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TREND DETECTION OF METROLOGICAL DROUGHT IN NORTH OF IRAQ

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Abstract: This study presents an analysis of meteorological drought using multi time-scales of Standardized Precipitation Index SPI (6, 9 and 12 month), based on observed 49-year daily mean precipitation data records at 11 stations over the Northern region of Iraq. The detection of drought trends in results of SPI analysis was studied to identify whether there is any increase or decrease in the severity of drought at the selected meteorological Stations; Mann Kendall test and Sen's slope estimator were used to detect statistically significant trends. The results indicate that there is a statistically significant decreasing trend of SPI time series at 5% significant level in most of the selected stations. Based on drought categories the meteorological drought in the study region can be classified as mild drought.

Keywords: *Trend detection; Standardized Precipitation Index; Mann-Kendall; meteorological drought.*

1. Introduction

Drought is considered as an environmental disaster and has attracted the attention of ecologists, hydrologists, meteorologists and geologists [1]. Drought generally means the water deficit in a specific area during a specific period of time. According to the National Climatic Data Center–NOAA, there are four types of drought: meteorological, hydrological, agricultural and socioeconomic drought. However, droughts often become worse due to low Precipitation, Meteorological drought is usually defined as the precipitation is less than expected average [2, 3]. The meteorological drought is one of the most important problems suffered by most semi-arid regions around the world, including the northern part of Iraq, which mainly and directly depends on rain for irrigation (Rainfed agriculture), thus affecting agricultural production. Meteorological drought also indirectly affect agriculture through groundwater by depleting soil moisture and affecting crop production [4]. Standardized Precipitation Index SPI is the most widely and successfully used method by many researchers to describe the severity of a meteorological drought around the world such as Khatiwada & Pandey [5], Jang [6], Osuch et al. [7] and Edwards & McKee [8].

Determining potential trends in meteorological time series is important because it helps researchers to develop a future vision based on what happened in the past. Most of the previous studies related to trend detection in hydrology field around world focused on meteorological and hydrological variables such as temperatures, precipitation and streamflows [9-12]. Mostafa et al. [13] have identified trends in temperature and precipitation at selected locations in Egypt, time series analysis indicated that the number of hot days in a year will increase and there is

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no significant trend in precipitation. The trends of seven meteorological variables (max and min temperatures, max and min relative humidities, actual vapor pressure, wind speed and precipitation) were analyzed in Serbia to determine whether there was a significant trend in data [14]. Garbrecht et al. [15] determined the impact of precipitation trends on evaporation in Nebraska, Kansas, and Oklahoma, USA.

In Iraq, there are very few studies carried out to determine the trends in drought and its association with meteorological or hydrological drought indices, among these studies is the study presented by Hasan & Saeed [16] who used the hydrological drought index. In general, there are several researches concerned in drought trend detection [7, 17, 18]. Trend analysis has been used by Osuch et al. [7] to estimate the potential impacts of climate change on drought in Poland. Seasonal drought trends were assessed by Hänsel et al. [19] over Central Europe.
The main objectives of this study are: a drought analysis to evaluate the severity of meteorological drought in the northern region of Iraq by applying the Standardized Precipitation Index (SPI) at various temporal scales (6, 9, 12 months); and trend detection to identify the trend pattern of meteorological drought by adopting the nonparametric Mann–Kendall test and Sen's slope estimator.

2. Study area and Data used

In this research, the region located between 34° 55' N to 37° 30' N latitude and between 41° 16' E and 46° 18' E longitude in northern Iraq was selected as the study area due to its economic importance in Rainfed agriculture where more than 90 % of the whole Rainfed lands in Iraq is located in this area Figure 1. Agriculture area in Iraq is divided into rainfed area in the north and irrigated area in the middle and south. The area of rainfed lands has decreased in recent years; Because of the low precipitation. The availability observed precipitation data collected from different stations to cover the entire study area in the best way possible. Mean annual precipitation ranges between 350 and 1000 mm. The analysis period was 49 years from 1965 to 2014 (exception of Makhmur and Tal Abth stations that start from 1970 and 1980 respectively Due to lack of precipitation data). Precipitation data were prepared based on calendar year October-September. In the study area the rainy season starts from the October and extends up to the May and dry season starts from the June and extends up to the September, with more than 80% of annual precipitation occurring during November–April.

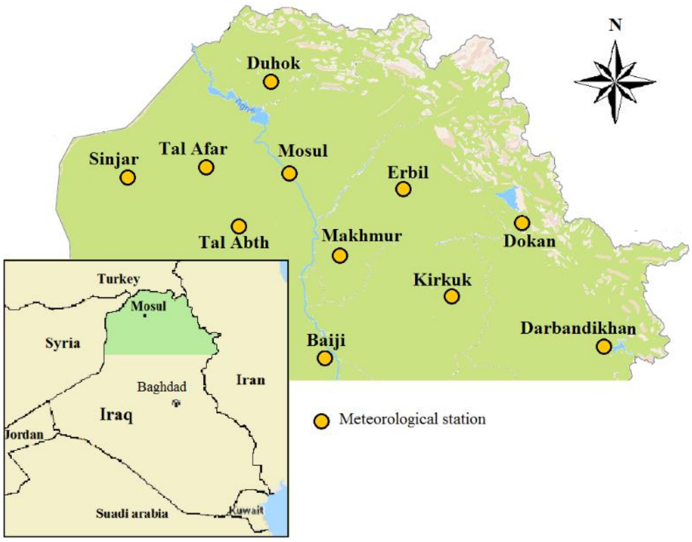


Figure 1. Location of meteorological stations used in this study (by researcher)

3. Materials and methods

3.1. Meteorological droughts

Drought causes crop production, economic losses and environmental problems, so it is necessary to study and assess historical drought in order to propose future plans to mitigate the effects of drought. The very simple and effective index for meteorological droughts is the Standardized Precipitation Index SPI [20]. It's only depends on precipitation data for drought assessment [21], and it is less complex than the many other indices. Different time scales (from 1 to 36 months) can be used in the calculation of the SPI. This study based on SPI for the identification and classification of drought or wet events and calculation of its severity. Multiple time scales of (SPI 6, 9 and 12-months) were used to determine drought. SPI 6 is very effective in indicating precipitation over different seasons and used to monitoring agricultural impacts. SPI 9 indicates precipitation over a medium periods. The SPI 12 reflects long-term precipitation patterns and used to monitoring hydrological impacts as streamflows, reservoir levels.

