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# Comparison of Some Drought Indices in Iraq

**Usama S. Nedham*, Ahmed S. Hassan**
Department of atmospheric science, College of science, Mustansiriyah University, IRAQ.
*Correspondent author email: usamameteoo@gmail.com

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## Abstract

Drought in Iraq was assessed using three drought indices for two different time periods, past period from 1970 to 2015, and future period from 2016 to 2050 for 4 stations (Mosul, Baghdad, Rutba, and Basra) in Iraq. These indices include: the Standardized Precipitation Index (SPI), Percentage of Precipitation Anomaly (PPA), and Z-Score Index (ZSI). The main sources of data were the monthly rainfall archive from Iraqi Meteorological Organization and Seismology (IMOS) for past period, and projection monthly precipitation data from Representative Concentration Pathway scenario (RCP4.5) for Fifth Assessment Report (AR5) affiliate to the Intergovernmental Panel on Climate Change (IPCC) for future period. The results showed good correlation of among the three indices, with different rank of them, were the lowest rank was 0.85. The three indices refer to were perfect to evaluate the drought severity of Iraq. It was found that the best index was PPA during past period, and the significant index was ZSI for the future period. The Mosul Station (North of Iraq) was the least vulnerable to drought according to analysis of the results of the three indices for the last period, the number of dry seasons were 12 on the basis of the PPA classification. Basra station (South of Iraq) has the highest number of wet season on the PPA classification. were (15) season.

**Keywords**: Iraq, SPI, PPA, ZSI, Drought.

## الخلاصة

تم تقييم الجفاف في العراق باستخدام ثلاثة مؤشرات للجفاف لفترتين زمنيتين مختلفتين ، الفترة الماضية من ١٩٧٠ إلى ٢٠١٥ ، والفترة المستقبلية من ٢٠١٦ إلى ٢٠٥٠ لـ ٤ محطات (الموصل ، بغداد ، الرطبة ، والبصرة) في العراق. تشمل هذه المؤشرات: مؤشر الهطول المعياري (SPI) ، النسبة المئوية لشذوذ الهطول (PPA) ، ومؤشر Z-Score (ZSI). كانت المصادر الرئيسية للبيانات هي أرشيف هطول الأمطار الشهري من هيئة الأرصاد الجوية والزلازل العراقية (IMOS) للفترة الماضية ، وبيانات هطول الأمطار الشهرية المتوقعة من سيناريو مسار التركيز التمثيلي (RCP4.5) لتقرير التقييم الخامس (AR5) التابع للجنة الحكومية الدولية بشأن تغير المناخ (IPCC) للفترة المقبلة. أظهرت النتائج وجود علاقة جيدة بين المؤشرات الثلاثة، برتب مختلفة، حيث كانت أدنى مرتبة ٠,٨٥ . المؤشرات الثلاثة المشار اليها كانت مثالية لتقييم شدة الجفاف في العراق. وقد وجد ان أفضل مؤشر كان PPA خلال الفترة الماضية ، وكان المؤشر الهام ZSI للفترة المقبلة. كانت محطة الموصل (شمال العراق) الاقل عرضة للجفاف من تحليل نتائج المؤشرات الثلاثة للفترة الماضية، كان عدد المواسم الجافة ١٢ على أساس تصنيف PPA . محطة البصرة (جنوب العراق) هي الاعلى بعدد المواسم الرطبة على أساس تصنيف PPA حيث كانت 15 موسم.

## Introduction

Drought is a natural phenomenon where there is a water depletion of reservoirs on the surface (lakes, and rivers), or water below the surface (soil moisture, and groundwater). Scientists disagreed on a common definition of drought because of the different conditions that lead to water supply shortages from one region to another, and season to season. The scientists identified 4 types of drought: Meteorological drought, Hydrological drought, Agricultural drought, and Socio-economic drought [1]. All climate systems in the world can be affected by drought as it is not limited to desert areas only. The risk of drought has negative effects on various economic and environmental sectors, including agriculture, food supply, hydropower generation, health sector, and etc. There are a number of indices that help in assessing the severity of drought in any region [2]. The

consequences and characteristics of drought must be understood in order to take appropriate measures to reduce its risk [3].

