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Comparative study of four meteorological drought indices in Iraq

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Abstract: *Drought monitoring is an essential component of drought risk management. It is normally performed using various drought indices that are effectively continuous functions of rainfall and other variables. A number of drought indices have been introduced and applied in different countries to date. In the current research, four meteorological drought indices including the standardized precipitation index (SPI), the Reconnaissance Drought Index (RDI), the Precipitation Declies Index (PDI) and Rainfall Anomaly Index (RAI) are compared and evaluated for monitoring droughts in Iraq. The results showed that all drought indices have strong positive linear correlations between each other, and that means the results of all drought indices are almost close and comparable. However, the strongest correlation is the correlation between SPI, and RDI was the correlation for all stations exceeded 0.99, then come the correlation between RAI and SPI and the correlation between RAI and RDI in the second and third place respectively. The comparison results of indices based on drought cases and classes showed that SPI, and RDI perform similarly with regard to drought identification and drought classes, they tend to have about the same frequencies for dry and wet conditions.*
Keywords: *Drought Indices; Meteorological drought; Iraq*

I. Introduction

Drought is an insidious natural hazard that is generally perceived to be a prolonged period with significantly lower precipitations relative to normal levels [1]. The reasons for the occurrence of droughts are complex because they depend not only on atmosphere, but also on the hydrologic processes [2]. Further, drought was ranked first followed by tropical cyclones, regional floods, earthquakes, and volcanoes based on most of the hazard characteristics and impacts [3]. Drought is perhaps the most complex natural hazard. It is often generally defined as a temporary meteorological event that stems from the lack of precipitation over an extended period of time compared with some long term average condition (e.g. precipitation).But droughts develop slowly, are difficult to detect and have many facets in any single region. The success of drought preparedness and mitigation depends, to a large extent, upon timely information on drought onset, progress and areal extent. These types of information may be obtained through drought monitoring. Monitoring is normally performed using drought indices. Drought indices provide decision makers with information on drought severity and can be used to trigger drought contingency plans, if they are available. The most popular indices include the Palmer drought severity index (PDSI), which has been widely used by the US Department of Agriculture, the decile index , which is operational in Australia, the China-Z index (CZI), which is used by the National Metrological Center of China and the standardized precipitation index (SPI), Another drought indicator is the reconnaissance drought index (RDI).This paper aims to compare the performance and evaluate the applicability of several rainfall-based drought indices in Iraq. Rainfall-dependent indices can point to both abnormally dry and abnormally wet conditions. The comparison of indices in this paper is, therefore, based on their ability to predict both cycles.

II. Study area

Iraq is located in the range of semi-tropical latitude in the Northern Hemisphere between latitudes (29.5°-37.5°) north of equator, and between longitudes (38.45°-48.45°) east of Greenwich line. Also Iraq is lies in southwest Asia in the northern part of the Arab homeland, and this location determines the closeness or the distance of Iraq from water bodies which have clear impact in the climate and thermal properties of Iraq, where the Mediterranean Sea and the Arabian Gulf are the most influential water bodies on Iraq [4].Iraq lies within the moderate northern region, system similar to that of Mediterranean where rainfall occurs almost in winter, autumn, spring and disappears in summer. The region is often divided into three rainfall zones according to the annual rainfall factor; Northern region, Middle region and Southern region . Rainfall in Iraq varies from 50 mm per year in the SW to 1200 mm per year in the NE. The western desert of Iraq mostly receives <100 mm per year. The Mesopotamian flood plain and Jezira area receive 100-300 mm of precipitation per year. Rainfall in the foothills is 300-700 mm per year; the mountainous region of N and NE Iraq receives >700 mm of rain. Over half of Iraq lies within the arid and semi-arid zones (with<150 mm/year rainfall) [5].The evaporation is very high in the country. the quantity of evaporation varies from one place to the other. Cyclones moving across Iraq are coming from the west;their source is the Atlantic Ocean. They are usually moving east toward the

Mediterranean Sea and then in the direction of Cyprus, Lebanon and Jordan finally toward Iraq, or the Arabian Gulf or the Caspian sea. The numbers of cyclones vary with seasons, months and places over which they are passing. Usually they are increasing in the winter, decreasing in the autumn and finally disappear completely in the summer. Also the number of cyclones moving over the south is greater than that moving across both zone of mountains and foothills.

III. Meteorological data collection and analysis

A historical records of monthly rainfall data, monthly maximum temperature and monthly minimum temperature were acquired from the Iraqi Meteorological Organization and Seismology (IMOS) for the period 1980-2014. The long term data were collected from 6 weather stations (Mosul, Khanaqin, Rutbah, Baghdad, Samawa and Basrah) located at different regions of the country, as shown in Table-1 and Fig.1.

Table-1: Meteorological stations used in the study.