To calculate the SPI value, the precipitation data of each selected station is fitted to the Gamma distribution function, which is then transformed into the standardized normal distribution with a mean of zero and variance of one, and this represents the SPI value as follows:

$$SPI = \mp\left(t - \frac{2.515517+0.802853t+0.010328t^2}{1+1.432788t+0.189269t^2+0.001308t^3}\right) \quad (1)$$

Minus for $0 < H(x) \leq 0.5$, plus for $0.5 < H(x) < 1.0$, $H(x)$ is cumulative probability distribution and t is:

$$t = \sqrt{ln\left(\frac{1}{H(x)^2}\right)} \qquad for\ \ 0 < H(x) \leq 0.5 \qquad (2)$$

$$t = \sqrt{ln\left(\frac{1}{1-H(x)^2}\right)} \qquad for\ 0.5 < H(x) \leq 1 \qquad (3)$$

SPI calculated using Excel program and drought calculator software. For more details about SPI calculation can be found in [22, 23]. Table 1. shows the classification of the severity of drought according to the SPI values [21].

Table 1. Drought severity classification according to the SPI index

SPI Value	Category
≥ 2	Extremely wet
1.5 to 1.99	very wet
1.0 to 1.49	Moderately wet
0.0 to 0.99	Mild wet
-0.99 to 0.0	Mild drought
-1.49 to -1.0	Moderately drought
-1.99 to -1.5	Severely drought
≤ -2	Extremely drought

In the present study, SPI (6, 9 and 12-month) values are used as an input data to trend analysis.

3.2. Trend Detection

Trend detection in the meteorological drought index values was attempted using two statistical methods: Nonparametric Mann–Kendall test and Sen's slope estimator. Trend analysis was used to determine whether there was an increase or decrease trends in meteorological droughts and its significance.

The widely used Mann-Kendall method [24, 25] was applied to test the existence of trends in the SPI values and the statistical significance of these trends. It is controlled by the null hypothesis (H0: Indicates no significant trend) and the alternative hypothesis (Ha: Indicates that there is a trend over time) at specific significance level α. The Mann–Kendall statistic (S) is calculated by Equation 4:

$$S = \sum_{i=1}^{n-1}\sum_{j=i+1}^{n} sign(X_j - X_i) \qquad (4)$$

Where Xj and Xi are the data values in j and i sequence respectively, n is the total number of data series (months), and sign () is the sign function. Positive value of S statistics indicates an increasing trend and vice versa. Standard normal statistic Z is computed by equation 5:

$$Z = \begin{cases} \frac{S-1}{\sqrt{VAR(S)}} & if\ \ S > 0 \\ 0 & if\ \ S = 0 \\ \frac{S+1}{\sqrt{VAR(S)}} & if\ \ S < 0 \end{cases} \qquad (5)$$

VAR(S) is the variance of the statistic S as given by [25].

$$VAR(S) = \frac{n(n-1)(2n+5)}{18} \quad (6)$$

The p-value is important in the concept of the statistical significance of the results of M-K trend test. The p-value is the probability of the M-K statistic Z which estimated by the normal cumulative distribution function as [26, 27]:

$$p = 0.5 - \frac{1}{\sqrt{2\pi}} \int_0^{|Z|} e^{\frac{-t^2}{2}} dt \quad (7)$$

The statistical significance of the trend was based on the 95% confidence level, i.e. the corresponding significance level α is 0.05. The significance of trends can be tested by comparing the p-value in equation 7 with the selected significance level. If the p-value is less than the significance level 0.05, the null hypothesis H0 is rejected and the alternative hypothesis Ha is accepted, this indicates that the results of the trend test are statistically significant. If the p-value is greater than the significance level, we accept the null hypothesis H0, which interpreted here as no trend or the trend is not statistically significant.

The M-K test detects the trend but does not quantify it; Therefore, nonparametric Sen's Slope method [28] was used to determine the magnitude of the real change per unit time in the meteorological drought trends (slope of the regression line). Sen's slope (β) can be calculated using the median of all slopes between data pairs as in equation 8.

$$\beta = Median\left\{\frac{x_j - x_i}{j-i}\right\} \quad (8)$$

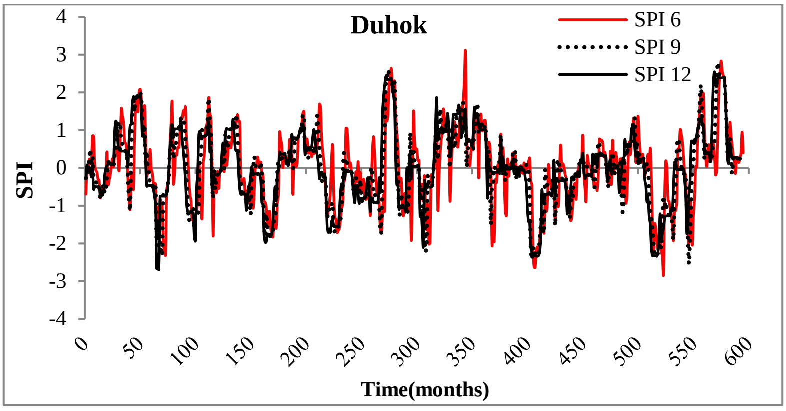
Where xj and xi are data values at times j and i respectively, i=1,2,… N and (i < j). β is tested by a two-sided test at the 95% confidence level. A positive value of β indicates an upward (increasing) trend whereas a negative value of β indicates a downward (decreasing) trend.