This study focuses on the assessment of drought in Iraq by studying the behavior of three meteorological indices named: Standardized Precipitation Index (SPI), Percentage of Precipitation Anomaly (PPA), and Z-Score Index (ZSI) for two study periods, first period was observation data from 1970 to 2015 (past period), and second period projection data from 2016 to 2050 (future period).The results of these indices were compare between them.

## Drought Indices

Drought indices are numerical numbers calculated to determine the severity of drought using climatic or hydrological inputs (weather factors). They show the measurement of dry condition for a certain period of time. Since there is no single definition suitable for all types of drought, there is no single index that can explain drought or apply to all drought-affected sectors [2].

Standardized Precipitation Index (SPI) established by McKee et al. in Colorado State University, 1993. It is based on precipitation data only. Its fundamental strength lies in its ability to be calculated to a variety of time scales from 1 month to 72 months [4]. It is usually applied to monitoring drought conditions and early warning, in a wide range of academic research in specialized scientific sections in this field, and in many organizations and bodies specializing in the field of meteorology around the world [5]. Positive SPI values indicate that the precipitation is of more than the mean whereas the negative values indicate the reverse. Once the value of random variable Z or SPI are obtained arithmetically using approximation, the cumulative probability of the variable Z can be calculated as in the following equation [6]:

$$Z = SPI = \pm \left( t - \frac{c_\circ + c_1 t + c_2 t^2}{1 + d_1 + d_2 t^2 + d_3 t^3} \right) \quad (1)$$

Where: $c_\circ$ = 2.515517, $c_1$ = 0.802853, $c_2$ = 0.010328, $d_1$= 1.432788, $d_2$ = 0.189269, $d_3$ = 0.001308

India Meteorological Department suggested the Percentage of Precipitation Anomaly (PPA) in 1971. The PPA is based on percentage anomalies of precipitation from its long term mean [7]. The negative values in which the precipitation amounts are less than the average duration of the study, positive values are the amounts of precipitation greater than average. It is index given by equation (2) [8]:

$$PPA = \frac{P - \bar{P}}{\bar{P}} \times 100\% \quad (2)$$

Where: P is the total of precipitation for a selected rainy season and $\bar{P}$ is the average precipitation for the entire period.

Z-Score Index (ZSI) is a commonly used index for drought assessment. It is coefficient of variation of rainfall anomaly, refers to standard deviations where values are lower or higher than the average. It does not resemble SPI because it does not need data control in the form of Gamma or Pearson Type III distribution [9]. It is calculated by dividing the product by subtracting the average of precipitation amount for the entire study period from precipitation amounts for the specified rainy season on the standard deviation. As in the following equation [10]:

$$ZSI = \frac{P_i - \bar{P}}{SD} \quad (3)$$

Where: $\bar{P}$ is the long time precipitation average, $P_i$ is total precipitation in selected rainy season, SD is define as standard deviation of study period. Table 1 shows the classification of SPI [5], PPA [8], and ZSI [9].

**Table 1:** The dry and wet categories of various drought indices (SPI, PPA, and ZSI) based on index value.

| Classes | SPI | PPA | ZSI |
|---|---|---|---|
| Extreme dry | ≥ -2.0 | | ≥ -2.0 |
| Severe dry | -1.99 to -1.5 | ≤ - 60 | -1.99 to -1.5 |
| Moderate dry | -1.49 to -1.0 | -20 to -59 | -1.49 to -1.0 |
| Near normal | ± 0.99 | ±19 | ± 0.99 |
| Moderate wet | 1.0 to 1.49 | 20 to 59 | 1.0 to 1.49 |
| Very wet | 1.5 to 1.99 | ≥ 60 | 1.5 to 1.99 |
| Extreme wet | ≥ 2.0 | | ≥ 2.0 |