Stations	Longitude (Degree)	Latitude (Degree)	Elevation (meter)
Mosul	43.15	36.32	223
Khanaqin	45.30	34.30	202
Rutbah	40.28	33.03	222
Baghdad	44.23	33.23	32
Samawa	45.27	31.32	11
Basrah	47.78	30.57	2

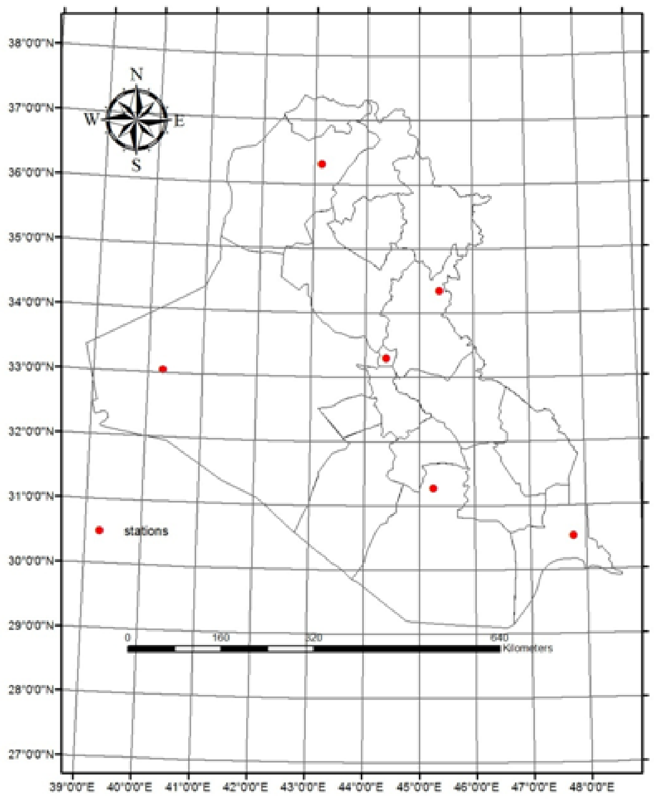


Fig.1: Distribution of meteorological stations in Iraq.

IV. Drought indices

Four drought indices have been selected for this study. They include Standardized Precipitation Index (SPI), the Reconnaissance Drought Index (RDI), the Precipitation Declies Index (PDI) and Rainfall Anomaly Index (RAI). A common feature of the indices selected is that they all are calculated using precipitation data . All indices considered have been applied to rainfall time series with a time step of 1 month in this study. A brief description of these indices is given in the following text.

Standardized Precipitation Index (SPI).

The SPI is one of the indices that are frequently used for forecasting, monitoring and planning operations. Since the drought is a multi-scalar phenomenon and the timescale over which the water deficits accumulate is extremely important to functionally separate the meteorological, agricultural, hydrological, and socio-economic forms of droughts. Therefore, the SPI is widely accepted as it can be computed at different time scales to monitor droughts with respect to specific water resources [6].

The SPI have several advantages over the other indices, where the calculation of SPI is easier than other complex indices like the Palmer Drought Severity Index (PDSI), because the SPI requires only precipitation data, whereas the PDSI uses several parameters [7].

The SPI is not affected by geographical or topographical factors and it is comparable in both time and space [8].The SPI could effectively represent the amount of rainfall over a given time scale, with the advantage to provide not only information on the amount of rainfall, but that it also gives an indication of what this amount is in relation to the normality [9]. Mckee et al. of the Colorado Climate Centre formulated the SPI in 1993. The purpose is to assign a single numeric value to the precipitation that can be compared across regions with markedly different climates. Technically, the SPI is the number of standard deviations that the observed value would deviate from the long-term mean, for a normally distributed random variable. Since precipitation is not normally distributed, a transformation is first applied so that the transformed precipitation values follow a normal distribution. The SPI was designed to quantify the precipitation deficit for multiple time scales. These time scales reflect the impact of drought on the availability of the different water resources. Soil moisture conditions respond to precipitation anomalies on a relatively short scale while groundwater, stream flow, and reservoir storage reflect the longer-term precipitation anomalies [10].
The SPI calculation for any location is based on the long-term precipitation record that is fitted to a probability distribution, which is then transformed into a normal distribution so that the mean SPI for the location and desired period is zero.