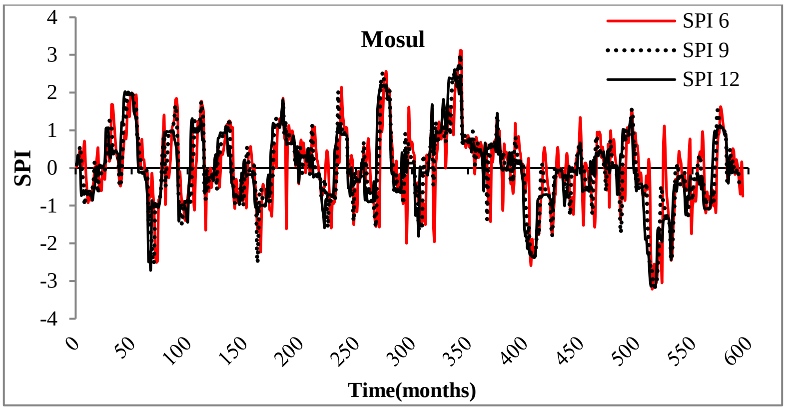
4. Results and discussion

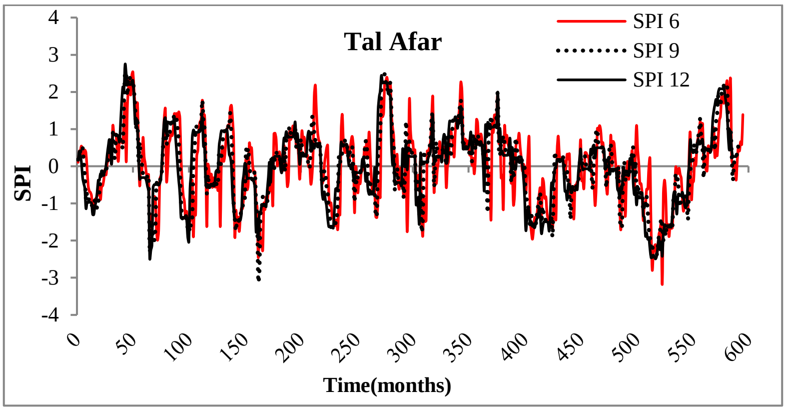
4.1. Meteorological drought analysis

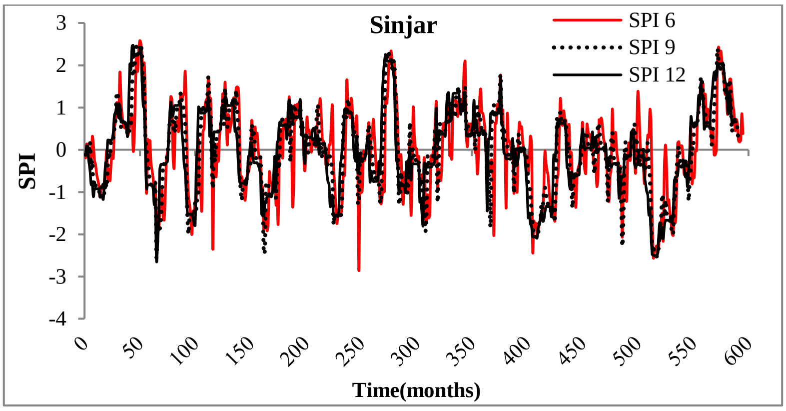
Based on the monthly precipitation collected from 11 stations, different time-scales of SPI 6, 9, and 12 months were used to identify and assess the meteorological drought in the study area.

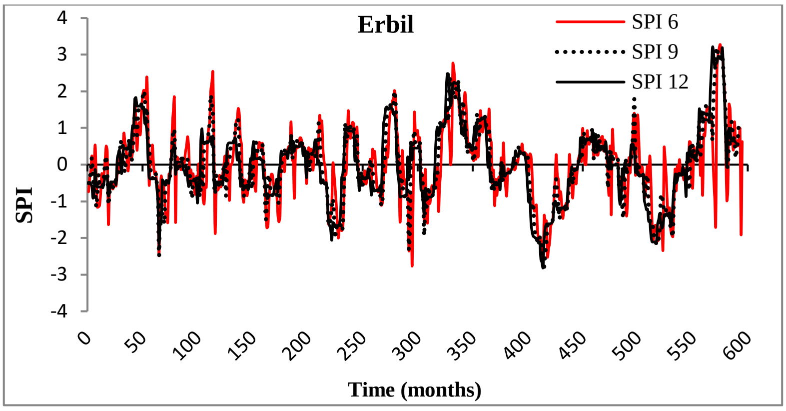
Figure 2 shows the spatial and temporal behavior of the SPI 6, 9, and 12-month values for selected stations, The time period of the all data starts from March 1965 to September 2014, with the exception of Makhmur and Tal Abth stations that start from March 1970 and March 1980 respectively. The results showed a different frequency of drought severity and the most significant drought occurred in 2008-2009. In each station the magnitude of drought (SPI values) varies from Mild drought to extreme drought. Generally, in the recent years the frequency of drought events is more protuberant and extends over long durations when compared to the early years of the SPI time series.