## Materials and Methodologies

### *Data source and study areas*

Iraq is located in the south-west of Asia and the north-east of the Arab Peninsula between latitudes 29°05' to 37°22' north of equator and longitudes 38°45' to 48°45' east of prime meridian .The total area of Iraq is 438320 $Km^2$ [11]. It is part of the northern temperate zone. Its semi-continental climate influenced by the Mediterranean climate. In the winter, the country is affected by the Red Sea low pressure, and the Mediterranean Sea low pressure. Both of them are potential to give rain. In the summer, Iraq is affected by the Indian seasonal low, especially on the southern and central parts, causing high temperatures. Rain abundance increases from southwest to northeast of Iraq reaching more than 1000 mm in the far north-east. While the total annual precipitation is less than 100mm in southwest. The prevailing winds in Iraq are the North West throughout the year [12].

The data source of past period is the monthly precipitation data archive which was acquired from the Iraqi Meteorological Organization and Seismology (IMOS) for the period from January 1970 to December 2015. The monthly precipitation data were collected for four weather stations (Mosul, Baghdad, Rutba, and Basra) representative of the different regions of the country (North, Center, West, and South) respectively.

The data source of future period from January 2016 to December 2050 are future projections of monthly precipitation which based on Representative Concentration Pathway (RCP4.5) scenario. Climate models are the basis for important components of the Intergovernmental Panel on Climate Change (IPCC) assessments. It provide the understanding of climate change, the projections of future climate change, and related impacts. The IPCC Fifth Assessment Report (AR5) relies heavily on the Coupled Model Inter-comparison Project, Phase 5 (CMIP5), and a collaborative climate modelling process coordinated by the World Climate Research Program (WCRP) [13]. Figure 1 shows location of weather stations and grid point of RCP4.5 scenario used in this study.

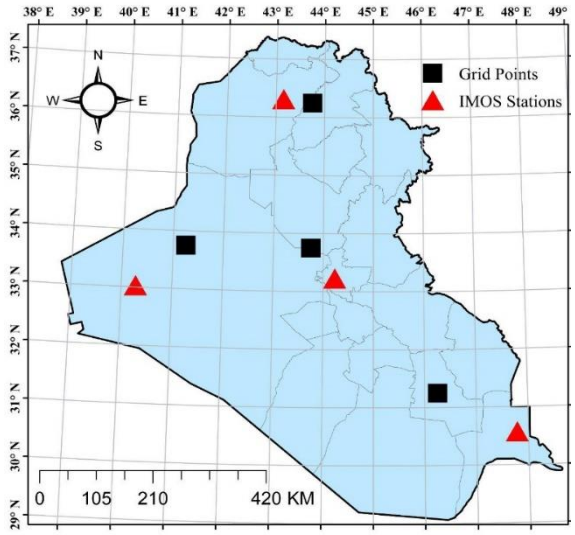


**Figure 1:** Location of weather stations (IMOS) and grid point (RCP4.5) scenario

## Results and Discussion

### *Drought Indices analyses*

The seasonally SPI was calculated on a time scale of six month (SPI-6), by calculated average monthly index values during the rainy months only. Figure (2a) shows the results of seasonally SPI-6 of four stations for past period, and Figure (2b) for future period. The minimum value of SPI-6 for past period was (-2.1) in the rain season (2007-08) at north of Iraq (Mosul station). The maximum value of SPI-6 was 1.98 in the rainy season (1994-95) at west of Iraq (Rutba station). The minimum

value of SPI-6 for future period was (-1.97) in the rainy season (2044-45) at west of Iraq, the maximum value of SPI-6 was (1.57) in the rainy season (2031-32) at the south.

