EVALUATION OF DROUGHT IN IRAQ USING DSI. BY REMOTE SENSING

T. K. Jawad — Researcher
O. T. Al-Taai — Assist. Prof.
Y. K. Al-Timimi — Assist. Prof.

Dept. of Atmospheric Sci. Coll. of Sci. Univ. of Mustansiriyah
thaerkadum@gmail.com.

ABSTRACT

Evaluation of drought patterns in Iraq and determining the most susceptible areas of this phenomenon were analyzed, using the remotely-sensed Drought Severity Index (DSI) through analysis the daily and annual DSI for three zones over Iraq, also have been analyzed DSI time series using run theory to evaluate the characteristics of drought in Iraq. The efficiency of DSI for drought monitoring was examined from compared with Percentage of Precipitation Anomaly (PPA) for three zones (Arid and Semi-Arid, Steppes and Desert), and compared with drought indicators (Evapotranspiration (ET), Potential evapotranspiration (PET) and total annual precipitation (PRE)) for the period 2000-2011, were derived from the Numerical Terradynamic Simulation Group (NTSG). The spatial interpolation techniques in Geographic Information System (GIS) package has been used, to cover the whole extent of country and extracting the zones. Statistical methods were applied to compute the probability of drought events at every zone. The results showed the drier year is 2008, the wetter years are 2001 in Desert zone and 2003 in steppes and Arid and Semi-Arid Zone zones. The results also showed a significant fluctuation in precipitation from the average, especially at Arid and Semi-Arid Zone when compared with other zones. The values of standard deviation of precipitation were compared with precipitation anomalies for each zone, Arid and Semi-Arid is the drier zone in 2007-2008, the wetter zone is also Arid and Semi-Arid in 2002-2003. Using run theory, the drier Zone is Arid and Semi-Arid and the wetter Zone is steppes during study period.

KEYWORDS: percentage of precipitation anomaly, evapotranspiration, potential evapotranspiration, NTSG, GIS, MODIS, standard deviation, drought events.

تقييم الجفاف في العراق باستخدام مؤشر شدة الجفاف عن طريق الاستشعار عن بعد

ياسين كاظم التميمي — أستاذ مساعد
أسامة طارق الطائي — أستاذ مساعد
ثائر كاظم جواد — باحث

قسم علوم الجو – كلية العلوم – الجامعة المستنصرية

المستخلص

تم تحليل أنماط الجفاف في العراق وتحديد المناطق الأكثر عرضه لهذه الظاهرة باستخدام مؤشر شدة جفاف الاستشعار عن بعد (DSI) وذلك من خلال تحليل قيم DSI اليومية والسنوية لثلاث مناطق في العراق، وكذلك تحليل السلاسل الزمنية DSI باستخدام نظرية التشغيل (Run theory) لتقيم خصائص الجفاف في العراق. تم اختبار كفاءة DSI لرصد الجفاف عن طريق مقارنة مع نسبة شذوذ هطول الأمطار (PPA) لثلاث مناطق (الجافة وشبه الجافة، السهوب، الصحراوية)، ومقارنة مع مؤشرات الجفاف التبخر-النتح (ET)، التبخر-النتح الجهدي (PET) والمجموع السنوي لهطول الامطار (PRE) للفترة 2000-2011، والمشتقة من مجموعة المحاكاة العددية لحركية الأرض (NTSG). تم استخدام تقنيات الاستيفاء المكاني في حزمة نظم المعلومات الجغرافية ArcGIS لتغطية جميع مساحة منطقة الدراسة واستخراج المناطق الثلاثة. تم تطبيق الأساليب الإحصائية لحساب احتمالية احداث الجفاف في كل منطقة. وأظهرت النتائج أن عام 2008 هو الأكثر جفافا والسنوات الأكثر رطوبة هي 2001 في المنطقة الصحراوية و2003 في منطقة السهوب والمنطقة الجافة وشبه الجافة. وأظهرت النتائج ان هنالك تذبذب كبيرة في هطول الأمطار عن المعدل، لا سيما في المنطقة الجافة وشبه الجافة بالمقارنة مع المناطق الأخرى. تم مقارنة قيم الانحراف المعياري لهطول الأمطار مع شذوذ هطول الامطار لكل منطقة، حيث تبين بان المنطقة الجافة وشبه الجافة هي المنطقة الأكثر جفافا في الموسم المطري 2007-2008، اما المنطقة الأكثر رطوبة هي أيضا الجافة وشبه الجافة في الموسم المطري 2002-2003. وباستخدام نظرية التشغيل تبين بان المنطقة الأكثر جفافا هي الجافة وشبه الجافة والمنطقة الاكثر رطوبة هي منطقة السهوب خلال فترة الدراسة.

كلمات مفتاحية: نسبة شذوذ الامطار، التبخر-النتح، التبخر-النتح الجهدي، مجموعة المحاكاة العددية لحركية الارض، نظم المعلومات الجغرافية، تصوير طيفي متوسط الدقة، الانحراف المعياري، احداث الجفاف.

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INTRODUCTION

Drought is a random natural phenomenon that emerges from a large deficiency in precipitation. It is the costliest natural disasters in the world and affects a very large number of people every year, it is important to monitor, understand and may be predict their frequency (21). The causes for the incidents of drought are complex because they don't just depend on the atmosphere but also on the hydrologic processes which provide moisture to the atmosphere (4). Drought events can be determined by characteristics of drought using the runs theory. Yevjevich in 1967 (23) who is proposed the runs theory and defined droughts as periods during which the water supply does not meet the current water demand by determining drought variables and their drought characteristics: (a) duration, (b) severity, and (c) intensity from the streamflow time series (12). This method has been widely used in the field of hydrology and there is a large amount of research on the characterization of droughts and the first few works that applied the runs theory in hydrology by (24), (18), (19), (11), (8), and (20) and has been applied in several drought models and analyzes, (for example, (6) and (13), which can be estimated the return periods of extreme events (7). This study focuses on five objectives: (i) Evaluation of the behavior of drought Indicators used in this study, (ii) Evaluation of the efficiency of remotely-sensed Drought Severity Index (DSI) for drought monitoring by Compared with Percentage of Precipitation Anomaly (PPA), (iii) Determining drought events by using DSI through analysis of daily and annual mean of DSI data for the period (2000-2011) over Iraq, (iv) Study climate change using Percentage of Precipitation Anomaly (PPA) for long-term study period 1980-2015 and (v) Evaluation of drought patterns in Iraq and determining the most Susceptible areas of this phenomenon using the runs theory.

MATERIALS AND METHODS

Study Area: Iraq is located in the range of semi-tropical latitude in the Northern Hemisphere between longitudes (38.45°-48.45°) east of Greenwich line and between latitudes (29.5°-37.5°) north of the equator (2). Iraq lies within the moderate northern region, a system similar to that of Mediterranean where rainfall occurs almost in winter, autumn, spring and disappears in summer. The general distribution of seasonal rainfall of Iraq in Climate Atlas illustrating, the lower rainfall in the south and southwest and increase towards to the north and north-east (5).