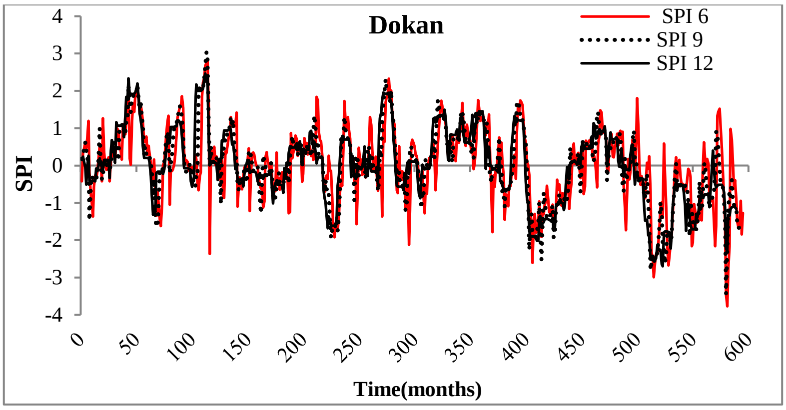

Duhok
SPI 6
SPI 9
SPI 12
SPI
4
3
2
1
0
-1
-2
-3
-4
0
50
100
150
200
250
300
350
400
450
500
550
600
Time(months)


Mosul
SPI 6
SPI 9
SPI 12
SPI
4
3
2
1
0
-1
-2
-3
-4
0
50
100
150
200
250
300
350
400
450
500
550
600
Time(months)


Tal Afar
SPI 6
SPI 9
SPI 12
SPI
4
3
2
1
0
-1
-2
-3
-4
0
50
100
150
200
250
300
350
400
450
500
550
600
Time(months)


Sinjar
SPI 6
SPI 9
SPI 12
SPI
3
2
1
0
-1
-2
-3
-4
0
50
100
150
200
250
300
350
400
450
500
550
600
Time(months)


Erbil
SPI 6
SPI 9
SPI 12
SPI
4
3
2
1
0
-1
-2
-3
-4
0
50
100
150
200
250
300
350
400
450
500
550
600
Time (months)


Dokan
SPI 6
SPI 9
SPI 12
SPI
4
3
2
1
0
-1
-2
-3
-4
0
50
100
150
200
250
300
350
400
450
500
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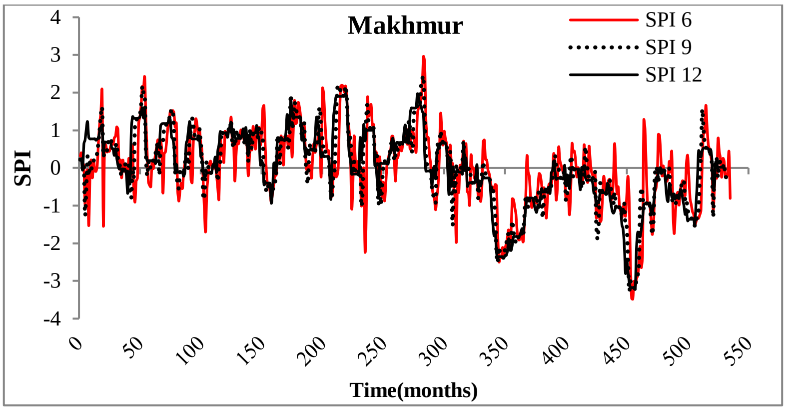
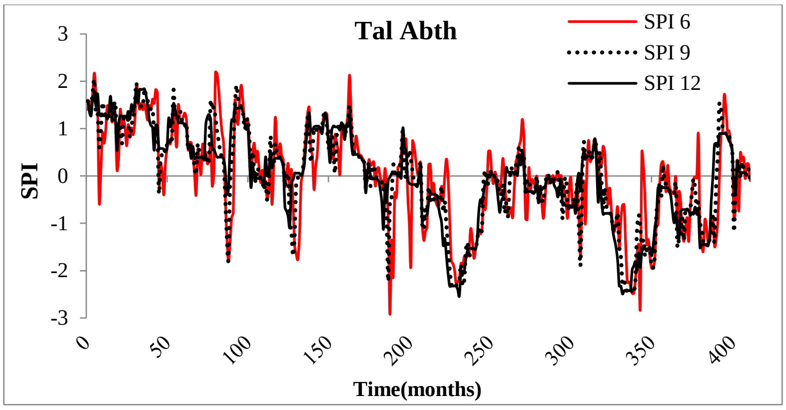
600
Time(months)


Makhmur
SPI 6
SPI 9
SPI 12
SPI
4
3
2
1
0
-1
-2
-3
-4
0
50
100
150
200
250
300
350
400
450
500
550
Time(months)


Tal Abth
SPI 6
SPI 9
SPI 12
SPI
3
2
1
0
-1
-2
-3
0
50
100
150
200
250
300
350
400
Time(months)