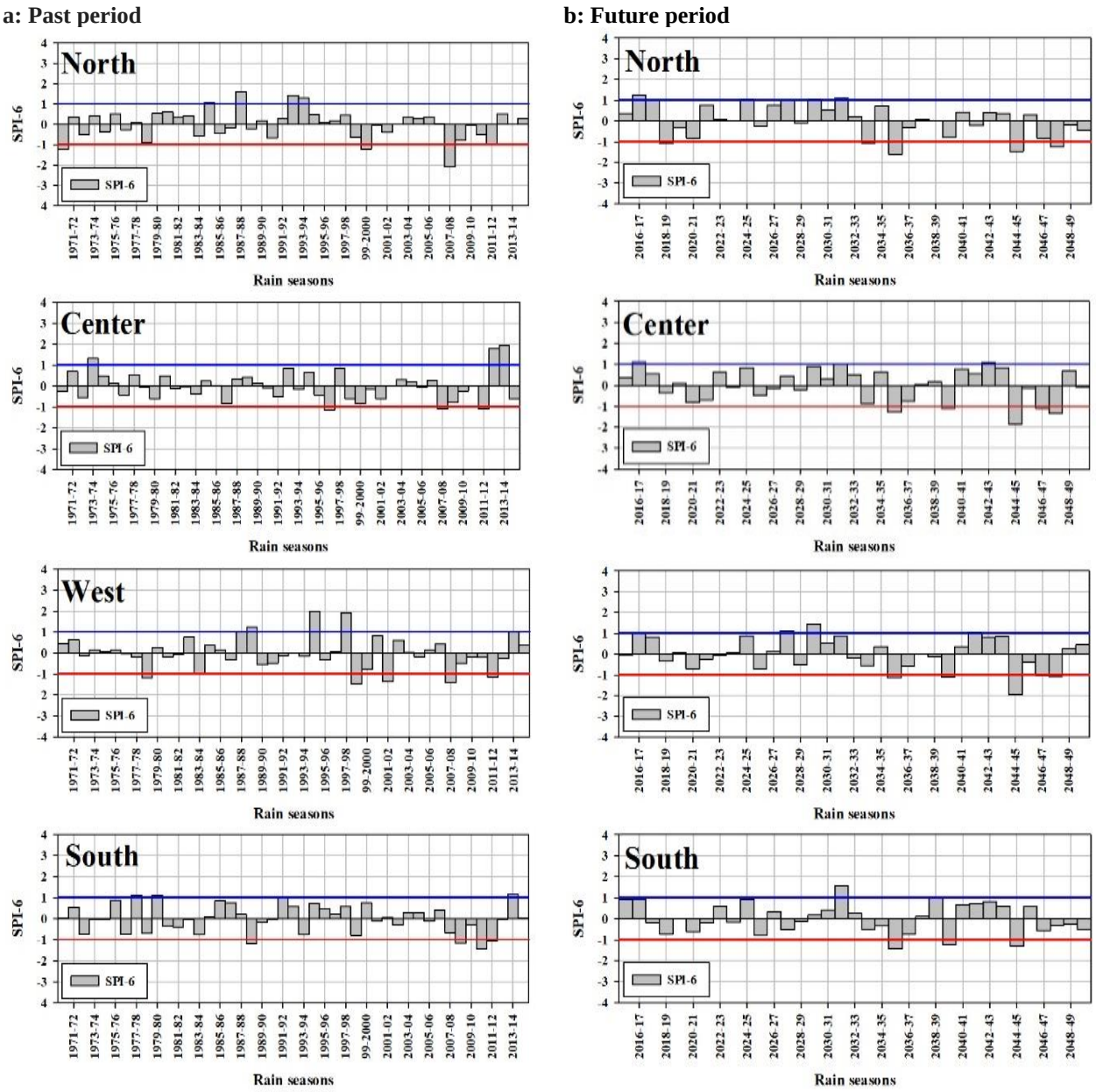


**Figure 2a:** Time series of Standardized Precipitation Index (SPI) values for 6 month time scale of (North, Center, West, and South) region. For 45 rainy season from 1970 to 2015.

**Figure 2b:** Time series of Standardized Precipitation Index (SPI) values for 6 month time scale of (North, Center, West, and South) region. For 35 rainy season from 2016 to 2050. Red line is negative, and blue line is positiveb.

Figure (3a) shows the ZSI values of all rainy seasons of four stations for past period, and Figure (3b) for future period in. The minimum value of ZSI for past period was (-2.15) in the rain season (2007-08) at north of Iraq (Mosul station). The maximum value of ZSI was (3.58) in the rain season (1994-95) at west of Iraq (Rutba station). While the minimum value, of ZSI for future period, was (-2.49) in the rainy season (2035-36) at the north of Iraq. The maximum value of ZSI was (1.94) in the rainy season (2042-43) at center of Iraq.