Data and Preprocessing

Data acquired mainly from two sources, firstly remote sensing data derived from **M**oderate **R**esolution **I**maging **S**pectroradiometer (MODIS) on board the NASA satellites (Terra and Aqua), and secondary monthly historical records of monthly rainfall data obtained from ground weather stations for the time period 1980-2015, see table (1).

Remote Sensing Data

In 2007 Mu et al. developed a MODIS ET (MOD16) to estimate Evapotranspiration (ET) and Potential evapotranspiration (PET) using MODIS data (4). MOD16 ET algorithm is based on the Penman-Monteith equation (hereafter P-M) (14). Numerical Terradynamic Simulation Group (NTSG) calculated DSI by using MODIS ET/PET and MODIS NDVI (9), which use global earth's data derived from NASA satellites (Terra and Aqua). The DSI dataset for the whole of earth 109.03 million km^2 of the vegetation areas of the earth's surface for the period (2000-2011) at 8-day and annual time periods, and spatial resolution 0.5 and 0.05 degrees (17).

Rainfall Data

In this study, real data of monthly rainfall (PRE) from ground stations were obtained from the Iraqi Meteorological Organization and Seismology (IMOS) for the period 1980-2015. The dataset was collected from 39 as shown in figure (1). The database was digitally encoded into a Geographic Information System (GIS) database for a distribution map which shows the general distribution of seasonal rainfall and climatic zones for the study area (3).

Table 1. Data Sources

Data	Spatial Resolution	Temporal Resolution	Source
ET	$0.5^{o} * 0.5^{o}$	annual	MODIS
PET	$0.5^{o} * 0.5^{o}$	annual	MODIS
DSI	$0.5^{o} * 0.5^{o}$	8-day and annual	NTSG
PRE	Stations	monthly	IMOS

Study area can be split into three climatic zones according to the rainfall factor, see figure (1): (i) Arid and Semi-Arid Zone where annual rainfall above 400 mm, Steppes Zone where annual precipitation of 200-400 mm, and Desert Zone where annual rainfall less than 200 mm (1) and (10). Rainfall data collected from weather stations for each rainfall season (October, November, December, January, February, March, April and May), to get total seasonal rainfall. Then, were aggregated to the Zones (Arid and Semi-Arid, Steppes, and Desert) to get *the average of each Zone*.

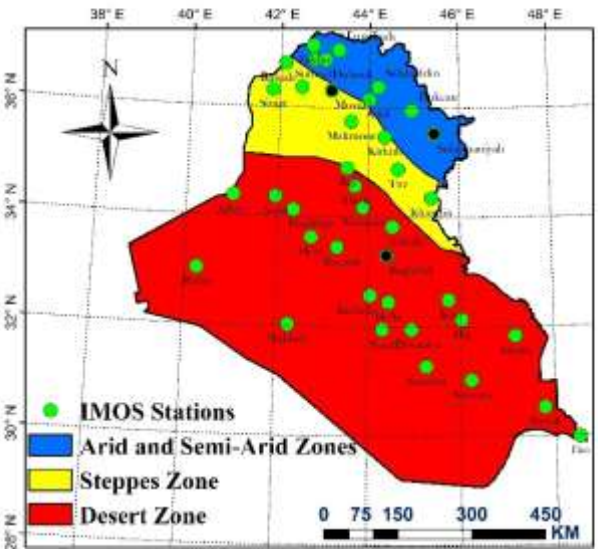


Fig. 1. Weather Stations and Climatic Zones

Methods

Remotely-Sensed DSI: The ratio of ET to PET is a useful measure of plant water supply in relation to plant water demand. It also can be used as an indicator of soil moisture conditions (22). It can be calculated as follows:

$$Ratio = \frac{ET}{PET} \qquad (1)$$

Where: ET represents **E**vapo**T**ranspiration and PET is **P**otential **E**vapo**T**ranspiration

To calculate the value of DSI, standardization for values of the Ratio and NDVI, see table (2).

$$Z_{Ratio} = \frac{\text{Ratio}-\overline{Ratio}}{\sigma_{Ratio}} \qquad (2)$$

$$Z_{NDVI} = \frac{\text{NDVI}-\overline{NDVI}}{\sigma_{NDVI}} \qquad (3)$$

Where: NDVI is **N**ormalized **D**ifference **V**egetation Index, σ_{ratio} represents temporal standard deviation, $\overline{Ratio}$ is Ratio average, and $\overline{NDVI}$ is Normalized Difference Vegetation Index average.

They have added Eq. 2 and Eq. 3, then standardized the result again to derive the DSI.

$$Z = Z_{Ratio} + Z_{NDVI} \qquad (4)$$

$$DSI = \frac{Z-\bar{Z}}{\sigma_Z} \qquad (5)$$

DSI combine NDVI and the ratio (ET/PET) for a single index extend from less than -1.5 (drier than normal) to greater than 1.5 (wetter than normal) (table 3) (16).

Table 2. The ratio of ET to PET and Z_{Ratio}

Years	Steppes Zone		Desert Zone		Arid and Semi-Arid Zone	
	Ratio	Z_{Ratio}	Ratio	Z_{Ratio}	Ratio	Z_{Ratio}
2000	-0.002	-0.18	0.004	1.05	-0.008	-0.68
2001	0.009	1.00	0.005	1.26	0.004	0.34
2002	0.005	0.59	0.003	0.81	0.012	1.05
2003	0.017	2.00	0.004	0.88	0.016	1.44
2004	0.011	1.29	0.003	0.80	0.010	0.86
2005	-0.003	-0.31	-0.003	-0.77	-0.008	-0.69
2006	0.001	0.14	0.002	0.49	0.008	0.69
2007	-0.008	-0.97	-0.001	-0.13	-0.002	-0.18
2008	-0.01	-1.59	-0.005	-1.13	-0.03	-2.52
2009	-0.007	-0.84	-0.005	-1.33	-0.002	-0.16
2010	-0.006	-0.68	-0.01	-1.83	-0.004	-0.33
2011	-0.004	-0.45	0.0001	-0.10	0.002	0.18

Table 3. Remotely-Sensed DSI classifications for dry and wet periods (16).

Index value	Classification
Extremely wet	1.5 or greater
Very wet	1.2 to 1.49
Moderately wet	0.9 to 1.19
Slightly wet	0.6 to 0.89
Incipient Wet spell	0.3 to 0.59
Near normal	0.29 to -0.29
Incipient drought	-0.3 to -0.59
Mild drought	-0.6 to -0.89
Moderate Drought	-0.9 to -1.19
Severe Drought	-1.2 to -1.49
Extreme Drought	-1.5 or less

Meteorological Drought Index

Another meteorological index, Percentage of Precipitation Anomaly (PPA), was used to comparison and evaluation with remotely-sensed Drought Severity Index (DSI).

$$PPA = \frac{\text{P}-\bar{P}}{\bar{P}} * 100\% \qquad (6)$$

Where P is the precipitation and $\bar{P}$ is the average precipitation for a certain period.