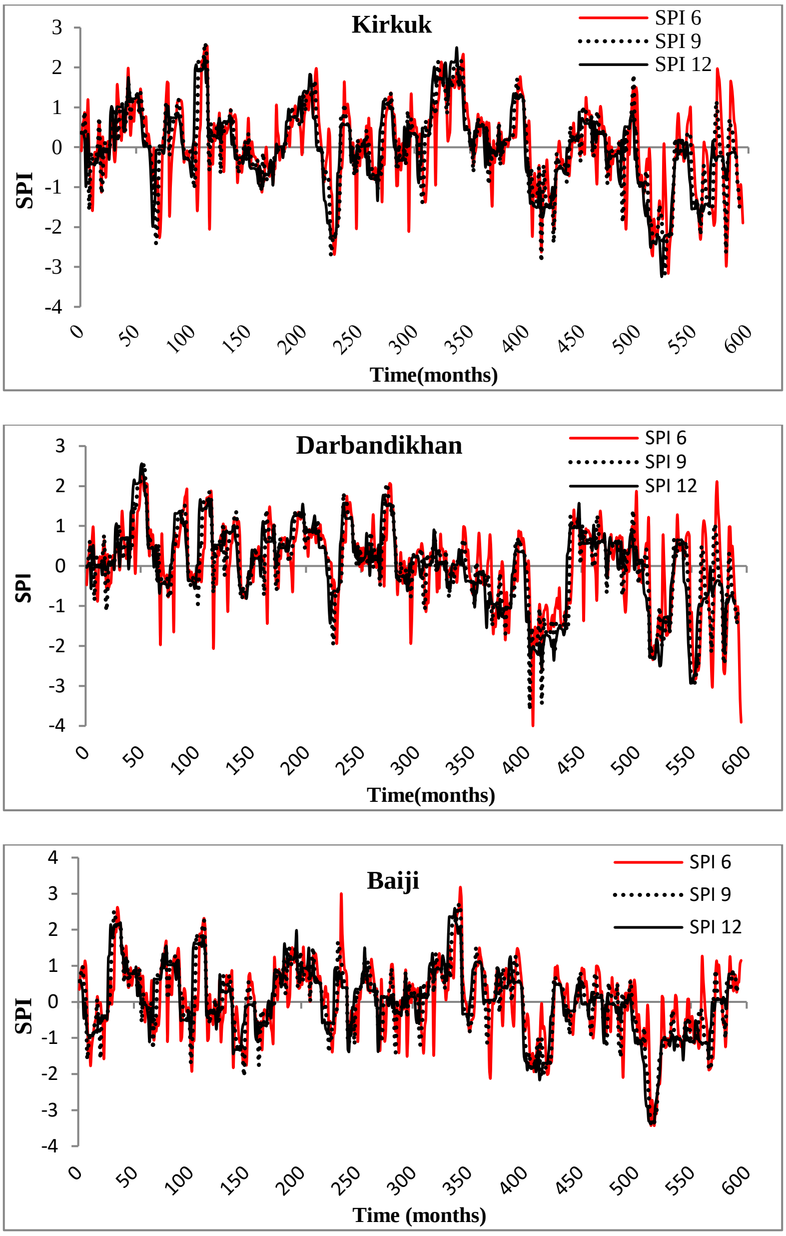


Figure 2. The SPI 6, 9, 12-month values for selected stations during the period March/1965(No. 1)–September/2012(No. 595)

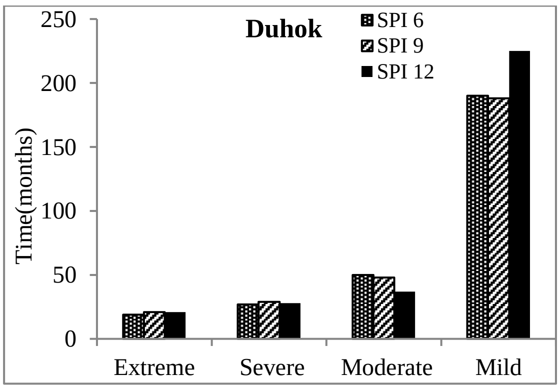
Relatively Darbandikhan station has more Frequency of extreme drought periods than the others where it was about 9%, 11%, 13% for SPI 6, SPI 9, SPI 12 respectively. The higher magnitude of extreme drought (minimum SPI score) of -3.99 in 1998, -3.77 in 2013 and -3.48 in 2008 were recorded at the Darbandikhan, Dokan and Makhmur station respectively. Table 2 shows the minimum SPI scores and years of occurrence at each station.

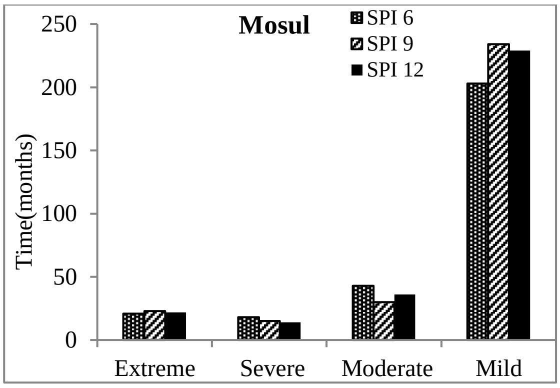
Table 2. Minimum SPI scores recorded for different time scales at selected stations

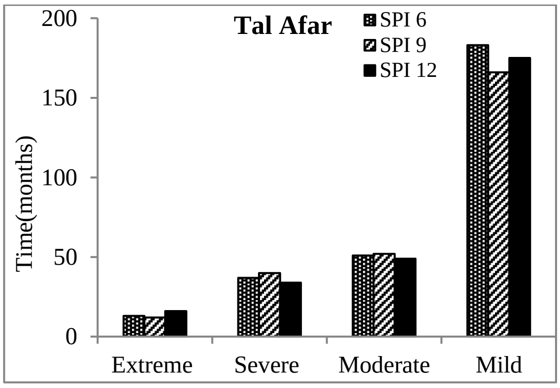
Stations	Time Scale	High SPI Score	Drought Category	Years
Duhok	SPI 6	-2.804	Extremely	2008
	SPI 9	-2.544	Extremely	2010
	SPI 12	-2.663	Extremely	1971
Mosul	SPI 6	-3.193	Extremely	2008
	SPI 9	-3.151	Extremely	2008
	SPI 12	-3.160	Extremely	2008
Tal Afar	SPI 6	-3.173	Extremely	2008
	SPI 9	-3.100	Extremely	1978
	SPI 12	-2.493	Extremely	2008

