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Trend Analysis of Hydrological Drought for Selected Rivers in Iraq

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A B S T R A C T

The surface water in study area supports a range of uses such as water supply, irrigation and hydropower generation. Therefore, the assessment and analysis of the hydrological drought are important in the planning and management of the water resources. In this paper, hydrological drought was assessed using stream-flow drought index (SDI) based on observed mean monthly stream-flow data collected from three selected gauging stations at Greater Zab River, Lesser Zab River and Khazir River located in the North-Eastern region of Iraq. Trend analysis of the hydrological drought was investigated using Mann-Kendall non-parametric method to evaluate the significance of trends and Sen's slope method to determine the magnitude of the slope of trends for 47 years during the period 1965-2011. According to the SDI 3, 6 and 12-month time scales, the recorded drought was severe, and M-K method showed that the decreasing trends in the SDI values were statistically significant at α=0.05 mostly in the Greater Zab River and Lesser Zab River basins, increasing trend in SDI values is insignificant. This indicates that the hydrological drought is increasing over time at the study area.

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تحليل اتجاه الجفاف الهيدرولوجي لأنهار مختارة في العراق

إحسان فصيح حسن/ مركز بحوث السدود والموارد المائية ، جامعة الموصل ، العراق
يونس نجيب سعيد / مركز بحوث السدود والموارد المائية ، جامعة الموصل ، العراق

الخلاصة

تمد المياه السطحية في منطقة الدراسة مجموعة من الاستخدامات كتجهيز المياه والري وتوليد الطاقة الكهرومائية. لذلك فإن تقييم وتحليل الجفاف الهيدرولوجي مهم في تخطيط وإدارة الموارد المائية. في هذه الورقة البحثية، تم تقييم الجفاف الهيدرولوجي باستخدام مؤشر جفاف الجريان (SDI) استنادًا إلى بيانات معدل الجريان الشهري المرصودة التي تم جمعها من ثلاث محطات قياس مختارة في نهر الزاب الكبير ونهر الزاب الصغير ونهر الخازر في المنطقة الشمالية الشرقية من العراق. تم تحليل اتجاه الجفاف الهيدرولوجي باستخدام طريقتي مان- كيندال غير المعلمية لتقييم أهمية الاتجاهات وطريقة انحدار سنس لتحديد قيمة ميل الاتجاهات لمدة 47 عامًا خلال الفترة 1965-2011. وفقًا للجداول الزمنية لـ SDI 3 و 6 و 12 شهرًا، كان الجفاف المسجل شديدًا، وأظهرت طريقة مان- كيندال أن الاتجاهات المتناقصة في قيم SDI كانت ذات دلالة إحصائية عند α = 0.05 معظمها في حوض نهر الزاب الكبير وحوض نهر الزاب الصغير، الاتجاهات المتزايدة في قيمSDI قليلة وغير مهمة. هذا يشير إلى أن الجفاف الهيدرولوجي يتزايد مع مرور الوقت في منطقة الدراسة.

الكلمات الدالة: الجفاف الهيدرولوجي، تحليل الاتجاه، مان- كيندال، ونهر الخازر.

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1. INTRODUCTION

Drought is one of the world's more costly natural disasters, which has significant impacts on human activities, economy, agriculture and environment. Drought differs from other natural disasters because its impacts are cumulative in an extended period of time over large spatial extent. Therefore, it is important to analyze and assess the severity of drought. In general Palmer [1] defined drought as a moisture deficiency. Drought can be classified into: Meteorological, hydrological, agricultural and socioeconomic drought [2].

Several studies have been developed for the quantification of drought in Iraq. They are mostly based on meteorological parameters (precipitation air temperatures etc.) [3-6] for example Awchi and Jasim [4] used rainfall data from 22 stations to evaluate the metrological draught in Iraq. They concluded that the study area has suffered from subsequent drought events through half of the years considered, there were also few studies that focused on hydrological and agricultural drought such as [5,7]. However, there is a lack of quantification of drought characteristics based on hydrological parameters (stream-flows) and trend analysis in specific study areas. Thus, the purpose of this study is to identify the hydrological drought severity and to detect trends in the stream-flow drought over particular time periods.