Estimate Unknown Points

In this study, spatial interpolation techniques were used in Geographic Information System (GIS) package to cover the whole extent of country and extracting the zones. The *ordinary kriging techniques* was used to estimate values at unknown points by using known measurements and the continues surface data can be interpolated from the isolated point data such as weather station (3). After the extracted average total annual precipitation for each zone used to calculate the PPA using Eq. (6).

Evaluation the DSI Efficiency

The regression models were used between DSI and Percentage of Precipitation Anomaly (PPA), and the determination coefficient (R^2) was selected as a criterion for evaluating the efficiency of drought monitoring. Pearson correlation coefficient (R) in Equation (7) between DSI and drought indicators selected at study period was also calculated to Evaluation of drought patterns in Iraq and determining the most Susceptible areas (Zones) of this phenomenon.

$$\mathbf{R} = \frac{\sum_{i-1}^{n}(x_i-\bar{x})(y_i-\bar{y})}{\sqrt{\sum_{i=1}^{n}(x_i-\bar{x})^2 \sum_{i=1}^{n}(y_i-\bar{y})^2}} \quad (7)$$

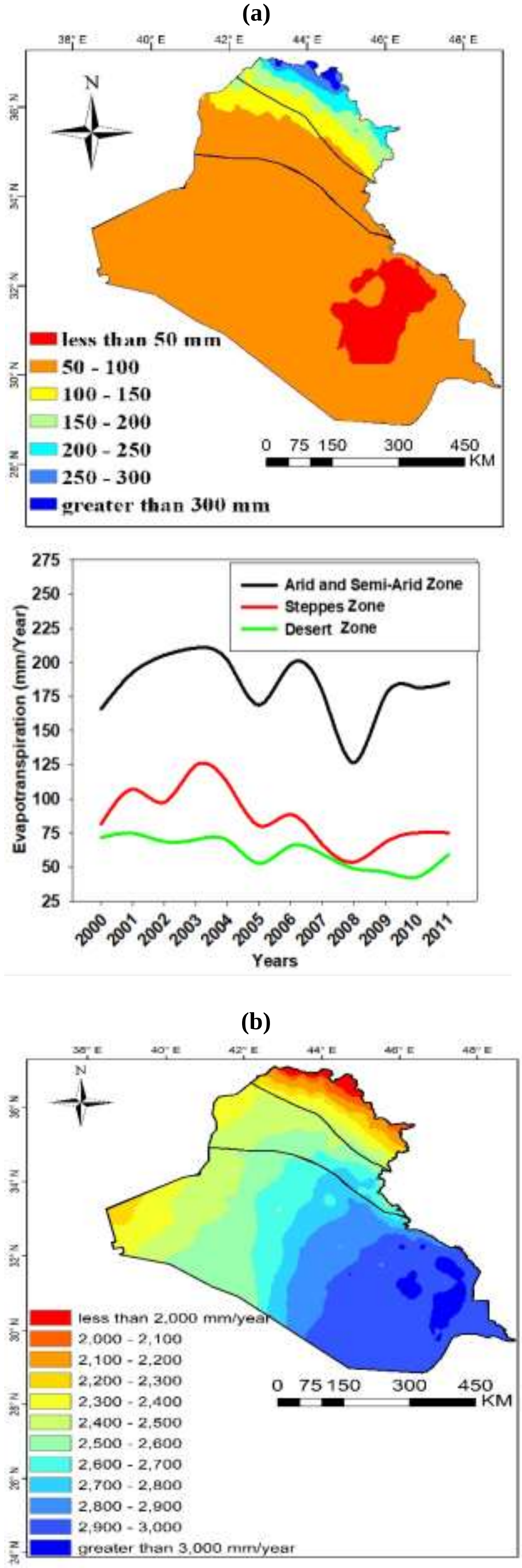
Where: **x** represents meteorological parameters (drought indicators), **y** the DSI at different time scales, $\bar{\mathbf{x}}$ The mean of DSI during time scale, $\bar{\boldsymbol{y}}$ The mean of drought indicator during time scale and n is the number of samples

RESULTS AND DISCUSSION

Evaluation of the behavior of drought indicators: The Evapotranspiration (ET), Potential evapotranspiration (PET), and Seasonal Precipitation (PRE) data for the period (2000-2011) were aggregated into average total annual values except Precipitation was aggregated into average of total seasonal precipitation, divided into three climatic zones. Average evapotranspiration during the study period, increasing towards the Arid and Semi-Arid Zone due to the increase in the amount of Precipitation in this Zone compared to the amount of Precipitation in the Steppes and Desert Zones, as shown in the figures (2a) and (2c), while average Potential evapotranspiration increases towards the Steppes and Desert Zones due to lack of precipitation in these Zones and increase the net solar radiation at earth surface (Penman-Monteith equation) when compared with the Arid and Semi-Arid Zone, As shown in figures (2b),(2c). Table (4) and figure (2c) shows a significant fluctuation in precipitation amount from the average at all zones over Iraq, especially at Arid and Semi-Arid Zone when compared with Steppes and Desert zones, and this is clear from the large standard deviation value (STDEV) in this zone, this fluctuation is decreasing towards the Steppes and Desert zones result of to the decreasing precipitation in these zones during the study period. From time series of evapotranspiration, it can be seen decreasing in trend of evapotranspiration during study period, result decreasing in the trend of precipitation which leads increasing the capacity of the atmosphere to removal water from the surface through the processes of evaporation and transpiration assuming no control on water supply (PET).

Table 4. Precipitation anomalies and Standard deviation of precipitation for each Zone during the period (2000-2011).

Years	Steppes	Desert	Arid & Semi-Arid
1999-2000	-127.6	-54.5	-180
2000-2001	-5.1	55	-153.7
2001-2002	67.5	16.6	118.2
2002-2003	113.5	-22.3	215.5
2003-2004	82.4	55	128.6
2004-2005	71.7	31.8	38.3
2005-2006	57.1	60.6	32.9
2006-2007	35.8	17.4	77
2007-2008	-177.7	-69.9	-232.9
2008-2009	-95.8	-58.8	-84.8
2009-2010	-2.3	-8.7	19.1
2010-2011	-14.9	-21.2	10.5
Average PRE	304.4	110.2	554.5
STDEV	91	46	136