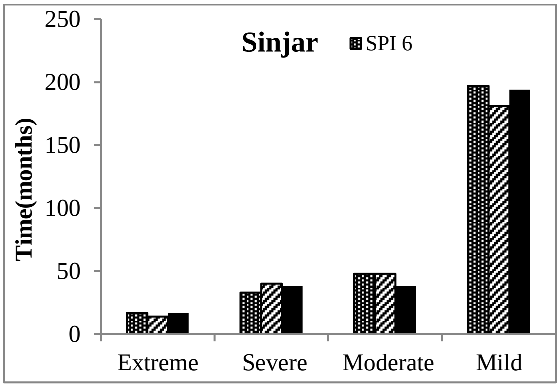
Sinjar	SPI 6	-2.863	Extremely	1985
	SPI 9	-2.532	Extremely	1970
	SPI 12	-2.610	Extremely	1971
Erbil	SPI 6	-2.769	Extremely	1989
	SPI 9	-2.816	Extremely	1999
	SPI 12	-2.804	Extremely	2000
Dokan	SPI 6	-3.771	Extremely	2013
	SPI 9	-3.444	Extremely	2013
	SPI 12	-2.698	Extremely	2009
Makhmur	SPI 6	-3.482	Extremely	2008
	SPI 9	-3.247	Extremely	2008
	SPI 12	-3.222	Extremely	2008
Tal Abth	SPI 6	-2.921	Extremely	1995
	SPI 9	-2.474	Extremely	2008
	SPI 12	-2.532	Extremely	1999
Kirkuk	SPI 6	-3.163	Extremely	2009
	SPI 9	-3.170	Extremely	2009
	SPI 12	-3.241	Extremely	2009
Darbandikhan	SPI 6	-3.999	Extremely	1998
	SPI 9	-3.582	Extremely	1998
	SPI 12	-2.930	Extremely	2011
Baiji	SPI 6	-3.432	Extremely	2008
	SPI 9	-3.392	Extremely	2008
	SPI 12	-3.358	Extremely	2008

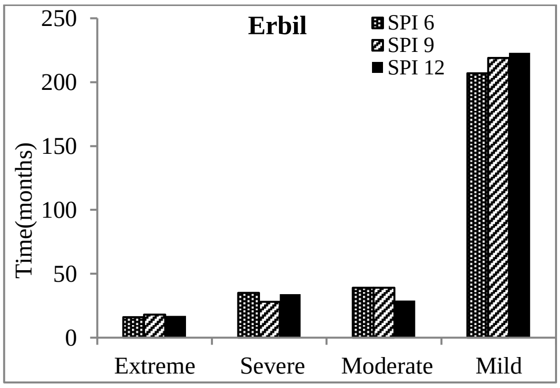
The most significant number of extreme drought events were observed at Darbandikhan station of 32 months in SPI 12-month, while the maximum number of severe drought events observed at Tal Afar station of 40 months in SPI 9-month, and The maximum number of moderate drought events observed at Baiji station of 66 months in SPI 9-month. Figure 3. Illustrates the distribution of the number of drought categories (Extreme, Severe, Moderate, Mild) observed in SPI 6, 9 and 12-months at the selected stations.