Various drought indices have been used in Hydrological drought analysis in many parts of the world such as [8-10]. Stream-flow Drought Index SDI is the frequently and successfully used method in hydrological drought analysis in several studies [11, 12], Soumyashri and Patil [13] estimate hydrological droughts by using SDI in Bhima River in South India; they concluded that the drought was very severe.

Trend detection of Hydrometeorological time series data has attracted the attention of hydrologists and meteorologists during the last decades around the world [14-16], Rosmann et al [17] analyzed the trends for Hydrometeorological data around the world the results indicate that the stream-flow trends were negative, and precipitation trends were not very common. Trend analysis of drought can have an important influence on drought severity in the future and will play a significant role in the sustainable management of water resources. [18-20], Wu et al [21] detected spatial and temporal trends in the stream-flow drought in terms of frequency, duration and severity in Nebraska. They concluded that there is no uniform trend in the whole state, though some trends were found for specific regions.

The aim of this study is to assess the hydrological drought in the North-Eastern region of Iraq based on SDI and conduct trend analysis of the hydrological drought using Mann-Kendall non-parametric tests to evaluate the significance of trend and Sen's slope test to determine the magnitude of the slope of the trend during the period 1965-2011.

2. STUDY AREA AND DATA

The study area is located approximately between 35° 21' N to 38° 06' N latitude and between 43° 25' E and 46° 03' E longitude in the North-Eastern region of Iraq, with a total drainage area of about 27517 km^2. The mean annual precipitation varies from 375 to 1200 mm. The study area is divided into three river basins namely Greater Zab River, Khazir River and Lesser Zab River, they provide water supply for irrigation, drinking and fishing along its course. The major part of the study area lies inside Iraqi border Fig. 1.

Greater Zab River and Lesser Zab River are the Tigris River tributaries, Greater Zab River has an about 370 km long flowing through Turkey and Iraq, the total river basin area is about 23470 km^2 of which 62 % is in Iraq, mean basin elevation is about 1365 m. Lesser Zab River is an about 418 km long flowing through Iran and Iraq, The total river basin area is about 18735 km^2 of which 74% is in Iraq, mean basin elevation is about 954 m. Khazir River is the main tributary of Greater Zab River with a length of 116 km and total basin area of about 3280 km^2, mean basin elevation is about 665 m, all of the Khazir River basin is within Iraqi boundaries [22].

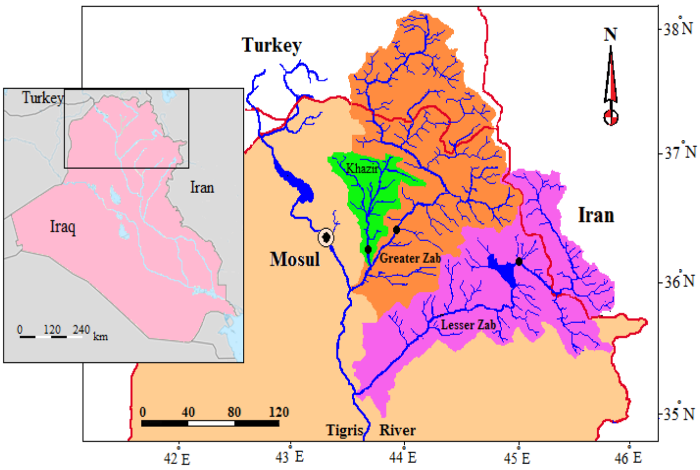

Fig. 1. Study area and location of gauging stations in the river basins

The observed mean monthly stream-flow data from three gauging stations (Aski-kalak at Greater Zab River, Dokan at Lesser Zab River and Manquba at Khazir River) located in the study area were selected for hydrological drought assessment Fig. 2. The duration of available data records at these stations are 47 years from 1965 to 2011.

3. METHODOLOGY

This study employed the SDI approach to analyze the hydrological droughts based on mean monthly stream-flow time series obtained from the selected three rivers gauging stations located in the study area. Then the Mann-Kendall trend test and Sen's Slope estimator were applied to the different aspects that resulted from the stream-flow drought analysis in order to determine their statistical significance.