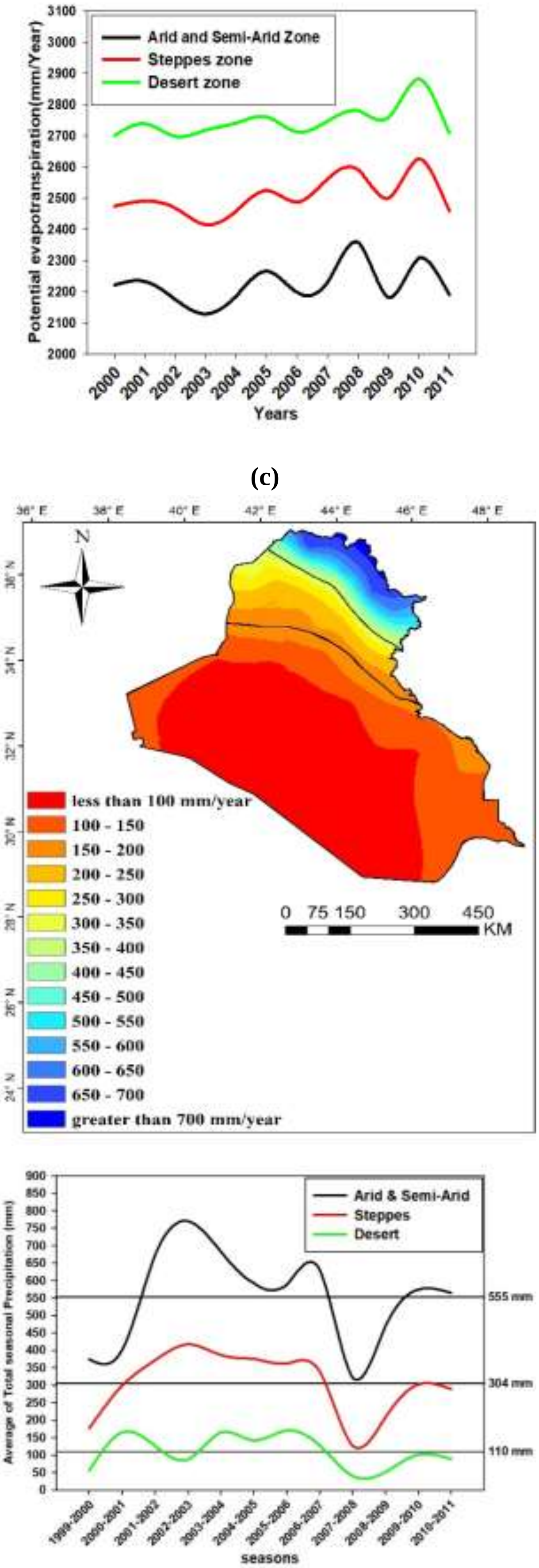


Fig. 2. Drought indicators for the period (2000-2011): (a) ET, (b) PET, and (c) PRE

Evaluation of Annual DSI For Drought Monitoring

The efficiency of DSI for drought monitoring was calculated from Compared with Percentage of Precipitation Anomaly (PPA). Figures (3a), (3b) and (3c) shows there is significant relationships between annual DSI and annual precipitation in all Zones

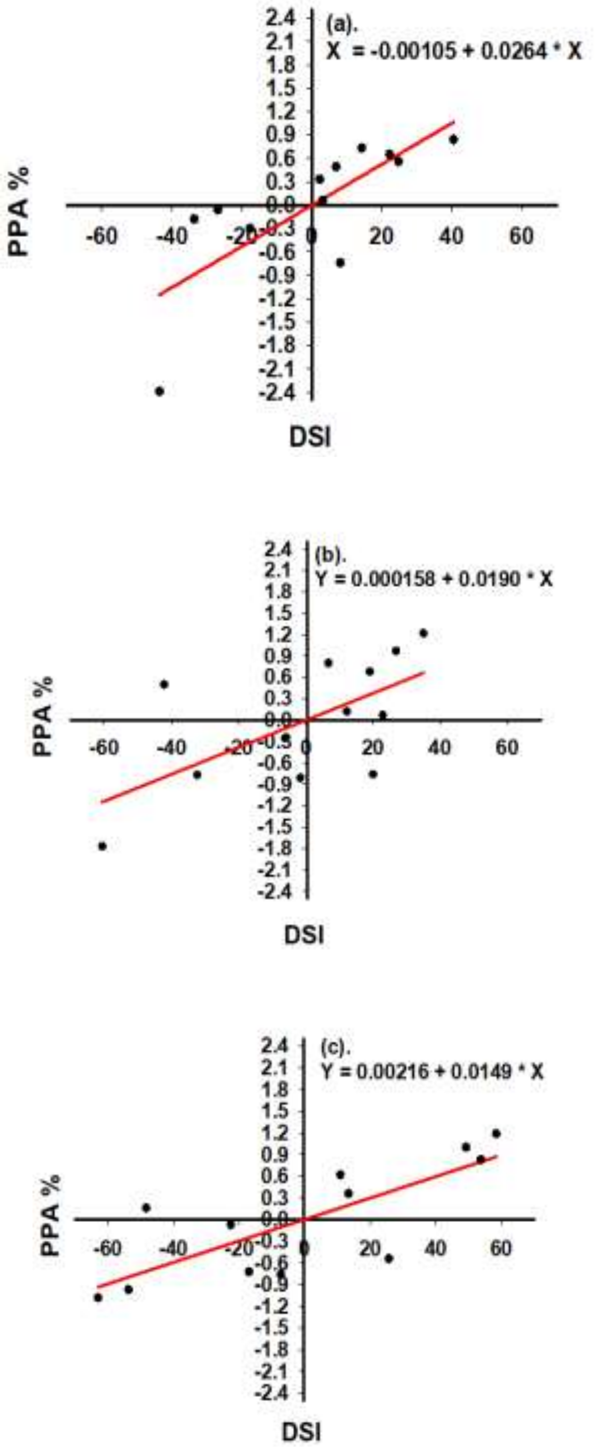


Fig. 3. The relationships between DSI-PPA for Iraq: (a) Arid and Semi-Arid Zone, (b) Steppes Zone and (c) Desert Zone.

Table 5. The relationships between DSI and indicators for Iraq

Zones	Arid and Semi-Arid		Steppes		Desert	
	(R^2)	(R)	(R^2)	(R)	(R^2)	(R)
PPA	0.6	0.8	0.4	0.6	0.6	0.8
ET	0.8	0.9	0.8	0.9	0.7	0.8
PET	0.6	-0.8	0.6	-0.8	0.2	-0.5
PRE	0.6	0.8	0.4	0.6	0.6	0.8

From Table (5), it can be seen the correlation coefficient (R) and determination coefficient (R^2) in Arid and Semi-Arid, Steppes and Desert Zones together, which demonstrating that the DSI has strong efficiency for drought monitoring at annual level. The results show that the steppes zone has weaker relationship between DSI-PPA than other zones, the reason is that the precipitation is average total of precipitation for entire zone, but the DSI have been aggregated from the vegetated lands in the Zone. Therefore, these doubts in the data whether from precipitation or DSI may have an impact on statistical relationships. The efficiency of DSI for drought monitoring was also examined by comparing with drought indicators. The annual ET, PET, and PRE were aggregated to zones over 2000–2011 from same way used to calculate DSI. Figures (4) and table (5) shows the correlation between DSI-ET, DSI-PET, and DSI-PRE. As seen, the annual DSI shows has a strong relationship with all indicators in all Zones. The correlation coefficient (R) and determination coefficient (R^2) in all Zones, which demonstrating that the DSI has strong efficiency for drought monitoring at annual level. The results also show that Desert Zone has Weaker relationship between DSI-PET than other zones and Other indicators, the reason is the Lack of precipitation in this Zone when compared with other Zones, because potential evapotranspiration depends on the amount of precipitation, this is illustrated in Arid and Semi-Arid and Steppes Zones.