The steps and equations to calculate SPI are as follows:The precipitation data are calculated using the gamma probability density function which is defined as[11];

$$g(x) = \frac{1}{\beta^{\alpha}\,\Gamma(\alpha)}\, x^{\alpha-1}\, e^{-x/\beta} \qquad (1)$$

where: α , β and $x > 0$, α is a shape parameter, β is a scale parameter and x is the precipitation amount.

$$\alpha = \frac{1}{4A}\left(1 + \sqrt{1 + \frac{4A}{3}}\right) \qquad (3)$$

$$\beta = \frac{\bar{x}}{\hat{\alpha}} \qquad (4)$$

where: $A = \ln(\bar{x}) - \frac{\sum \ln(x)}{n}$, n = number of precipitation observations. The resulting parameters are then used to find the cumulative probability of an observed precipitation event for the given month and time scale for the station in question. The cumulative probability is given by:

$$G(x) = \int_0^x g(x)dx = \frac{1}{\beta^{\alpha}\Gamma(\alpha)}\int_0^x x^{\alpha-1}e^{-x/\beta}dx \qquad (4)$$

Since the gamma function is undefined for x=0 and a precipitation distribution may contain zeros, the cumulative probability becomes:

$$H(x) = q + (1 - q)G(x) \qquad (5)$$

where q is the probability of a zero.The cumulative probability, H(x), is then transformed to the standard normal random variable Z with mean zero and variance of one, which is the value of the SPI.

Precipitation Declies Index (PDI).

In this method, the amounts of precipitation distribution put in order from minimum to maximum in a long period are divided into 10 parts. Each of these parts is called a "Decile". The first decile represents the amount of precipitation lower than 10 percent of total precipitation. The fifth or "middle" decile is the amount of precipitation not more than 50 percent of total precipitation [12].

The Reconnaissance Drought Index (RDI).

The equations to calculate the RDI are the follows: The initial value (αk) of the index for a certain period, indicated by a certain month (k) during a year, is calculated by the following equation [13]:

$$\alpha_k = \frac{\sum_{j=1}^{j=k} P_j}{\sum_{j=1}^{j=k} PET_j} \qquad (6)$$

Where Pj and PETj are the precipitation and potential Evapotranspiration of the j-th month of the hydrological year. The hydrological year for Mediterranean countries starts in October, hence for October k=1. Equation (2.13) can be calculated for any period of the year. It can be also written starting from any month of the year different than October if it is necessary. The normalized RDI (RDIn) is computed using the following equation [56]:

$$\mathrm{RDI_n}(k) = \frac{\alpha_k}{\bar{\alpha}_k} - 1 \quad (7)$$

The values of (αk) follow satisfactorily both lognormal and the gamma distributions in a wide range of locations and different time scales, in which they are tested. By assuming that the lognormal distribution is applied, the following equation can be used for the calculation of standardized RDI (RDIst) [14]:

$$\mathrm{RDI_{st}}(k) = \frac{y_k - \overline{y_k}}{\hat{\sigma}_k} \quad (8)$$

where y_k is the ln αk, $\overline{y_k}$ is its arithmetic mean and $\hat{\sigma}_k$ is its standard deviation. The calculation of the RDIst could be performed better by using a similar procedure to the one that is used for the calculation of SPI, which is performed by fitting the gamma probability density function (pdf) to the given frequency distribution of the (αk). This approach also solves the problem of calculating the RDIst for small time steps, such as monthly, which may include zero-precipitation values (αk= 0).

Rainfall Anomaly Index (RAI).

The positive and negative RAI indices are computed by using the mean of ten extremes. Let $\overline{M}$ be the mean of the ten highest precipitation records for the period under study, $\overline{P}$ the mean precipitation of all the records for the period, and P the precipitation for the specific year. Then the positive RAI (for positive anomalies) for that year is[15]:

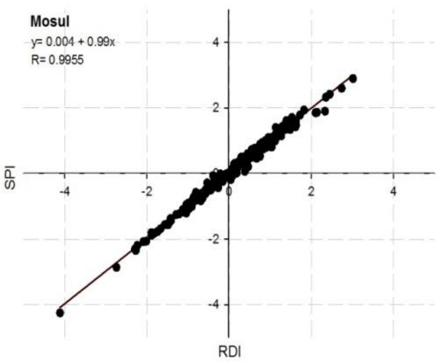
$$\mathrm{RAI} = 3\,\frac{P - \overline{P}}{\overline{M} - \overline{P}} \qquad \text{If } P > \overline{P} \quad (9)$$

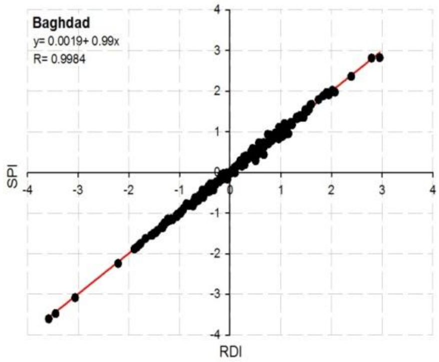
Let $\overline{m}$ be the mean of the ten lowest precipitation records for the period under study. Then the negative RAI (for negative anomalies) for that year is [59]:

$$\mathrm{RAI} = -3\,\frac{P - \overline{P}}{\overline{m} - \overline{P}} \qquad \text{If } P < \overline{P} \quad (10)$$