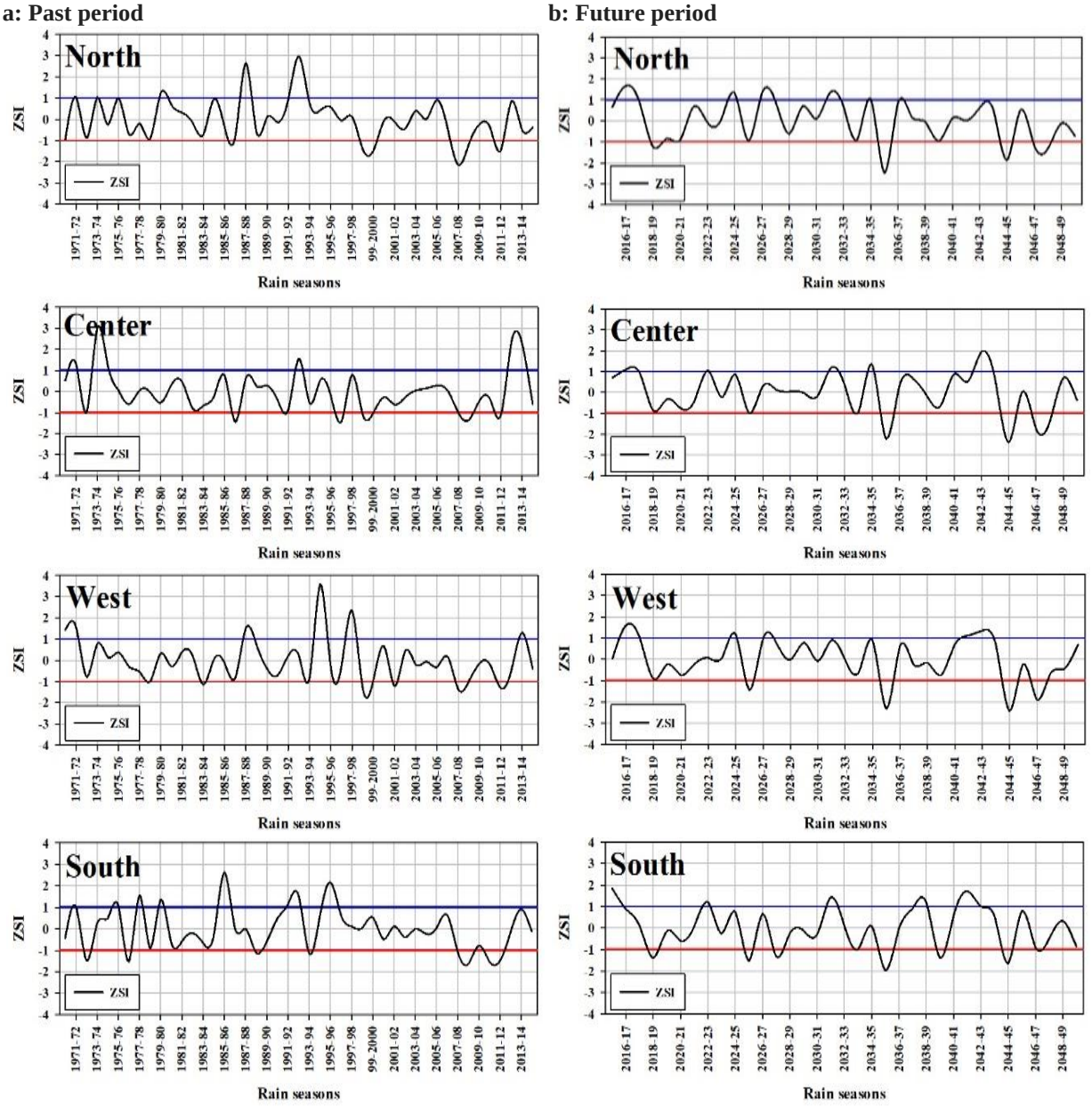


**Figure 3a:** Time series of Z-Score Index (ZSI) values of (North, Center, West, and South) of Iraq. For 45 rainy seasons from 1970 to 2015.