In the proposed methodology for drought assessment, successive and non-overlapping time periods are used. October is considered the beginning of the hydrological year. Three time scale cases were included, these are: 3, 6 and 12 months. They defined in case of 3-month (seasonal) as (Oct to Dec), (Jan to Mar), (Apr to Jun) and (July to Sept), in case of 6-month (Semi-annual) as (Oct to Mar) and (Apr to Sept), and in case of 12-month (annual) as (Oct to Sept).

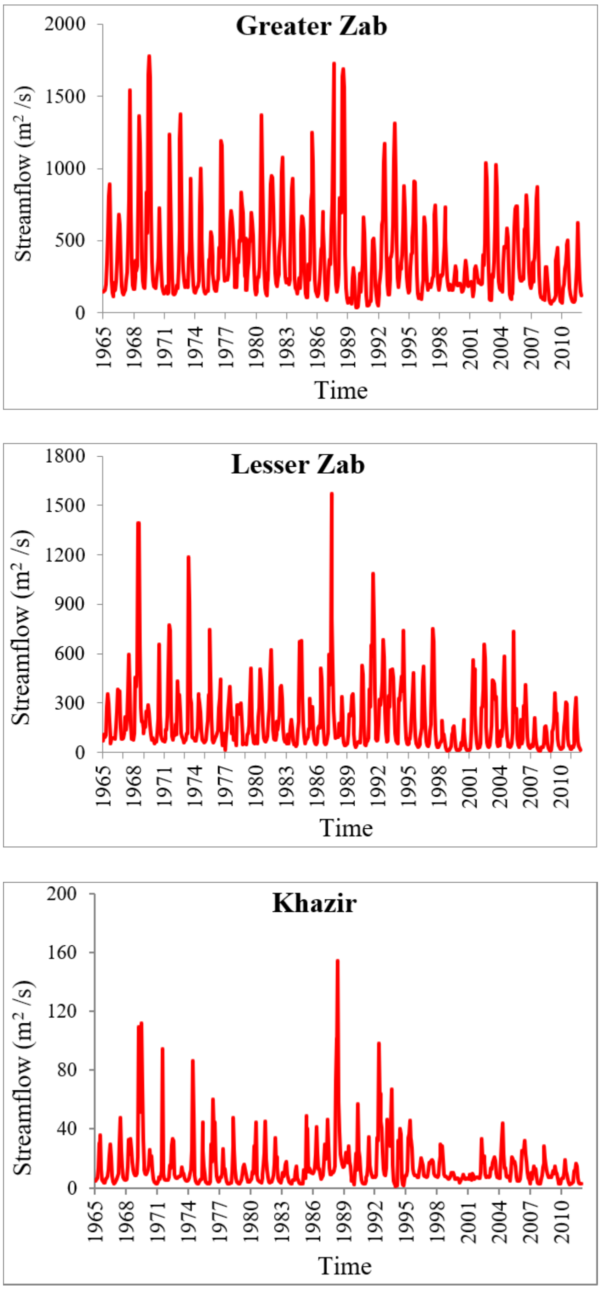

Fig. 2. Mean monthly streamflows of the selected rivers in the study

4. DROUGHT ANALYSIS

Based on mean of monthly stream-flow records for 47 years collected from 3 stream-flow gauging stations the SDI was applied for the purpose of drought assessment within the study area for time scale cases of 3, 6, and 12 months.

4.1 Streamflow Drought Index (SDI)

The SDI calculation procedures are similar to Standardized Precipitation Index (SPI). Nalbantis and Tsakiris [23] recently developed SDI using the methodology of SPI as the basis in order to characterize the hydrological drought. Using time series of observed monthly stream-flow volumes ($Q_{i,j}$) cumulative stream-flow volume ($V_{i,k}$) can be computed as follows [11]:

$$V_{i,k} = \sum_{j=3(k-1)+1}^{3k} Q_{i,j} \qquad k = 1,2,3,4 \qquad (1)$$

$$V_{i,k} = \sum_{j=6(k-1)+1}^{6k} Q_{i,j} \qquad k = 1,2, \qquad (2)$$

$$V_{i,k} = \sum_{j=1}^{12} Q_{i,j} \qquad (3)$$

i= 1, 2, 3, …….., j= 1, 2, …………..12

Calculation was carried out based on time scales (3-months) in equation -1, (6-months) in equation -2 and (12-months) in equation -3. Where i: is the hydrological year, j: is the month within that hydrological year and k: is the reference period. Based on the cumulative stream-flow volumes $V_{i,k}$, SDI is calculated for each k of the ith hydrological year by using Equation (4):

$$SDI_{i,k} = \frac{V_{i,k} - \overline{V}_k}{S_k} \qquad i = 1,2, \dots \dots, \quad k = 1,2,3,4 \qquad (4)$$

Where V_k and S_k is the mean and standard deviation of the cumulative stream-flow volumes of the reference period k respectively.