V. Results and Discussion

Values of SPI, RDI, PDI and RAI indices for months and annual time series were calculated and then the highest values of these indices and their times of occurrence were computed. The four drought indices were calculated for the period of 34 years. Linear regressions and the Pearson correlation coefficient (R) between the monthly values of the SPI versus the RDI, PDI and RAI were estimated for four chosen stations. The monthly results showed that the SPI and RDI, generally showed a good relationship in terms of the time scale for one month. For all stations, as shown in Fig.2, it can be seen that, correlation coefficient exceeded 0.99 and that mean, there is a very strong positive correlation between SPI and RDI for both cases (monthly or annually).The maximum value of correlation coefficient for the time scale of month was 0.9988 in Basrah station, and the minimum value was 0.9946 in Khanaqin station. There is no big difference between the maximum and the minimum value. The maximum value of correlation coefficient for the annual case was 0.9991 in Rutbah station, and the minimum value was 0.9964 in Basrah station. In general the relationship between the SPI and RDI show a good relationship for the time scale of monthly and annual, the SPI and RDI could be used as a good meteorological drought predictor.





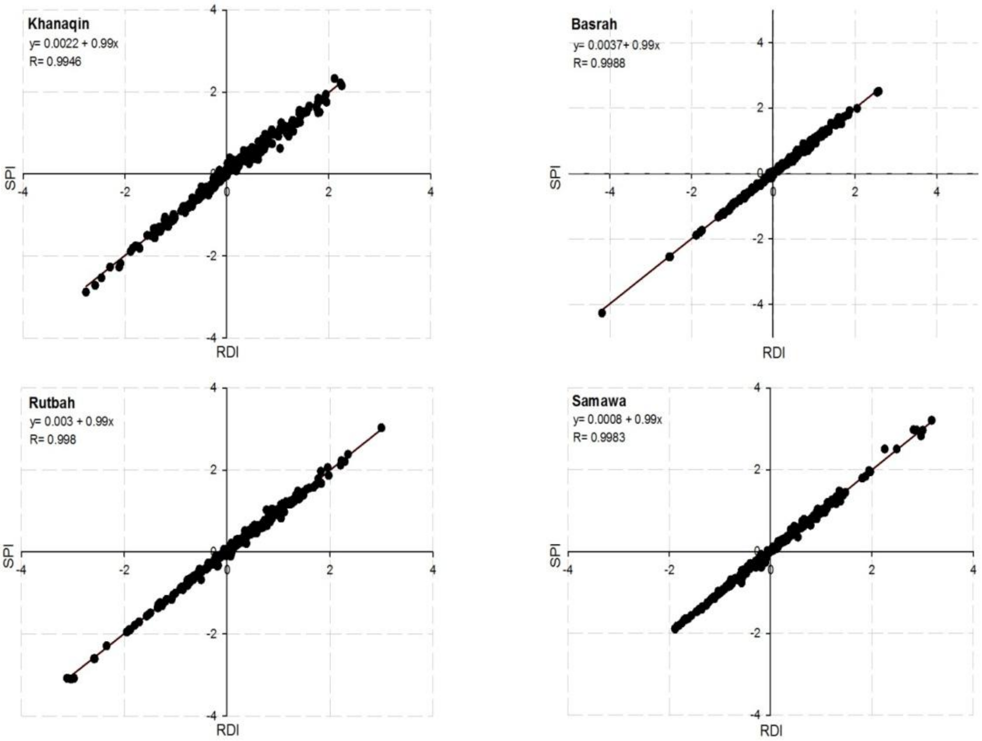
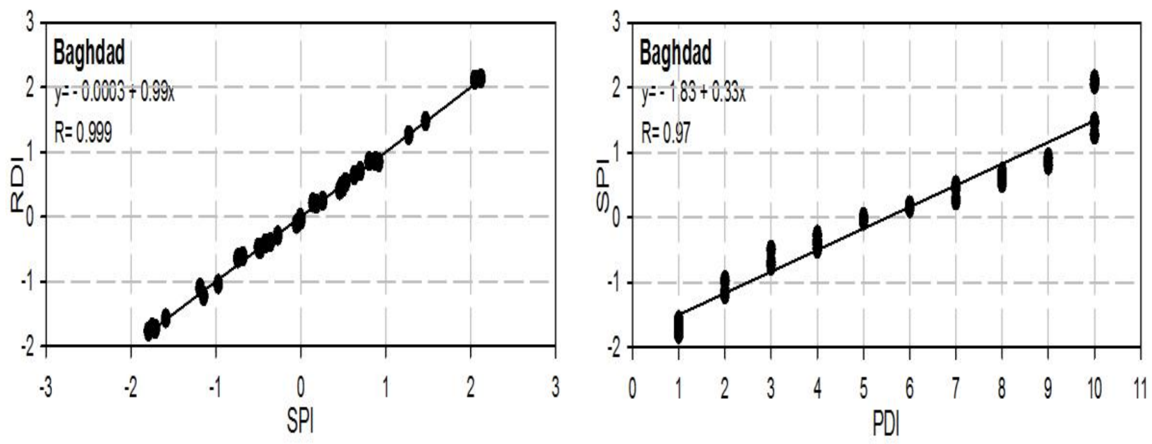


Fig.2: Scatter diagram for the (monthly) SPI and RDI for the selected stations.