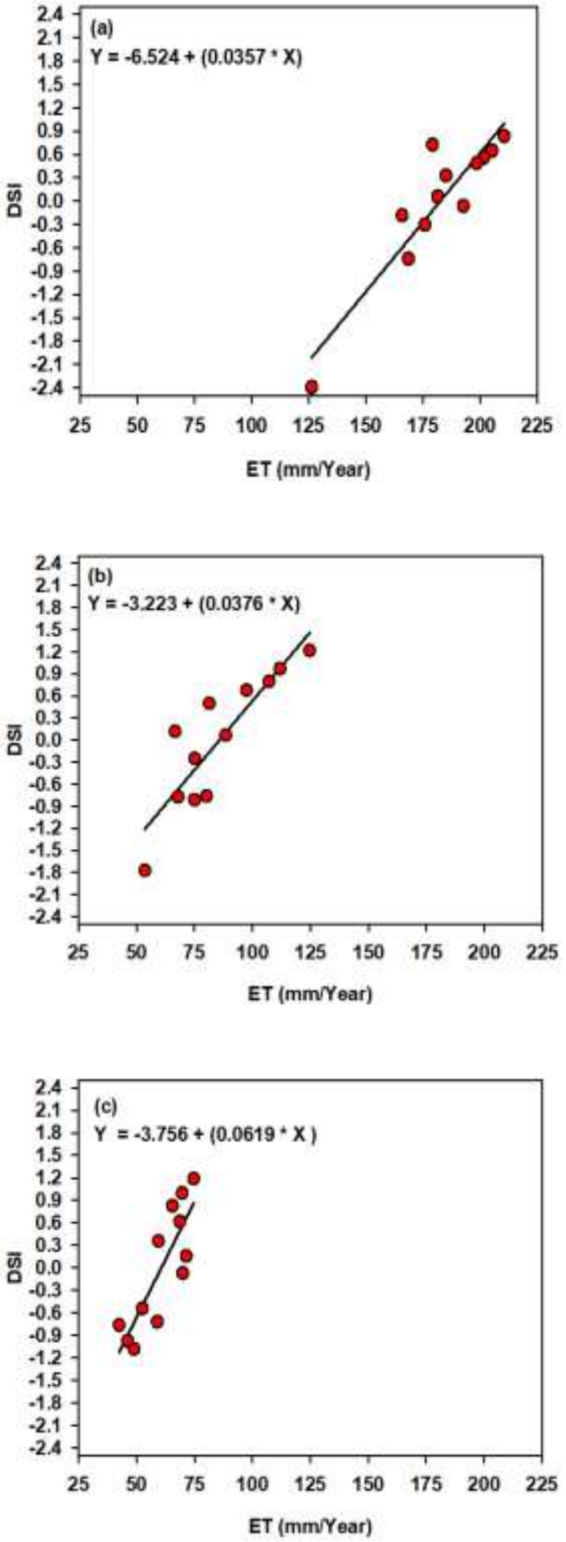
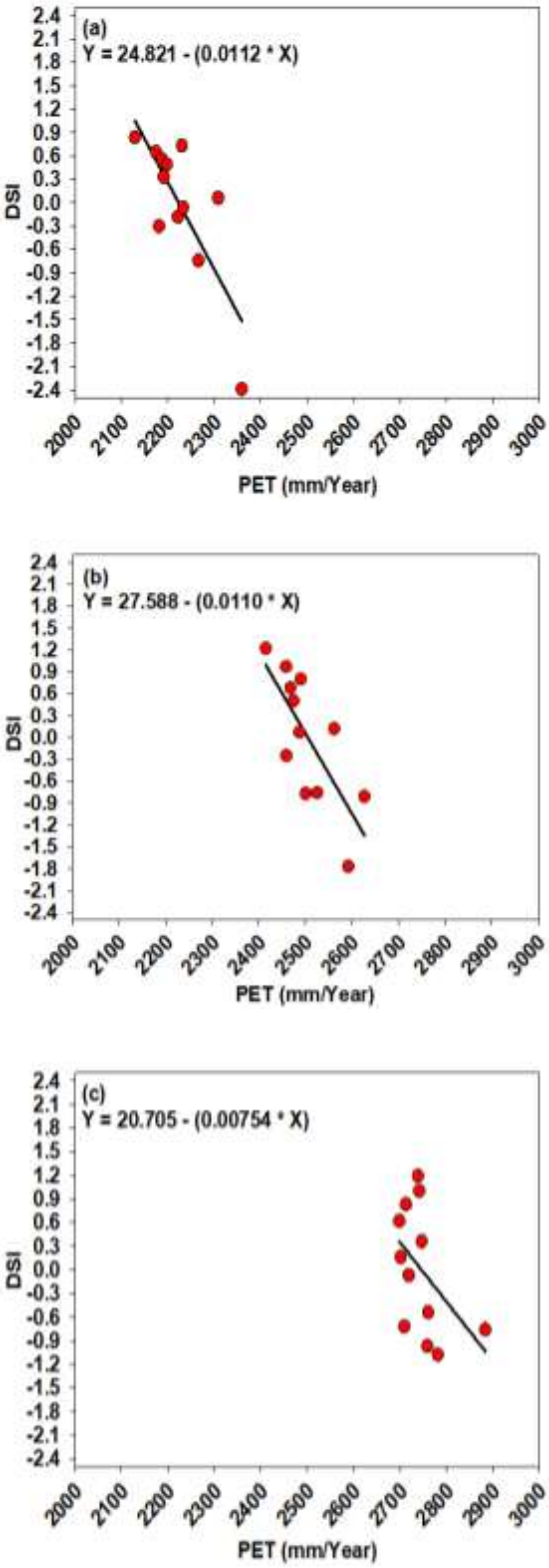


Fig. 4. The relationships between DSI-indicators for Iraq: (a) Arid and Semi-Arid Zone, (b) Steppes Zone and (c) Desert Zone.