Based on SDI, Hydrological drought classification is defined through Table-1 [23], hydrological drought occurs when the SDI value is below zero (i.e., decreasing in the SDI value refers to an increasing in the drought severity) and Positive values indicate wet conditions.

Table 1
Classification of hydrological drought based on SDI values [23].

State	Description	Criterion
0	Non-drought	SDI ≥ 0.0
1	Mild drought	-1.0 ≤ SDI < 0.0
2	Moderate drought	-1.5 ≤ SDI < -1.0
3	Severe drought	-2.0 ≤ SDI < -1.5
4	Extreme drought	SDI < -2.0

5. TREND ANALYSIS

Trend analysis of droughts in a changing climate is essential to suggest appropriate water resource management strategies for the future. Trend analysis of drought is carried out using the commonly employed non-parametric Mann-Kendall test in order to examine the presence of an increasing or decreasing trend and to determine the statistical significance of trends in the SDI. Sen's slope was used to determine magnitude of the slope of the trends. The tests were performed based on the cases of time scales used in the calculation of SDI.

5.1 Mann-Kendall (MK) Test

The Mann–Kendall (MK) test is one of the most commonly used tests for detecting trends in climatological and hydrological time series data. The test is nonparametric, so it does not require any assumptions about normality or linearity [24]. MK test was originally developed by Mann [25]. The main purpose of MK test is to statistically investigate if there is a monotonic upward (increasing) or downward (decreasing) trend of a time series, and to determine their significance. In this test, the null hypothesis (H_0) refers to a non-existence of significant trend and the alternative hypothesis (H_a) refers to an existence of trend. The Mann- Kendall test statistics S can be computed using the following equation:

$$S = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} sign(X_j - X_i) \qquad (5)$$

Where:

$$sign(X_j - X_i) = +1 \quad if \quad (X_j - X_i) > 0$$

$$sign(X_j - X_i) = 0 \quad if \quad (X_j - X_i) = 0$$

$$sign(X_j - X_i) = -1 \quad if \quad (X_j - X_i) < 0$$

Where X_i and X_j is the data values at times i and j respectively, with $j > i$, n is the total number of data. A positive value of S means an upward trend, while a negative value means a downward trend, whereas zero means that there is no trend.

The variance of the statistic S and the standardized test statistic Z can be calculated by Equation (6) and (7) respectively [26]:

$$VAR(S) = \frac{n(n-1)(2n+5) - \sum_{i=1}^{m} t_i(t_i-1)(2t_i+5)}{18} \qquad (6)$$

$$Z = \begin{cases} \frac{S-1}{\sqrt{VAR(S)}} & if \quad S > 0 \\ 0 & if \quad S = 0 \\ \frac{S+1}{\sqrt{VAR(S)}} & if \quad S < 0 \end{cases} \qquad (7)$$

Where m is the number of tied groups and t_i is the number of data values in the ith tied group.

A positive value of Z refers an increasing trend, while a negative value refers a decreasing trend. In this study, significance levels of α =0.05 was used. At the 5% significance level, when $|Z| > Z1-\alpha/2=1.96$ then H_0 is rejected and H_a is accepted [26].

Based on two-sided test, when the probability value p of the Z statistic p-value is less than or equal to the chosen significance level, the null hypothesis H_0 (no trend in the time series) is rejected and the alternative hypothesis H_a (a trend exists) is accepted which means that there is a significant trend. Otherwise, H_0 is accepted and H_a is rejected which means that there is no significant trend. The customary confidence level in many statistical tests is 95%, this means that the significance level is 5%. In this study, the p-value of 0.05 is used as significant level.