Fig.3, shows the linear regression between the annual value of the four indices for Baghdad station. it can be seen that the correlation coefficient exceeded 0.95, that means there is a strong positive correlation between the indices. The maximum value was 0.999 between SPI and RDI indices, the minimum value was 0.95 between PDI and RAI. The results show that all drought indices have strong positive linear correlations between each other, and that means the results of all drought indices are almost close and comparable. However, the strongest correlation is the correlation between SPI, and RDI was the correlation for all stations exceeded 0.99, then come the correlation between RAI and SPI and the correlation between RAI and RDI in the second and third place respectively. The weakest correlation is the correlation of PDI with the rest of other indices.

To compare SPI and RDI, a histogram of dry and wet classes was classified in seven classes as follows: EW (Extremely Wet); VW (Very Wet); MW (Moderately Wet); NN (Near Normal); MD (Moderately Dry); SD (Sever Dey) and ED (Extremely Dry). The Table (4.8) show the SPI, the and RDI has the similar range of numerical values. Therefore, they can be applied as comparable. However, the ranges of the RAI are not similar to that of SPI and RDI. To make RAI comparable with SPI and RDI classes, Original RAI classes of 0.50 to 0.99 (Slightly wet), 0.49 to –0.49 (Near normal) and -0.50 to –0.99 (Slightly dry) have been added up to 'Normal' RAI class of 0.99 to – 0.99 (corresponding to the 'Normal' SPI range).



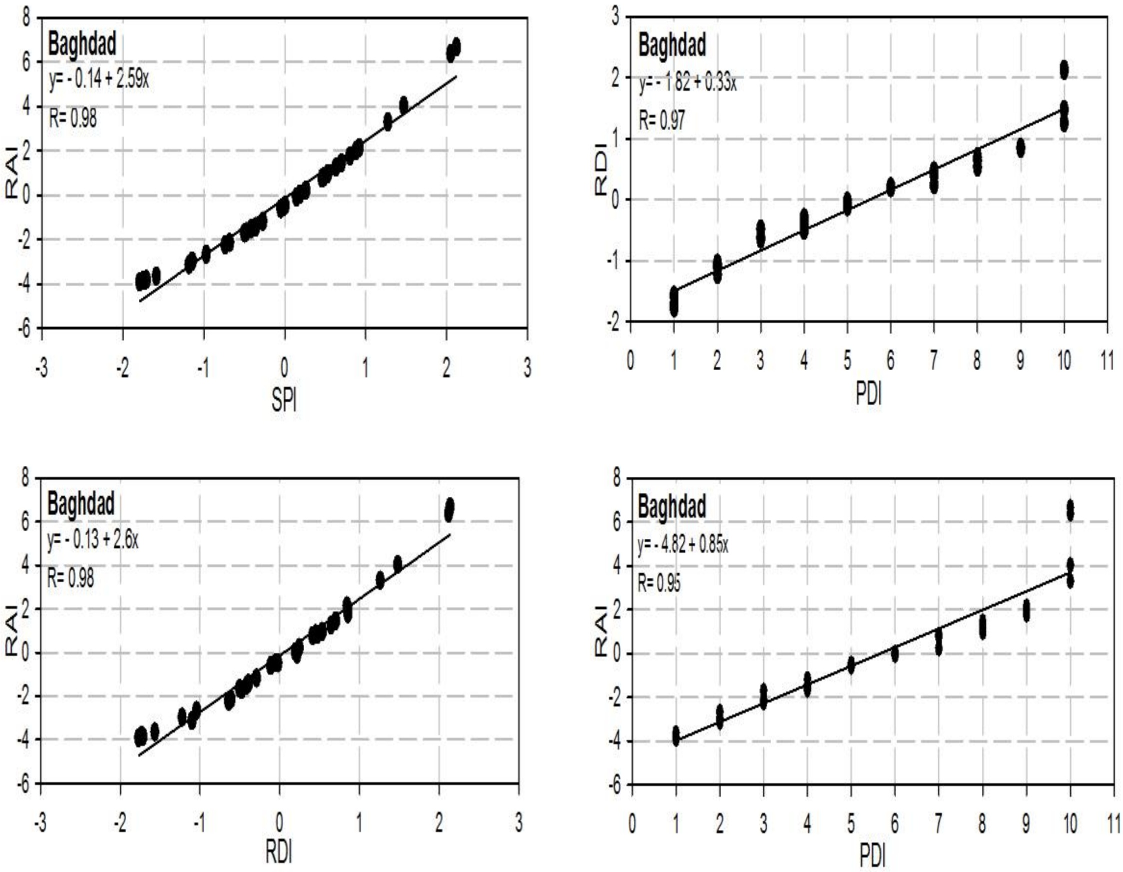
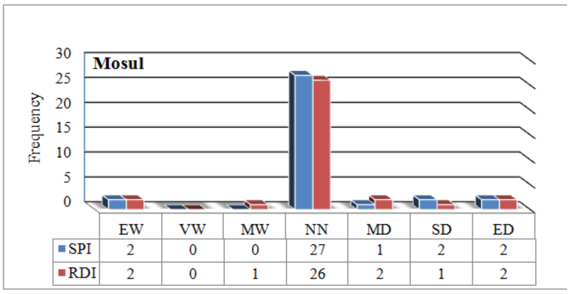