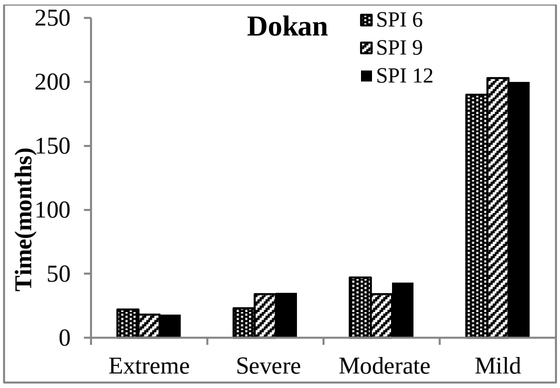


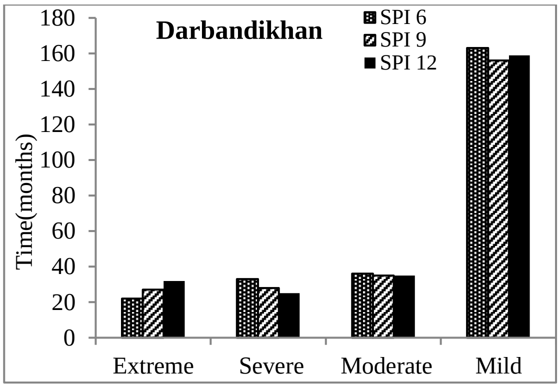


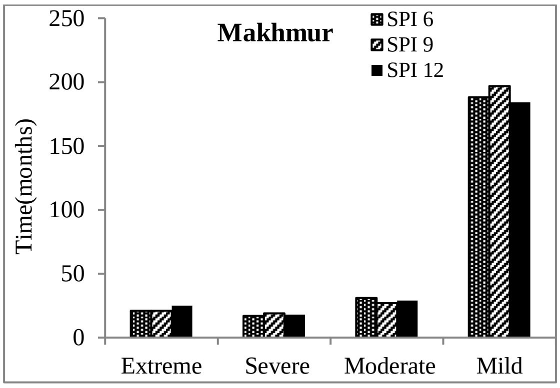


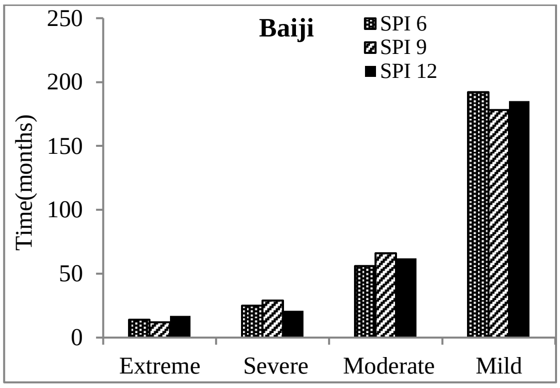


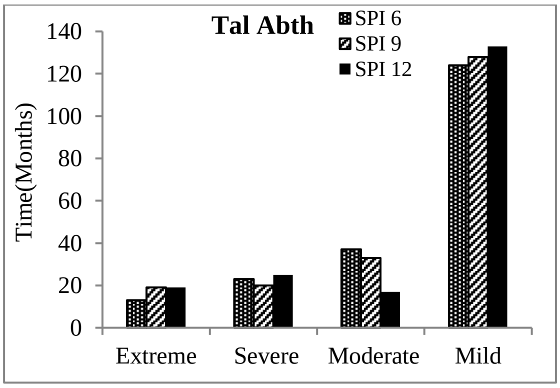












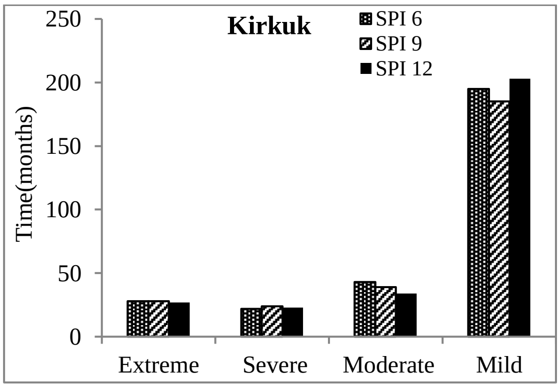
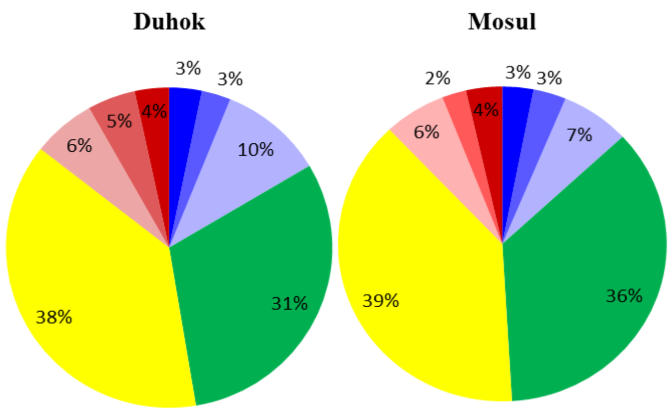
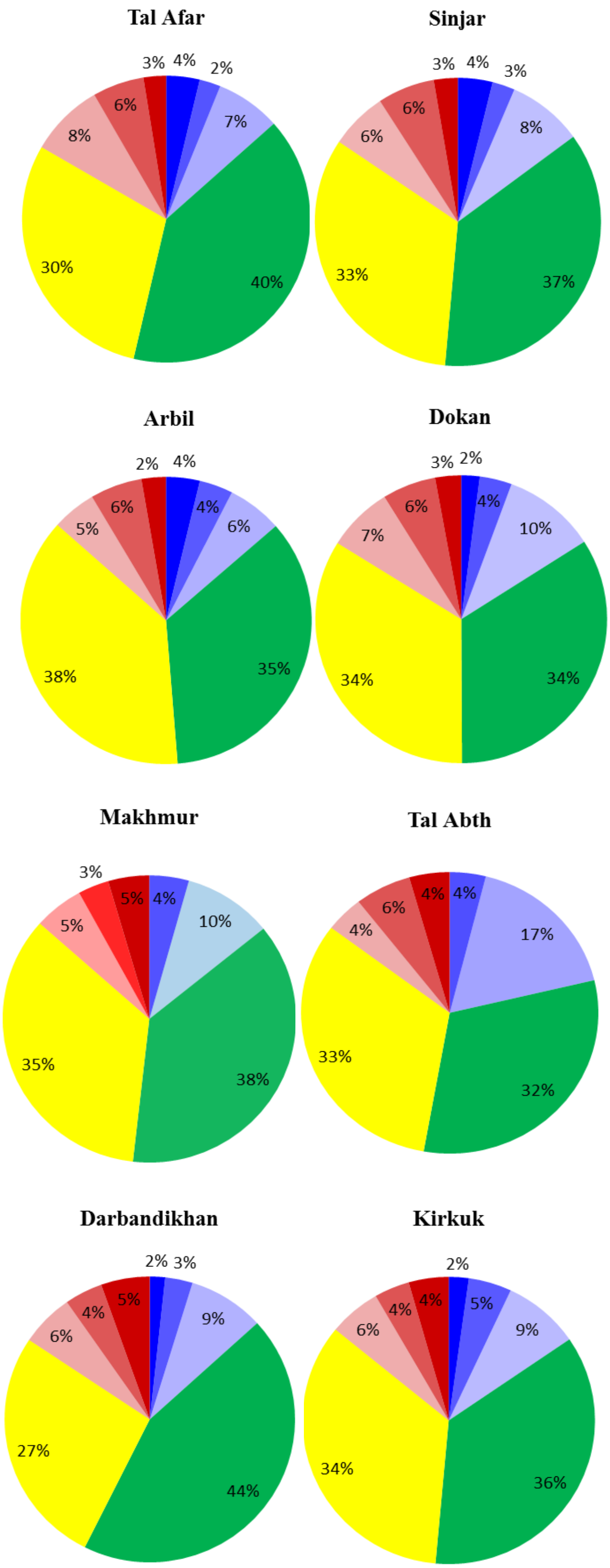


Figure 3. Number of drought categories in months at the selected stations

In the study region the ratio of drought months from total number of drought and wet months of the study period is about 47%, 47 and 48% for SPI 6, 9 and 12-month respectively, and the ratio of mild drought months of 67%, 67% and 69% from total number of drought months of the study period for SPI 6, 9 and 12-month respectively was higher than the moderate, severe and extreme drought rates. Figure 4 shows the percentages of the drought classification according to the SPI index for 12-month for each station.