5.2 Sen's Slope Estimator

Sen's slope estimator is a simple non-parametric method developed by Sen [27], This method is used to compute the magnitude of the slope after the identified trend tests. The slope (Qi) calculated between each pair of data by the Equation (8).

$$Q_i = \left(\frac{x_j - x_i}{j - i}\right), \quad i = 1, 2, \ldots..N, \quad i < j \qquad (8)$$

Where: x_j and x_i are data values at time j and i respectively. The median of N values of Q_i is Sen's estimator β of slope which is calculated as: $\beta = Q_{(N+1)/2}$, if N is odd and $\beta = (Q_{N/2} + Q_{(N+2)/2})/2$ if N is even. β is tested at a 95% confidence interval. A positive value of β indicates an upward (increasing) trend whereas a negative value indicates a downward (decreasing) trend in the time series.

6. RESULTS and DISCUSSION

The SDI values were computed for non-overlapping 3, 6 and 12-month time scales to assess the hydrological drought severity based on available monthly stream-flow volume data from the three selected gauging stations, and then the trend of calculated SDI values was analyzed using the MK and Sen's slope methods. Gamma distribution function was used to compute SDI values.

The calculated SDI values were classified based on Table 1; the results shown in the Fig. 3. represent values of SDI 3-months. For all stations the most severe drought occurred during (Oct - Dec) and (July - Sept) time scales while the most wet periods and moderate drought was recorded during (Jan to Mar) and (Apr to Jun) time scales. For the Greater Zab River the drought was extreme during (July - Sept) in 1989 and 2008 and during (Oct - Dec) in 1991, for other years, the drought was moderate to wet. For the Lesser Zab River extreme drought occurred during (July - Sept) in 2007. For the Khazir River the drought ranged from category 0 (non-drought) to 2 (moderate drought) in all periods except for one year was extreme drought during (Oct - Dec) in 1994. The minimum value of SDI-3 recorded was -3.31 during (July - Sept) at Greater Zab River Basin.

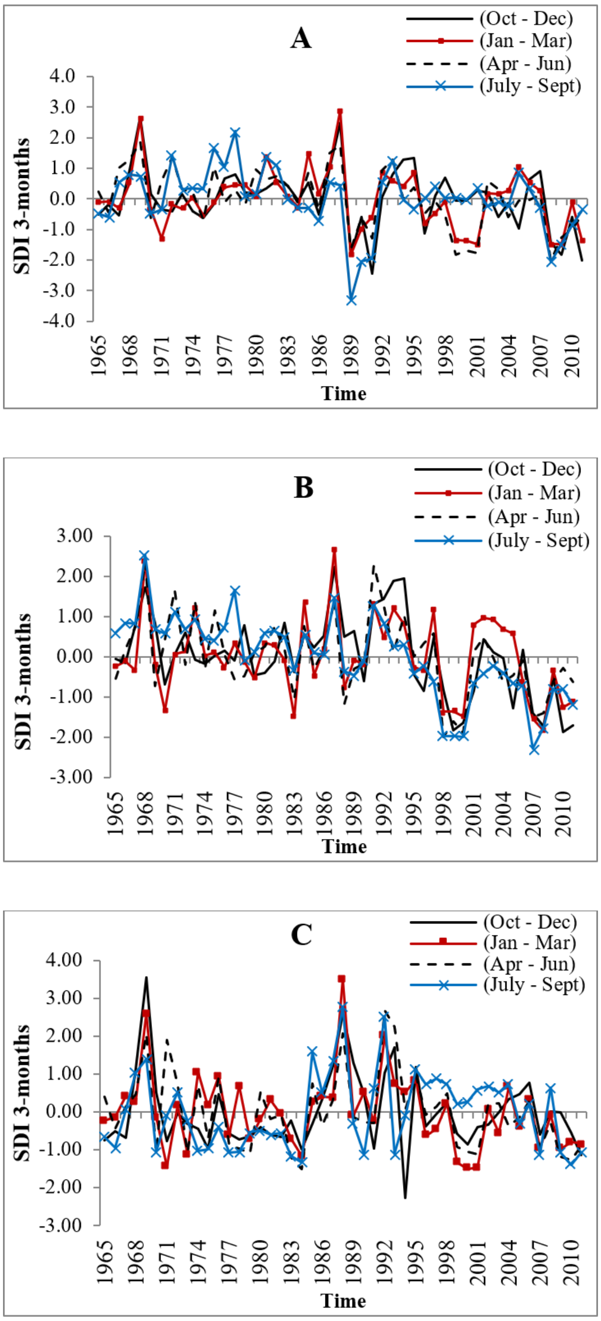

Fig. 4. SDI values based on 6-month timescale of: (A) Greater Zab River, (B) Lesser Zab River and (C) Khazir River