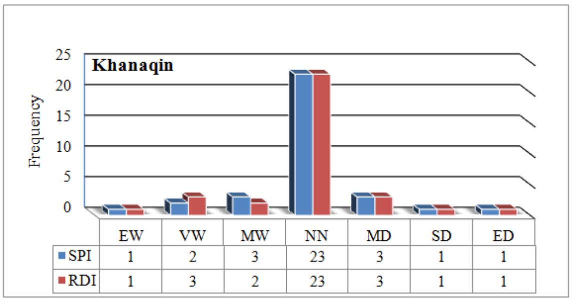
Fig.3: Scatter diagram showing four indices for Baghdad stations

Table-2 Categorization of SPI ,RDI and RAI values into classes

Values	Class	SPI	RDI	RAI
3	Extremely wet	≥ 2	More than 2	≥ 3.00
2	Very wet	1.5 to 1.99	1.5 to 1.99	2.00 to 2.99
1	Moderately wet	1.0 to 1.49	1.0 to 1.49	1.00 to 1.99
0	Normal	-0.99 to 0.99	-0.99 to 0.99	-0.99 to 0.99
-1	Moderately dry	-1.0 to -1.49	-1.0 to -1.49	-1.00 to –1.99
-2	Very dry	1.5 to -1.99	1.5 to -1.99	-2.00 to –2.99
-3	Extremely dry	≤ - 2	Less than -2	≤ -3.00

Category of indices was classified into seven intervals as follows: Extremely Wet (EW), Very Wet (VW), Moderately Wet (MW), Near Normal (NN), Moderately Dry (MD), Severely Dry (SD) and Extremely Dry (ED). For more accurate evaluation, the frequencies of the dry and wet classes identified by the indices were compared. Fig.4, shows the plot histogram of the dry and wet classes. It can be seen that 'Normal class' of the SPI and RDI is much larger than the other classes. Also Approximately the values of SPI and RDI are equal in all classes for all stations spatially Baghdad and Basrah stations. To compare the SPI and the RAI, a histogram of dry and wet classes was classified in seven classes.