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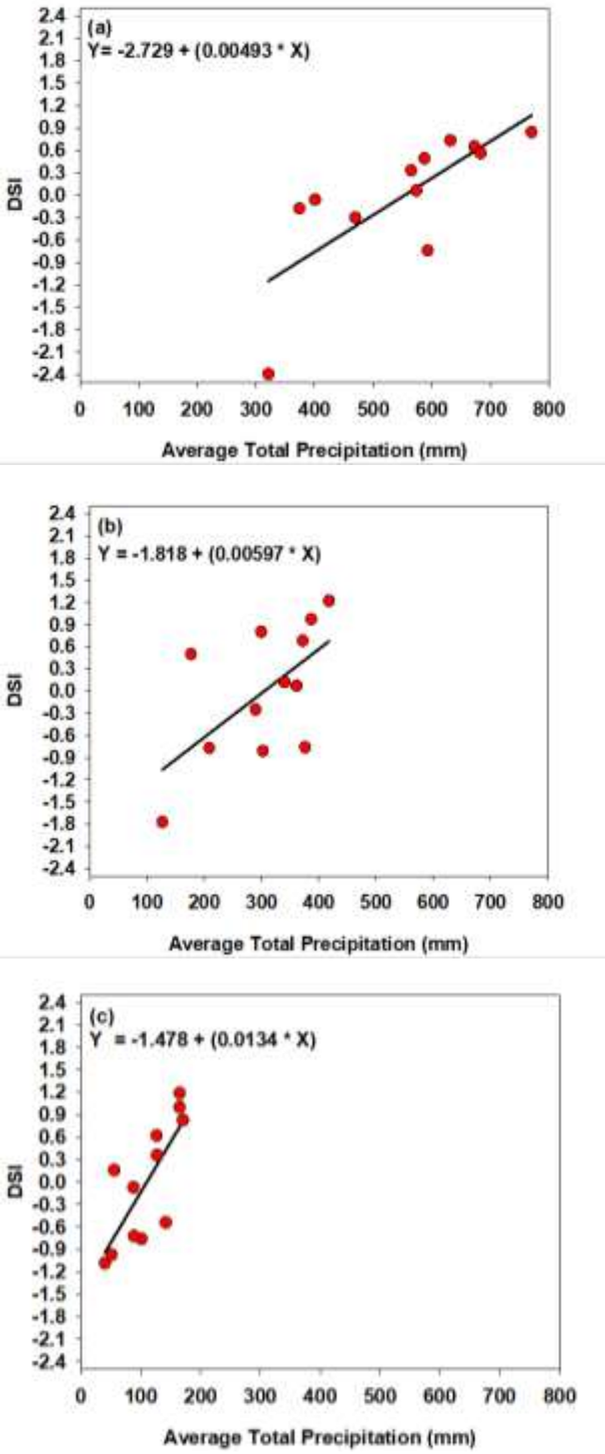


Followed Figure 4

From Figure above it can be seen that the relationship between DSI-ET was positive while DSI-PET was negative, the reason as mentioned earlier that potential evapotranspiration (PET) is the capacity of the atmosphere to removal water from the surface through the processes of evaporation and transpiration assuming no control on water supply. While evapotranspiration is the quantity of water that is actually removed from a surface due to the processes of evaporation and transpiration and this is dependent upon the amount of water in surface as shown in section of *evaluation of behavior of drought indicators* and values of Ratio in table (2), which can be seen the minimum values of ratio were -0.03 and -0.01 in 2008 at Arid and Semi-Arid and Steppes Zones respectively while at desert zone was -0.01 in 2010 with minimum values of evapotranspiration and average precipitation see figures (2a) and (2c), which that mean the relationship between them are positive correlation while the values of potential evapotranspiration in 2008 and 2010 were maximum value during study period that mean the relationship between them are inverse correlation , see figure (2b).

Drought Events

The Drought events and most Susceptible Zone of drought in Iraq can be determined from the DSI time series and from precipitation anomalies, see figure (5) and table (4). The annual DSI and precipitation anomalies were extracted per Zone for the period 2000-2011 using same way used in sections (1.3.2) and (2.2). Every drought event is determined by unlimited negative values, see table (3). Figures (6), shows the DSI values at Arid and Semi-Arid, Steppes, and Desert zones of Iraq for years: 2001, 2003, 2004, 2006 and 2008. The drier year is 2008 in all zones, the wetter years are 2001, 2003 and 2004 in all zones except Arid and Semi-Arid zone in 2001 and Desert zone in 2003 where were near normal. For example, Arid and Semi-Arid zone, Steppes Zone, and Desert zone; the maximum negative value of DSI are -2.39 (Extreme drought), -1.77 (Extreme drought) and -1.08 (Moderate drought), respectively in 2008, It is a result of a deficit in amount of precipitation in season (2007-2008) Compared with average precipitation (precipitation anomaly) during the study period, see figure (2c) and table (4), and therefore decrease in the evapotranspiration process and increase in potential evapotranspiration process, see figures (2a and 2b), while the wetter year was 2003 at all zone except Desert zone, this is clear from the positive values of precipitation anomalies in season (2002-2003) and annual DSI in 2003, which leads increasing in evapotranspiration process and decreasing in potential evapotranspiration