According to the SDI for the 12-month (annual) time scale results shown in Fig. 5, at Greater Zab River Basin extreme drought was recorded during the hydrological years 1989 and 2008, severe drought occurred during 2009. At Lesser Zab River Basin severe drought indicated during the hydrological years 1989–2000 and 2007–2008. With regard to the Khazir River, results are similar to those obtained from the case of 6-months and 3- months period where they tended to wet and moderate drought conditions. The minimum value of SDI-12 recorded was -2.60 at Greater Zab River Basin.

In general, hydrological drought tended to be a severe drought for the Greater Zab River and Lesser Zab River, while it was moderate drought for the Khazir River.

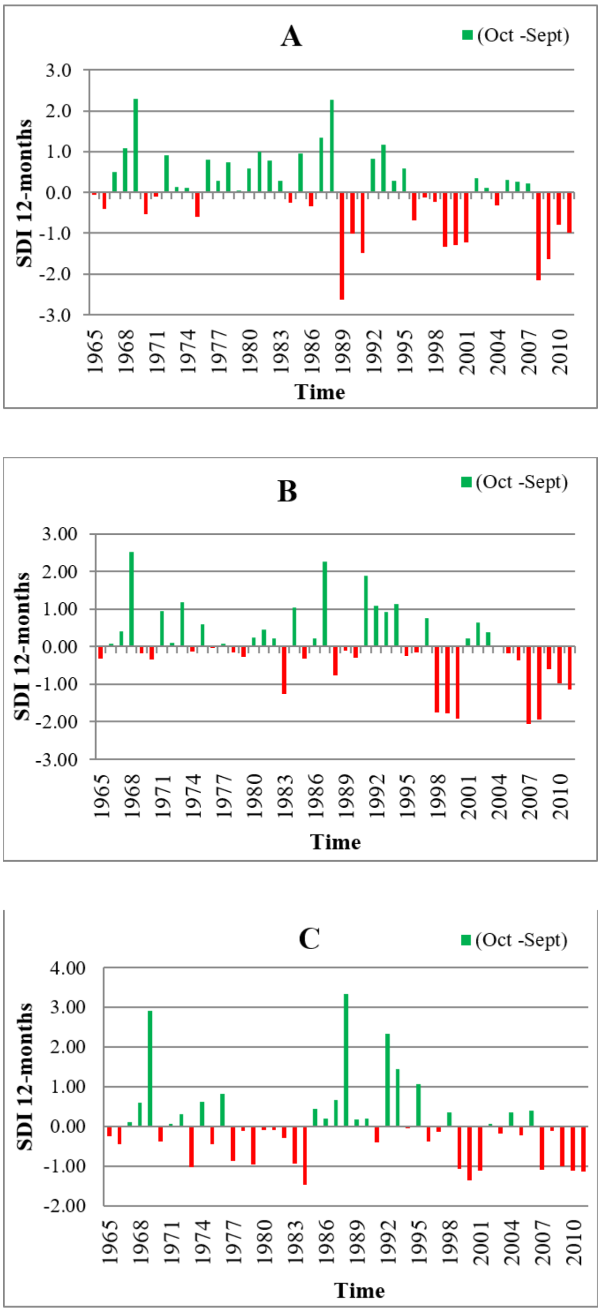

Fig. 5. SDI values based on 12-month timescale of: (A) Greater Zab River, (B) Lesser Zab River and (C) Khazir River