**Figure 3b:** Time series of Z-Score Index (ZSI) values of (North, Center, West, and South) of Iraq. For 35 rainy seasons from 2016 to 2050. Red line is negative, blue line is positive.

Figure 4 shows the PPA values of all rainy seasons for four stations for past period. The maximum value of PPA was 200 in the rainy season (1994-95) at west of Iraq (Rutba station). The minimum value of PPA was -76 in the rainy season (2007-08) at west of Iraq (Rutba station) too.

Table 2 shows maximum and minimum values of SPI-6, ZSI, and PPA for 4 stations for past period. Table 3 shows that maximum and minimum values of SPI-6, and ZSI for 4 stations for future period.

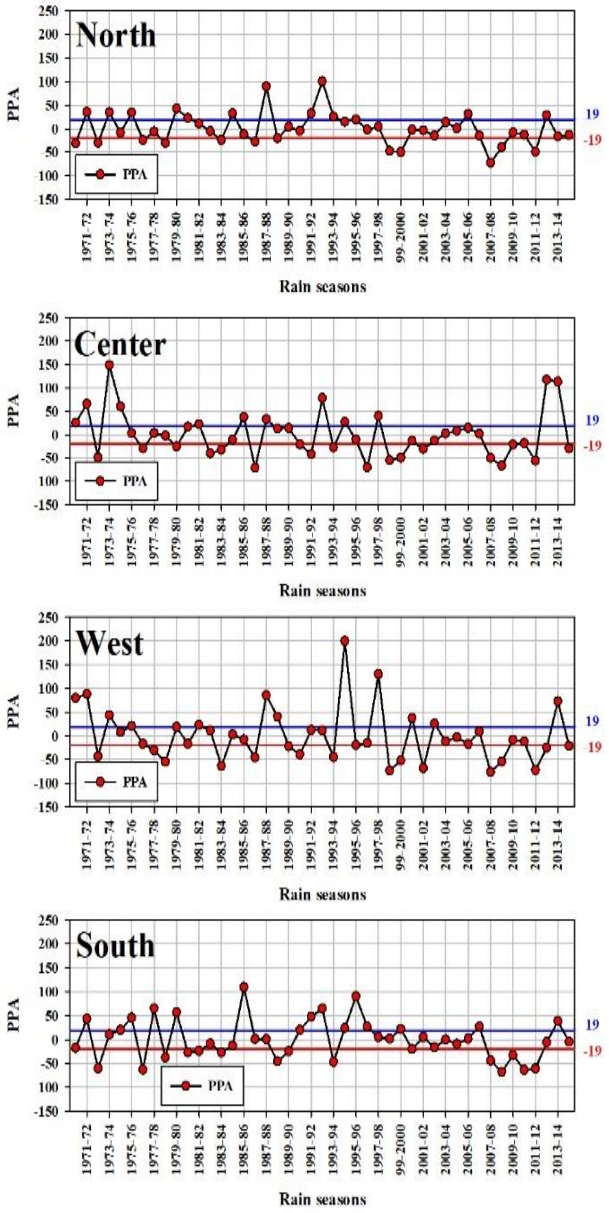


**Figure 4:** Time series of Percentage of Precipitation Anomaly (PPA) values of (North, Center, West, and South) of Iraq for 45 rainy season from 1970 to 2015 (past period). Red line is negative, blue line is positive.

The number of wet, dry, and near normal rain seasons were determined on the basis of PPA classification for past period. Baghdad station (center of Iraq) has the largest number of dry seasons (18 cases), and Rutba station (west of Iraq) was second rank has (17) dry seasons. Dry seasons due to lack of precipitation amounts in comparison with the normal rates of the region. The largest number of wet seasons in the south of Iraq (Basra station) were (15) seasons. Wet seasons are due to the increase of precipitation amounts comparison with the normal rates of the region. Based on the SPI-6 classification were the number of dry seasons (about 5) for each study period of all stations. Based on ZSI classification the number of dry season about 6 for all stations of both periods except Basra station has the largest number of dry seasons (8) for past period. The wet season based on ZSI classification for past period about 6 wet seasons for all stations. Table 4 shows the number of dry, wet, and near normal seasons based on classification of indices for past period, and table 5 for future period.

