefficients (m and C) of the modal are determined using the Least-Squares method, which is the most commonly used method. Slope sign defines trend variable direction; increases if the sign is positive and decreases if the sign is negative.

The analysis of trend for the monthly and annual rainfall data has been obtained using Sen’s slope estimator and Mann – Kendall for Sinjar District using Minitab v19. The regression analysis was also used to establish a linear regression regarding time between the observed rainfall results.

RESULTS AND DISCUSSION

The results of statistical analysis of the rainfall data for the study area for the period 1940 – 2010 are discussed in this section, as shown in Table 1. From the table 1, it can be seen clearly, the average of annual rainfall data for over 70 years was found to be 400.5 mm, the minimum and maximum annual rainfall were 128.9 mm and 845.6 mm, respectively. Also, the maximum and minimum average monthly rainfalls over the same period were found to be 72.4 mm and 10.3 mm in December and October, respectively. For the months June to September all data has been neglected due to there no rainfall in this months and all statistical

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parameter near zero.

Table (1): Statistical Parameters for the rainy season (monthly and Annual Data)

Statistical Parameter \ Month	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	Annual
Average	10.3	34.5	72.4	71.1	63.9	70.3	51.1	27.0	400.5
S.D.	13.7	33.0	51.9	53.8	43.1	48.7	39.8	38.4	153.7
Skewness	2.5	1.2	1.1	1.5	1.0	0.7	1.0	2.1	0.5
Max.	80.3	132.4	213.0	234.9	208.8	184.9	174.5	185.7	842.6
Min.	0.0	0.1	9.8	3.5	4.9	8.3	1.3	0.0	128.9

Table 2 presented the magnitude of annual rainfall patterns obtained from the Mann-Kendall test, the slope estimator from Sen, and the linear regression. From table 2, the annual data trend is decreasing as both the slope estimator of the Sen and the tau (Z) values of Kendall were negative and found to be -0.728 and -0.065, respectively.

Table (2): Annual and Monthly rainfall trend analysis results with Significance level (α) = 5%.

Parameters \ Stat.	OCT.	NOV.	DEC.	JAN.	FEB.	MAR.	APR.	MAY	Annual
Kendall's tau	0.111	-0.044	-0.063	-0.117	-0.066	-0.031	0.012	-0.032	-0.065
P-Value	0.177	0.591	0.444	0.154	0.423	0.708	0.883	0.696	0.429
Sen's Slope	0.016	-0.055	-0.181	-0.304	-0.206	-0.092	0.026	-0.025	-0.728

Also there are a positive (increasing) trend for months October and April because the Sen's slope and Kendall's tau (Z) values were both positive, whereas the Kendall's tau (Z) and the Sen's slope values indicated a negative for trend for other months.

Figure 2, shows the linear regression analysis for the annual data, the linear regression slope is negative and equal to -0.9163 mm/year, which represents the decreasing annual rainfall trend similar to the rainfall trends found by the Sen slope estimator and the Mann-Kendall test as a negative trend indicated.

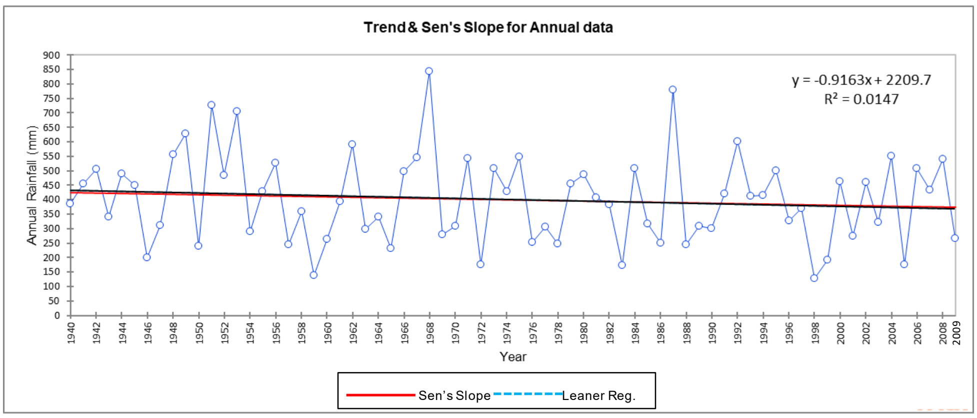

Fig. (2): Annual rainfall variation of the study area duration from 1940–1941 to 2009–2010

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Figure 3, show the regression analysis for the average monthly rainfall data. From these figure, the analysis of slope of linear regression was positive only for October with a value of 0.068 mm/year. The slope values were negative for the other months. This slope represents the monthly rainfall increasing or decreasing trend rate per year. The linear regression trend test result was almost similar to the monthly rainfall trends found by the Mann-Kendall test and the Sen's slope estimator. Table 3 shows the results of the analysis the linear regression.

Table (3): Linear Regression Results.