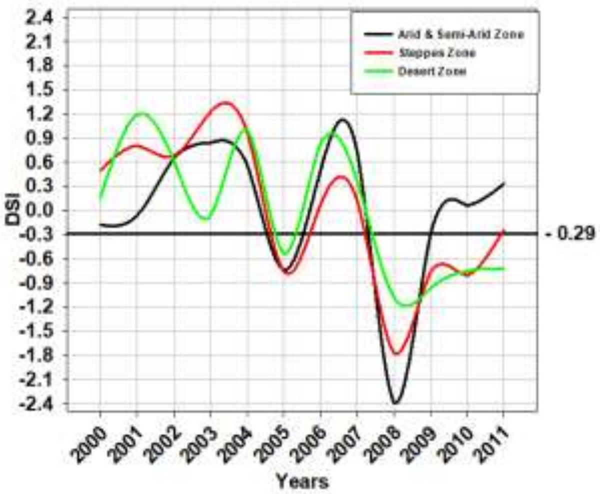
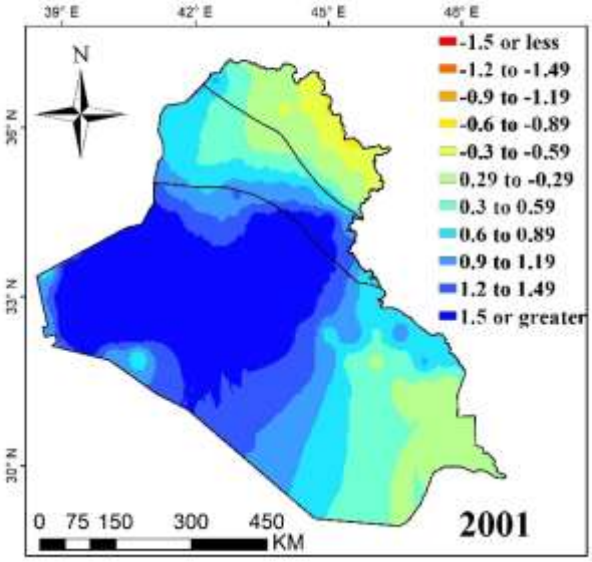
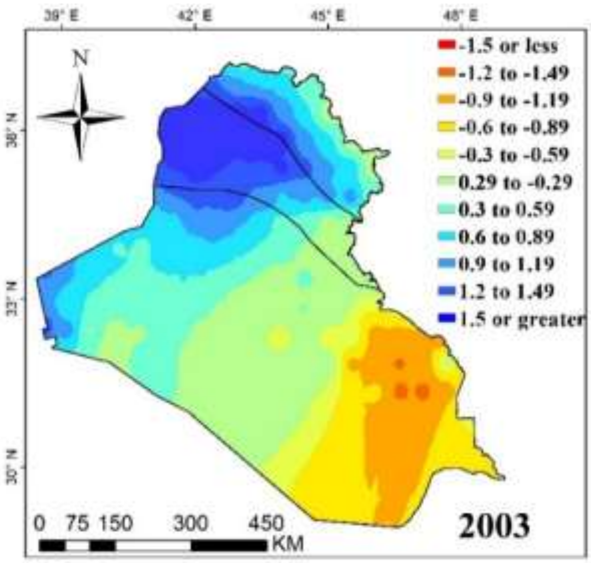
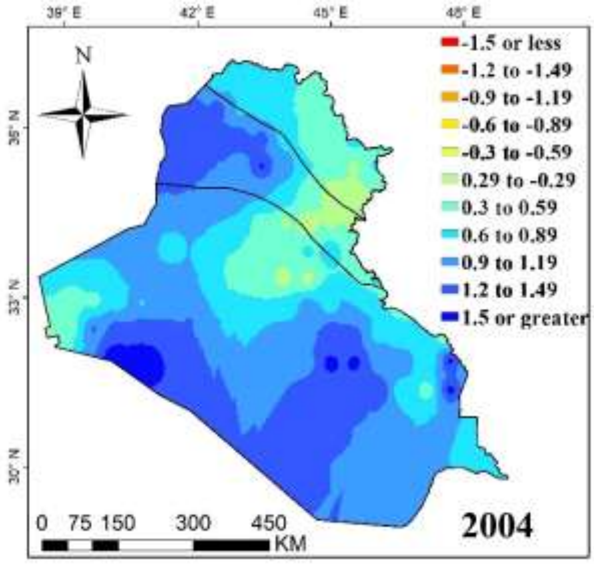
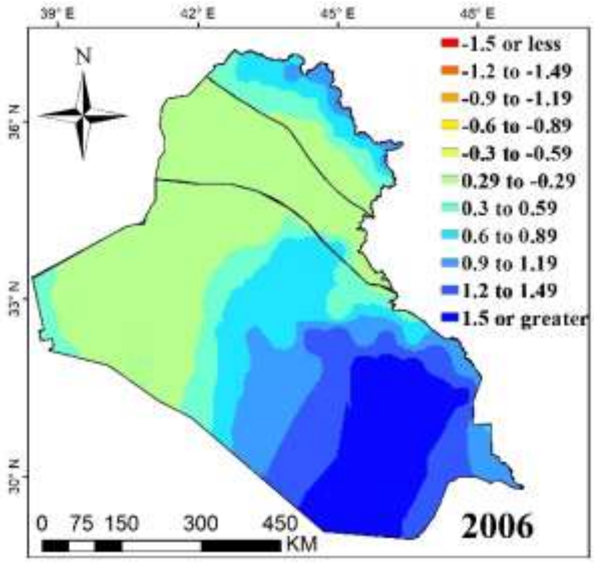


Fig. 5. Annual mean of DSI for Iraq: Arid and Semi-Arid Zone, Steppes Zone and Desert Zone









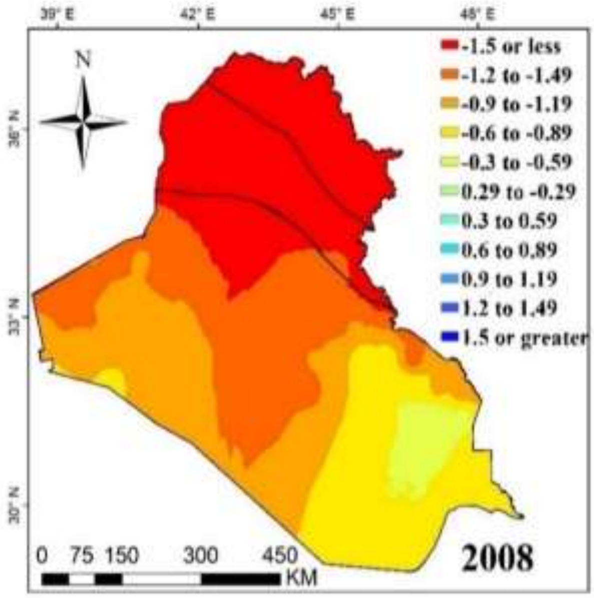


Fig. 6. Annual DSI for Iraq in: 2001, 2003, 2004, 2006 and 2008

The Drought events also can be determined from precipitation anomalies. From table (4), it can be seen that there is a significant fluctuation in precipitation amount when compared the standard deviation of precipitation values for each zone with precipitation anomalies during the study period especially in seasons: (1999-2000), (2000-2001), (2002-2003), (2003-2004), (2005-2006), (2007-2008) and (2008-2009). The greater positive anomaly value was 215.5 mm at Arid and Semi-Arid Zone in (2002-2003), which is greater than the standard deviation of precipitation at this zone (136mm), So, this is leads to the load the soil with water and increasing the vegetation cover, this is evident from the value of DSI in 2003 as a result of increased vegetation cover (NDVI) and thus increased evapotranspiration process (ET). The greater negative anomaly value was -232.9 mm also at Arid and Semi-Arid zone in (2007-2008), which is greater than the standard deviation of precipitation at this zone. Also, from table (4), The greater positive anomaly value at Steppes and Desert Zones were in (2002-2003) and (2005-2006) respectively, which is greater than the standard deviation of precipitation at these zones. So, it is clear that (2007-2008) is the drier season in all Zones, the wetter seasons are (2002-2003) at Arid and Semi-Arid and Steppes zone and (2005-2006) at Desert zone. Also, the Arid and Semi-Arid zone has greater fluctuation in precipitation amount from other zones during study period. Figure (7) shown Percentage of Precipitation Anomaly (PPA) during study period for three zones, it can be seen the maximum positive percentage value of PPA are 58.4% in 2000-2001 at Desert Zone, 40.4% and 35% in 2002-2003 at Arid and Semi-Arid Zones and Steppes respectively, and minimum negative percentage value of PPA are -63%, -60.5%, and -43.5% at Desert zone, Steppes and Arid and Semi-Arid Zones respectively in 2007-2008. From table (4), It can be seen the Desert zone is characterized by the greatest value of Precipitation from the average (Anomaly) in 2005-2006, but from figures (5), (6) and (7) noted That the greatest value at Desert zone was in (2000-2001), The reason for the amount of Precipitation during this season comparing with season 1999-2000, which lead to soil kept amount of water a result of the high amount of precipitation, therefore an increase of vegetation cover and increased evapotranspiration process during this season. So, the wetter year at Desert Zone was 2001, this is evident through the large value of DSI in 2001 and PPA in season (2000-2001).