**Table 2:** Maximum and minimum values of SPI-6, PPA,and ZSI for (North, Center, West, and outh) stations for past period

| Stations | Index | Max. | Season | Min. | Season |
|---|---|---|---|---|---|
| North | SPI-6 | 1.6 | 1987-88 | -2.1 | 2007-08 |
| | PPA | 100 | 1992-93 | -72 | 2007-08 |
| | ZSI | 2.97 | 1992-93 | -2.15 | 2007-08 |
| Center | SPI-6 | 1.92 | 2013-14 | -1.15 | 1996-97 |
| | PPA | 149 | 1973-74 | -71 | 1986-87 |
| | ZSI | 3.00 | 1973-74 | -1.44 | 1986-87 |
| West | SPI-6 | 1.98 | 1994-95 | -1.50 | 1998-99 |
| | PPA | 200 | 1994-95 | -76 | 2007-08 |
| | ZSI | 3.58 | 1994-95 | -1.37 | 2007-08 |
| South | SPI-6 | 1.14 | 2013-14 | -1.44 | 2010-11 |
| | PPA | 109 | 1985-86 | -68 | 2008-09 |
| | ZSI | -68 | 2008-09 | -1.64 | 2008-09 |

**Table 3:** Maximum and minimum values of SPI-6, and ZSI for (North, Center, West, and South) stations for future period

| Stations | Index | Max. | Season | Min. | Season |
|---|---|---|---|---|---|
| North | SPI-6 | 1.23 | 2016-17 | -1.61 | 2035-36 |
| | ZSI | 1.66 | 2016-17 | -249 | 2035-36 |
| Center | SPI-6 | 1.12 | 2016-17 | -1.88 | 2044-45 |
| | ZSI | 1.94 | 2042-43 | -2.40 | 2044-45 |
| West | SPI-6 | 1.05 | 2041-42 | -1.97 | 2044-45 |
| | ZSI | 1.61 | 2016-17 | -2.42 | 2044-45 |
| South | SPI-6 | 1.57 | 2031-32 | -1.45 | 2035-36 |
| | ZSI | 1.83 | 2015-16 | -1.97 | 2035-36 |

### *The Relationship between Drought indices*

The results of analysis for the seasonally three drought indices for past period for four region (north, center, west, and south) (Mosul, Baghdad, Rutba, and Basra) stations respectively showed that they all had a strong positive relation between each other. However, the strongest correlation was between ZSI, and PPA with a perfect correlation coefficient (R=1). The relationship among SPI-6 and other indices also give a high correlation (0.85). Table 6 shows the correlation coefficient of the three indices for the four stations.

**Table 4:** The number of (dry, wet, and near normal) rain seasons basis of SPI-6, PPA and ZSI classification for past period for four stations.

| Stations | Index | Dry | Wet | Near normal |
|---|---|---|---|---|
| North | SPI-6 | 3 | 4 | 38 |
| | PPA | 12 | 12 | 21 |
| | ZSI | 5 | 6 | 34 |
| Center | SPI-6 | 3 | 3 | 39 |
| | PPA | 18 | 12 | 15 |
| | ZSI | 7 | 6 | 32 |
| West | SPI-6 | 5 | 4 | 36 |
| | PPA | 17 | 12 | 16 |
| | ZSI | 5 | 6 | 34 |
| South | SPI-6 | 4 | 4 | 37 |
| | PPA | 15 | 15 | 15 |
| | ZSI | 8 | 8 | 29 |

**Table 5:** The number of (dry, wet, and near normal) of rain seasons basis on SPI-6, and ZSI classification for future period for stations.