Statistical Parameter	OCT.	NOV.	DEC.	JAN.	FEB.	MAR.	APR.	MAY	Annual
Slope of linear regression analysis (m)	0.068	-0.061	-0.139	-0.137	-0.222	-0.099	-0.027	-0.262	-0.916

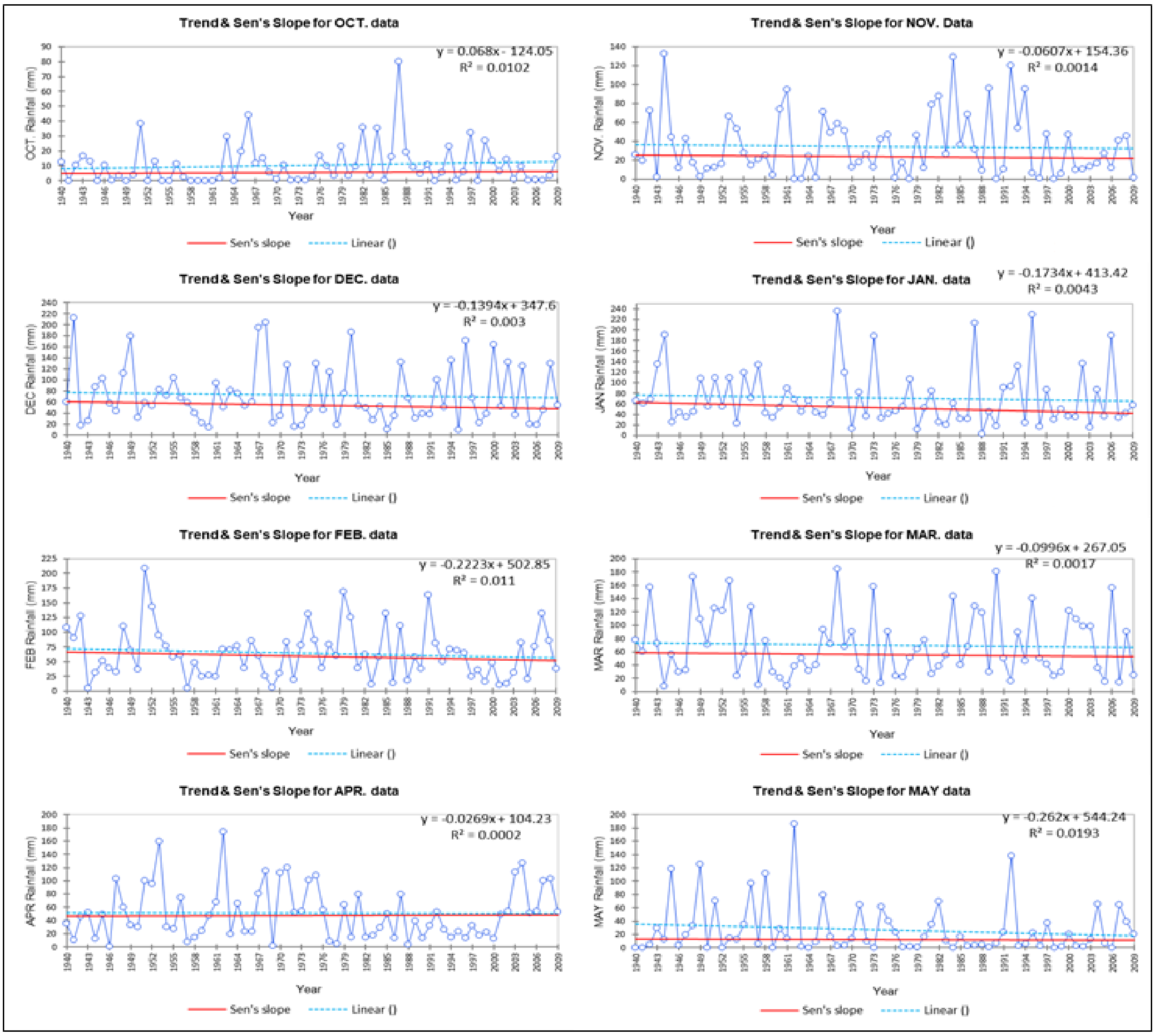

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Fig. (2): Average monthly rainfall variation for 70 years from October to May for the study area

3. CONCLUSIONS

In this study, Sen's slope estimator, non-parametric Mann-Kendall test, and linear regression test were investigating trends of average monthly and annual rainfall for Sinjar district. The records of Sinjar District rain station for the period of 70 years from 1940–1941 to 2009–2010 were analyzed. The results showed that there is decreasing in the trend of the annual rainfall data with significant trends observed at the 95% confidence levels. The trend of the annual rainfall decreasing rate was equal to −0.9163 mm/year. The results of analysis the average monthly rainfall trend revealed an increasing trend for the months October and April and decreasing for the other months. The analysis of linear regression showed the same trend results, except for the April which show the negative linear regression. The rate of increasing for the monthly rainfall of the October was 0.068 mm/year, and rate of decreasing for the monthly rainfall was equal to -0.061, -0.139, -0.137, -0.222, -0.099, -0.027 and -0.262 mm/year for months November, December, January, February, March, April and May respectively. The results obtained in this work are promising and might help engineers when designing the water resources structures and decision makers of agricultural sector in the district.

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