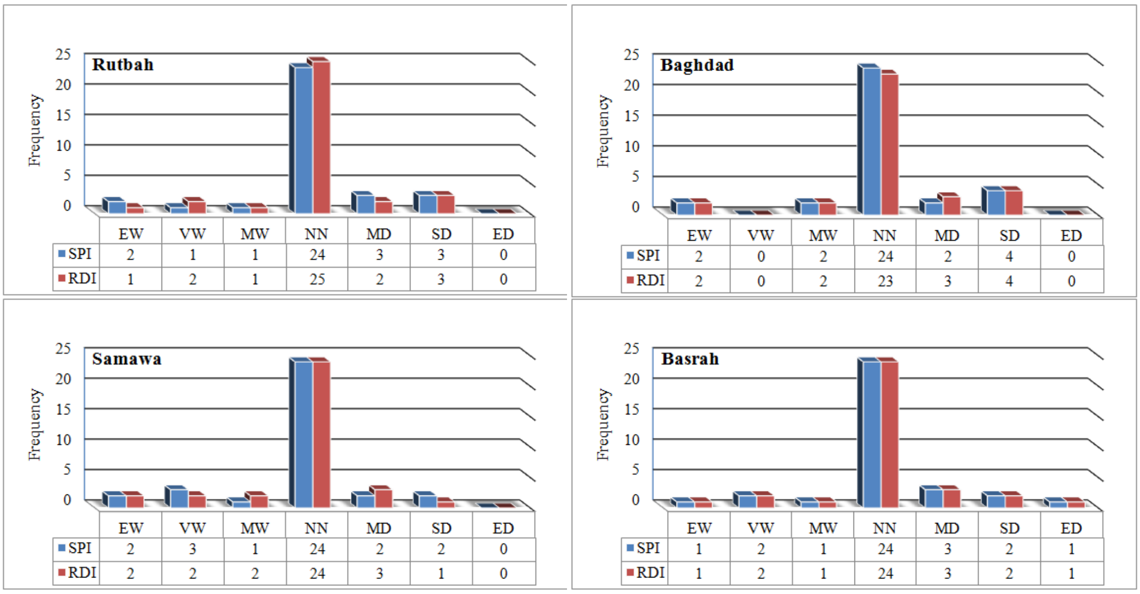


Fig.4: Histograms of the drought frequency classes of the SPI and RDI.

Fig.5, showed that both indices SPI and RAI have a bell-shaped histogram, also the frequency of SPI for dry and wet classes differed from RAI, frequencies of negative values of RAI (dry classes) are greater than the negative values of SPI in all stations, also a normal class in SPI index are bigger (approximately twice) than RAI index in all cases.

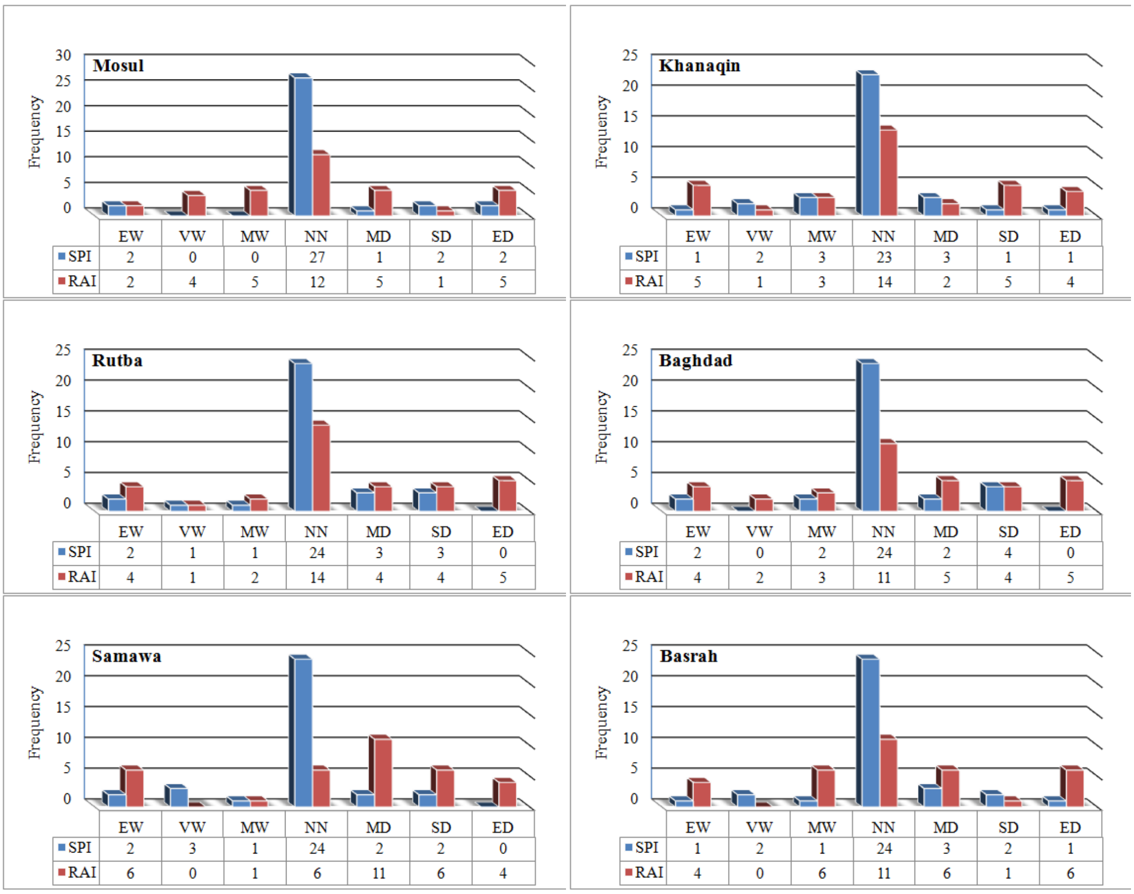


Fig.5. Histograms of the drought frequency classes of the SPI and RAI .

Both indices RDI and RAI have a bell-shaped histogram, the ‘normal class’ of the RDI was much larger than that of the RAI, other classes in the RAI were higher than those in the RDI. See fig.6.