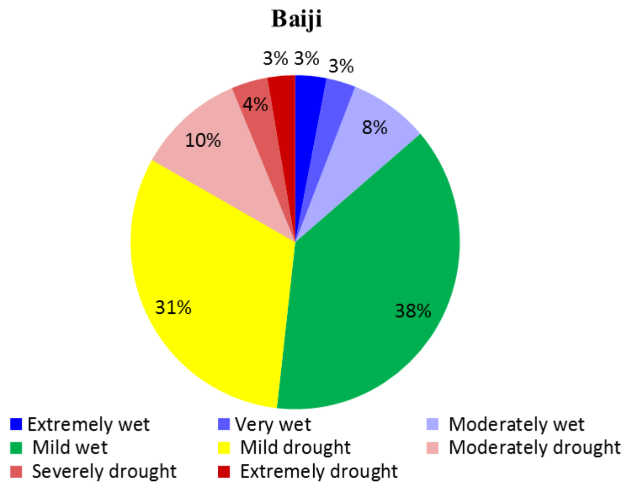


Figure 4. percentages of the drought classification for 12-month for each station

4.2. Trend analysis of Meteorological droughts

Trends of SPI time series values for 6, 9 and 12-months were analyzed. The Mann-Kendall test and Sen's slope estimator used to detect possible trends in the meteorological drought over the period of 1965 to 2014. The trend analysis results from both Mann-Kendall and Sen's slope for the different time scales of the SPI at selected stations are shown in Table3.

The trend in the SPI time series was statistically significant decreasing trend for all stations except for Duhok, Sinjar and Erbil was Non-significant trend at significance level of 0.05. Moreover, the decreasing trend estimated was also found to be significant at the 0.01 significant level for Mosul, Dokan, Kirkuk, Makhmur, Darbandikhan, Baiji and Tal Abth, This could be interpreted as a very strong (more Decreasing) trend. The detected trend in SPI 6, 9 and 12-month at Sinjar station and SPI 6-month at Duhok and Tal Afar stations also were decreasing but non-significant due to the p-value was above significance level of 0.05 and the very small values of Sen's Slope, which ranged between -0.04% and -0.6%. No increasing significant trend was recorded in the SPI time series at any station in any time scale. The decreasing trends in SPI time series indicate an increasing trend in meteorological droughts and vice versa. both methods agree in identifying the increasing (By positive values of S and Sen's slope) and decreasing (By negative values of S and Sen's slope) trends of meteorological drought events at all stations.

Table 3. Trend analysis results by the MK and Sen's slope

stations		S	p-value	Sen's slope	Trend
Duhok	SPI 6	-200	0.620	-0.0004	Non-significant
	SPI 9	10	0.982	0.002	Non-significant
	SPI 12	66	0.872	0.003	Non-significant
Mosul	SPI 6	-1304	0.001*	-0.009	Decreasing significant
	SPI 9	-1422	0.0004*	-0.009	Decreasing significant
	SPI 12	-1653	0.0001*	-0.011	Decreasing significant
Tal Afar	SPI 6	-519	0.197	-0.004	Non-significant
	SPI 9	-844	0.036	-0.007	Decreasing significant
	SPI 12	-856	0.033	-0.006	Decreasing significant
Sinjar	SPI 6	-466	0.247	-0.003	Non-significant
	SPI 9	-672	0.095	-0.006	Non-significant
	SPI 12	-753	0.061	-0.005	Non-significant
Dokan	SPI 6	-2342	0.0001*	-0.021	Decreasing significant
	SPI 9	-3248	0.0001*	-0.026	Decreasing significant
	SPI 12	-3651	0.0001*	-0.027	Decreasing significant
Erbil	SPI 6	19	0.964	0.003	Non-significant
	SPI 9	287	0.477	0.002	Non-significant
	SPI 12	357	0.376	0.004	Non-significant
Makhmur	SPI 6	-3340	0.0001*	-0.037	Decreasing significant
	SPI 9	-4153	0.0001*	-0.04	Decreasing significant
	SPI 12	-4890	0.0001*	-0.044	Decreasing significant
Tal Abth	SPI 6	-2676	0.0001*	-0.056	Decreasing significant
	SPI 9	-3140	0.0001*	-0.062	Decreasing significant
	SPI 12	-3424	0.0001*	-0.066	Decreasing significant
Kirkuk	SPI 6	-1965	0.0002*	-0.02	Decreasing significant
	SPI 9	-2506	0.0001*	-0.02	Decreasing significant
	SPI 12	-3002	0.0001*	-0.021	Decreasing significant
Darbandikhan	SPI 6	-2790	0.0001*	-0.022	Decreasing significant
	SPI 9	-3700	0.0001*	-0.03	Decreasing significant
	SPI 12	-4363	0.0001*	-0.032	Decreasing significant
Baiji	SPI 6	-2245	0.0001*	-0.019	Decreasing significant
	SPI 9	-3070	0.0001*	-0.024	Decreasing significant
	SPI 12	-3363	0.0001*	-0.025	Decreasing significant

*Trend is statistically significant at 1% as well as 5% significant level.

Non-significant increasing trends in the SPI time series are detected in Erbil station for SPI 6, 9 and 12-month time scale and Duhok station for SPI 9 and 12-month time scales, these were considered non-significant increasing trends through the computed p-value (above significance level of 0.05) and the small values of Sen's Slope, which ranged between 0.2% and 0.4%.

5. Conclusions

The results of trend analysis of meteorological drought for the Previous 49 years (1965-2014) in Northern region of Iraq clearly appear a statistically significant decreasing trend of SPI time series (i.e.

increasing in meteorological drought) at 5% significant level in addition to 1% significant level in most of the selected stations. No statistically significant increasing trend was recorded in the SPI time series at any station in any time scale.
The results of the SPI analysis of meteorological drought severity showed that the droughts tend to become more intensive over time and extreme drought is observed at all stations. The results of the drought analysis also showed that the most significant droughts occurred frequently in 2008-2009 for different time scales at different stations.

Generally, Since the ratio of mild drought months for the selected time scales of the entire study region was about 68% from total number of drought months of the study period, therefore, drought in the study region can be classified as mild drought.

The results of methodology of the meteorological drought analysis presented here is useful to carry out an integrated study with hydrological drought in order to proper management of drought hazards in the study region.

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Conflict of interest

There are no conflicts to declare.

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