| Stations | Index | Dry | Wet | Near normal |
|---|---|---|---|---|
| North | SPI-6 | 5 | 6 | 24 |
| | ZSI | 5 | 5 | 25 |
| Center | SPI-6 | 5 | 2 | 28 |
| | ZSI | 5 | 5 | 25 |
| West | SPI-6 | 5 | 3 | 27 |
| | ZSI | 4 | 4 | 27 |
| South | SPI-6 | 3 | 1 | 31 |
| | ZSI | 6 | 6 | 23 |

**Table 6:** Correlation coefficient for 3 indices of 4 station for past period.

| Stations | Index | SPI-6 | ZSI |
|---|---|---|---|
| North | PPA | 0.884 | 1 |
| | ZSI | 0.884 | |
| Center | PPA | 0.910 | 1 |
| | ZSI | 0.910 | |
| West | PPA | 0.895 | 1 |
| | ZSI | 0.895 | |
| South | PPA | 0.851 | 1 |
| | ZSI | 0.851 | |

### *PPA and ZSI*

The three indices used in this study are good in assessing of drought severity in the study area. It is found that the percentage of precipitation anomaly (PPA) is the best index to determine the rain seasons (wet, dry, near normal) during past period 45 rainy season. Also, it is found that the Z-score index (ZSI) is the best index to determine rain seasons (wet, dry, near normal) during future period 35 rainy season. Depending on the classification of PPA, and ZSI which divided into three categories (wet, dry, and normal) seasons, where (±19% for PPA, and ±0.99 for ZSI) the precipitation is close to normal. Figure 5 shows the PPA values of four stations for past period. Figure 6 shows the ZSI values of four regions for future period.

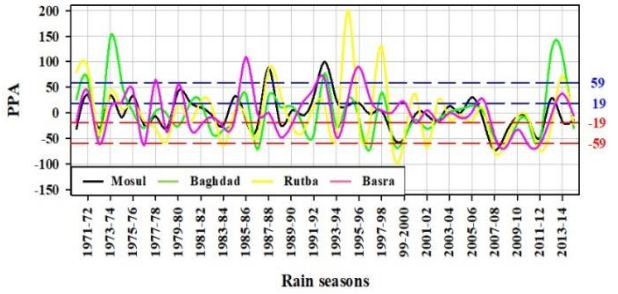


**Figure 5:** The value of PPA for (Mosul, Baghdad, Rutba, and Basra) stations for past period. (Red) dash line is negative, and (Blue) dash line is positive.

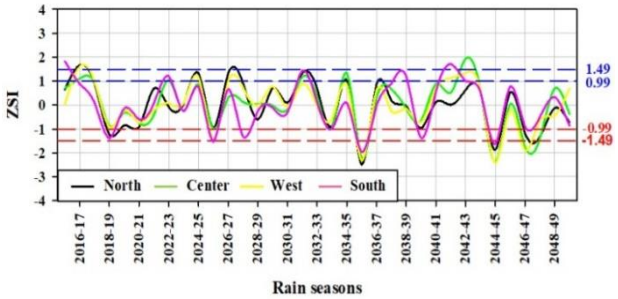


**Figure 6:** The value of ZSI for (north, center, west, and south) regions for future period. (Red) dash line is negative, and (Blue) dash line is positive.

## Conclusions

Based on the results obtained through this study for the two study periods (1970-2015) and (2016-2050). One can conclude that:

- The center of Iraq (Baghdad station) was the most prone to drought from the results analysis of the 3 indices for the past period. The number of dry seasons were 18 based on the classification of PPA, followed by the west of Iraq (Rutba station) based on the same index. Rutba station has the highest number of dry seasons based on the classification of SPI-6 with (5) dry seasons for past period.

- All drought indices had a strong positive relationship between each other for past period. However, the weaker correlation coefficient (R) between SPI-6 and other indices were exceeded (0.85) for 4 stations.
- All indices were good in assessing of drought severity in the study area, but the percentage of precipitation anomaly (PPA) is the best index to determine the rain seasons (wet, dry, near normal) during past period, and the Z-score index (ZSI) is the best index to determine rain seasons (wet, dry, near normal) during the future period.

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