The non-parametric trend was examined (using MK and Sen's Slope) for all non-overlapping of SDI 3, 6 and 12-month time scales at selected gauging stations. The results shown in Table 2 explain the trend analysis of non-overlap SDI-3, decreasing trend (i.e., the calculated S and Sen's slope values negative) was found during the most of periods, based on a two-sided test these decreasing trends were considered significant (i.e., the p value is less than significance level of 5%) in Greater Zab River Basin during (Apr - Jun) and (July - Sept), and in Lesser Zab River Basin during (Oct - Dec), (Apr - Jun) and (July - Sept), while decreasing trends were insignificant (i.e., the p value is greater than significance level of 5%) in Greater Zab River Basin during (Oct - Dec) and (Jan - Mar) in Lesser Zab River Basin during (Jan - Mar) and in Khazir River Basin during (Jan - Mar) and (Apr - Jun). Increasing trend (i.e., the calculated S and Sen's slope values positive) is very few and insignificant and was found in Khazir River Basin during (Oct - Dec) and (July - Sept).

Table 2
Results of the MK test and the Sen's Slope estimator for SDI 3-month

Basin		Oct - Dec	Jan - Mar	Apr - Jun	July - Sept
Greater Zab	S	-117.0	-91.0	-321.0	-243.0
	p-value	0.289	0.411	0.003*	0.026*
	Sen's slope	-0.011	-0.009	-0.034	-0.02
Lesser Zab	S	-297.0	-129.0	-269.0	-369.0
	p-value	0.006*	0.242	0.013*	0.0001*
	Sen's slope	-0.03	-0.014	-0.026	-0.047
Khazir	S	55.0	-173.0	-171.0	32.0
	p-value	0.622	0.115	0.119	0.776
	Sen's slope	0.004	-0.015	-0.015	0.003

* Indicates significant trend at 95% confidence level.

The results of the Semi-annual SDI-6 trend analysis are shown in Table 3, a significant decreasing trend during (Apr - Sept) period and an insignificant decreasing trend during (Oct - Mar) period were found in the Greater Zab River and Lesser Zab River basins, whereas insignificant decreasing trend during both (Oct - Mar) and (Apr - Sept) periods was found in the Khazir River Basin.

Table 3
Results of the MK test and the Sen's Slope estimator for SDI 6-month.

Basin	Oct - Mar			Apr - Sept		
	S	p-value	Sen's slope	S	p-value	Sen's slope
Greater Zab	-91.0	0.411	-0.009	-337.0	0.002*	-0.033
Lesser Zab	-151.0	0.170	-0.014	-353.0	0.001*	-0.03
Khazir	-139.0	0.207	-0.01	-131.0	0.233	-0.011

*Indicates significant trend at 95% confidence level.

Finally, the results of the annual SDI-12 trend analysis are shown in Table 4, a decreasing trend was found in all basins. However, this result was considered significant trend for the Greater Zab River and Lesser Zab River Basins, whereas considered insignificant trend for the Khazir River Basin.

Table 4
Results of MK test and the Sen's Slope estimator for annual SDI 12-month.

Basin	Oct - Sept		
	S	p-value	Sen's slope
Greater Zab	-269.0	0.011*	-0.028
Lesser Zab	-291.0	0.006*	-0.027
Khazir	-165.0	0.121	-0.013

* Indicates significant trend at 95% confidence level.

7. CONCLUSIONS

In the present study hydrological drought was assessed using the SDI during the period 1965-2011 with monthly stream-flow data at the three selected stream-flow gauging stations.

According to the SDI results, the severe drought in Greater Zab River and Lesser Zab River Basins was especially observed during the time scales of summer months for both 3 and 6-months due to the very low of rain.

The time scale has an effect on SDI values, as the increase in the time scale from 3 to 12-month led to an increase in SDI value from -3.31 to -2.60 (i.e., decrease in drought severity), the decreasing in SDI values indicates increasing in drought severity.

Trend in SDI was analyzed using M-K and Sen's Slope methods. Both methods (MK and Sen's Slope) led to the same conclusions by detecting upward (increasing) and downward trends for all SDI time scales at selected gauging stations.

Statistically significant decreasing trends (at confidence level of 95%) in the SDI values are mostly found in the Greater Zab River and Lesser Zab River basins, this means that the severity of drought will be more in the future whereas decreasing trends considered statistically insignificant for the Khazir River Basin. The main conclusion from trend analysis is that the hydrological drought became more intensive over time, this is associated with human activity and climate change in the study area.

In the future, a large number of stations with sufficient length of stream-flow data could be engaged to assess and trend test of the hydrological drought in a more accurate method.

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