The comparison of indices was based on drought cases and classes that were detected in the study area over the 34 years of data. The results show that SPI, and RDI perform similarly with regard to drought identification and drought classes, they tend to have about the same frequencies for dry and wet conditions while the RAI had shown a higher frequency in dry and wet categories. The SPI and RDI were found to be able to detect the onset of drought, and it may be recommended for operational drought monitoring in the Iraq.

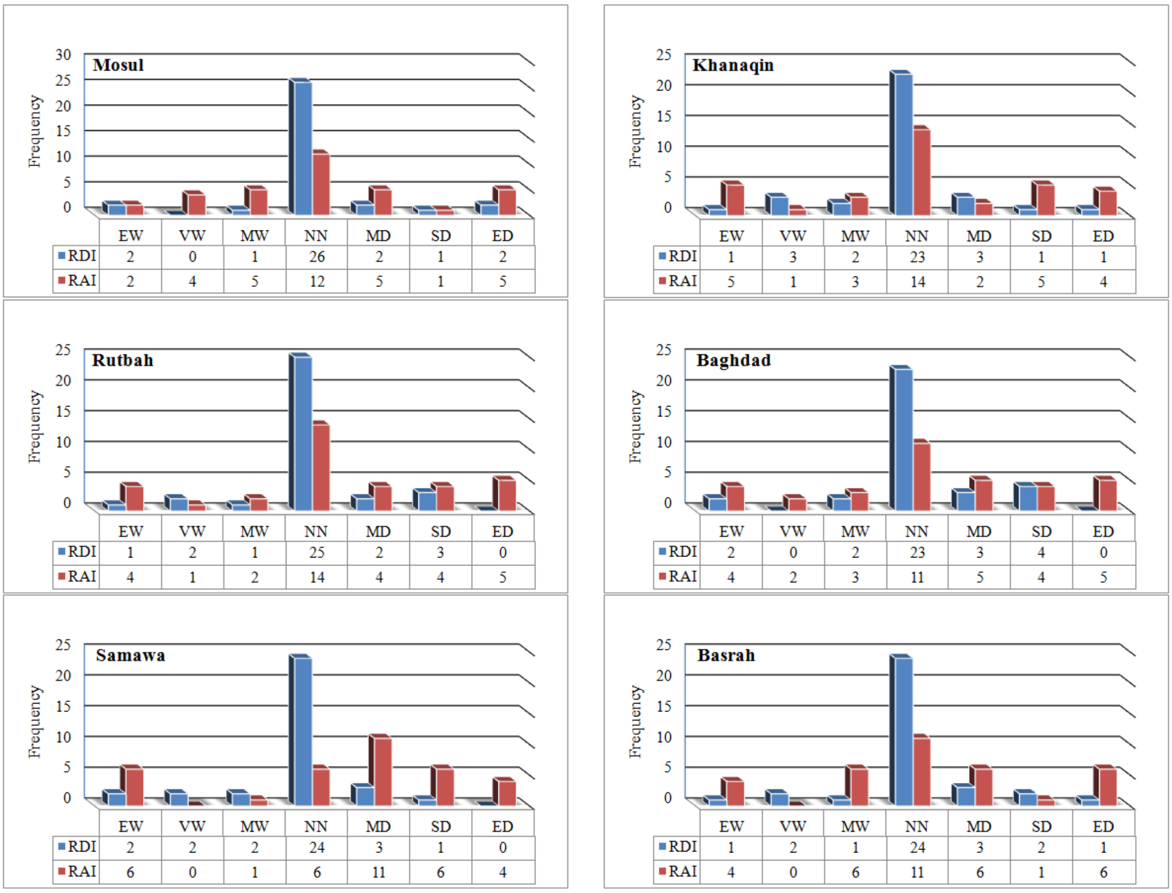


Fig.6: Histograms of the drought frequency classes of the RDI and RAI for the selected stations in 1980 – 2014.

VI. Conclusions.

The comparison results of indices based on drought cases and classes showed that SPI, and RDI perform similarly with regard to drought identification and drought classes, they tend to have about the same frequencies for dry and wet conditions. while the RAI had shown a higher frequency in dry and wet categories. The results showed that all drought indices have strong positive linear correlations between each other, and that means the results of all drought indices are almost close and comparable. However, the strongest correlation is the correlation between SPI, and RDI was the correlation for all stations exceeded 0.99, then come the correlation between RAI and SPI and the correlation between RAI and RDI in the second and third place respectively. The weakest correlation is the correlation of PDI with the rest of other indices. There is a positive correlation coefficients between the monthly rainfall values and the SPI index in the studied stations, the maximum value of was 0.97 in Khanaqin station, and the minimum value was 0.84 in Basrah station. There is a positive correlation coefficients between the monthly rainfall values and the RDI index in the studied stations, the maximum value was 0.97 in Khanaqin station, and the minimum value was 0.83 in Mosul station.

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