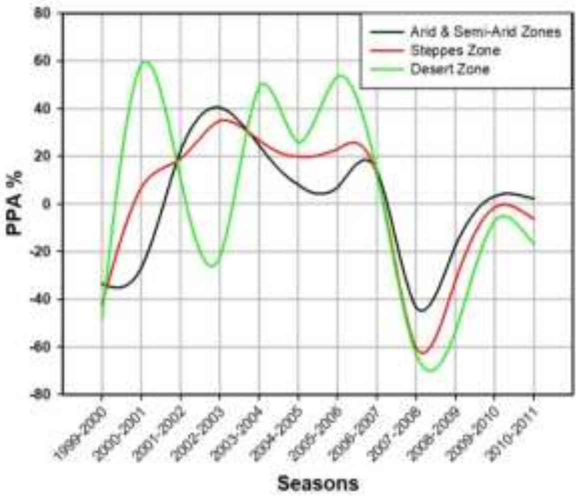


Fig. 7. The values of PPA for Iraq: Arid and Semi-Arid Zone, Steppes Zone and Desert Zone

In order to study climate change at study area, Percentage of Precipitation Anomaly (PPA) was used as an index of drought monitoring and thus determining the most Susceptible areas of this phenomenon for long-term study period 1980-2015. From equation (6) and table (4) we can conclude the Maximum and Minimum threshold of PPA for every Zone (the ratio of the standard deviation to the average precipitation for every zone), which that wet year if year exceed maximum threshold and dry year if that year exceed minimum threshold and between this maximum and minimum values are represent the normal fluctuation of precipitation for each zone. The threshold levels are $\pm$ 25% mm, $\pm$ 32% and $\pm$ 39% for Arid and Semi-Arid, Steppes, and Desert Zone for long-term study period respectively. Figure (8) shows that the behavior of Percentage of Precipitation Anomaly is similar to his of previous figure for the first study period, with a difference in the average values for each zone of the study period. The maximum positive percentage value of PPA are 83.9% and 51.7% in season 1987-1988 at Steppes and Arid and Semi-Arid Zones respectively, while at Desert Zone was 81.5% in seasons 1994-1995 and 1997-1998.

The minimum negative percentage value of PPA are -70.3% and -62.6%, at Desert and Steppes Zones respectively in season 2007-2008 and -48.3% at Arid and Semi-Arid Zone in season 1998-1999 while at Arid and Semi-Arid Zone in season 2007-2008 was -43.9%. From Figure below we can see the drier year also was 2008 in all zone because has lower amount of total precipitation during long-term study period.

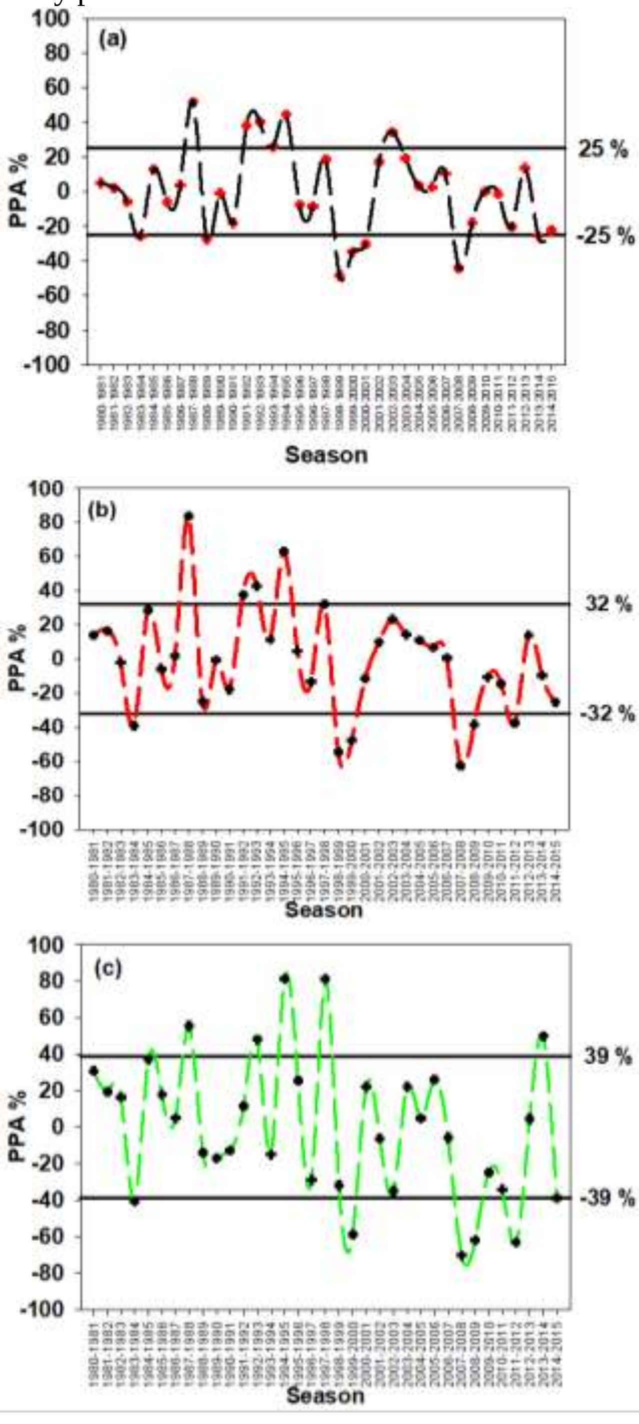


Fig. 8. The values of PPA during long-term study period (1980-2015) for Iraq: (a). Arid and Semi-Arid Zone, (b). Steppes Zone and (c). Desert Zone

Evaluation of Drought Events Using Runs Theory

Drought events in Iraq were analysis using run theory. The results show that the characteristics of drought in Iraq can be determined from the DSI time series. The drought duration is determined from number of DSI values below the threshold level. Based on the classification of DSI in Table (3), the threshold value was held as -0.29 in this runs analysis, because any value below that indicates the onset of a drought event. Total accumulative values below the threshold level for DSI indicates drought severity and drought severity divided by the duration it's Drought intensity which indicates average value of DSI below the threshold level. Figure (9) shows the time series of annual DSI for period (2000-2011) for three zones. The highest drought severity of DSI was -4.11 in steppes zone during study period with drought duration 4 years below threshold level and intensity -1.03. But the highest intensity was -1.14 in Arid and semi-Arid Zone with drought duration only 3 years below threshold level and drought severity -3.43, the reason is the highest severity of droughts have been recorded at the Arid and semi-Arid Zone in 2008, So, it's clear that the drier zone was Arid and Semi-Arid Zone during study period. But the most susceptible areas to dry spell is desert zone with longest drought duration 5 years during study period and drought severity of DSI was -4.1 with lowest drought intensity -0.81. Also, can using run theory to calculate characteristics of wet. The threshold value was held as 0.29 in this runs analysis, any value above that indicates the onset of a wet spell. the highest wet severity of DSI was 4.17 in steppes zone during study period with wet duration 5 years above threshold level and intensity 0.83. The lowest wet severity was 3.6 in Arid and Semi-Arid Zone during study period with longest wet duration 6 years above threshold level and lowest intensity -0.6.

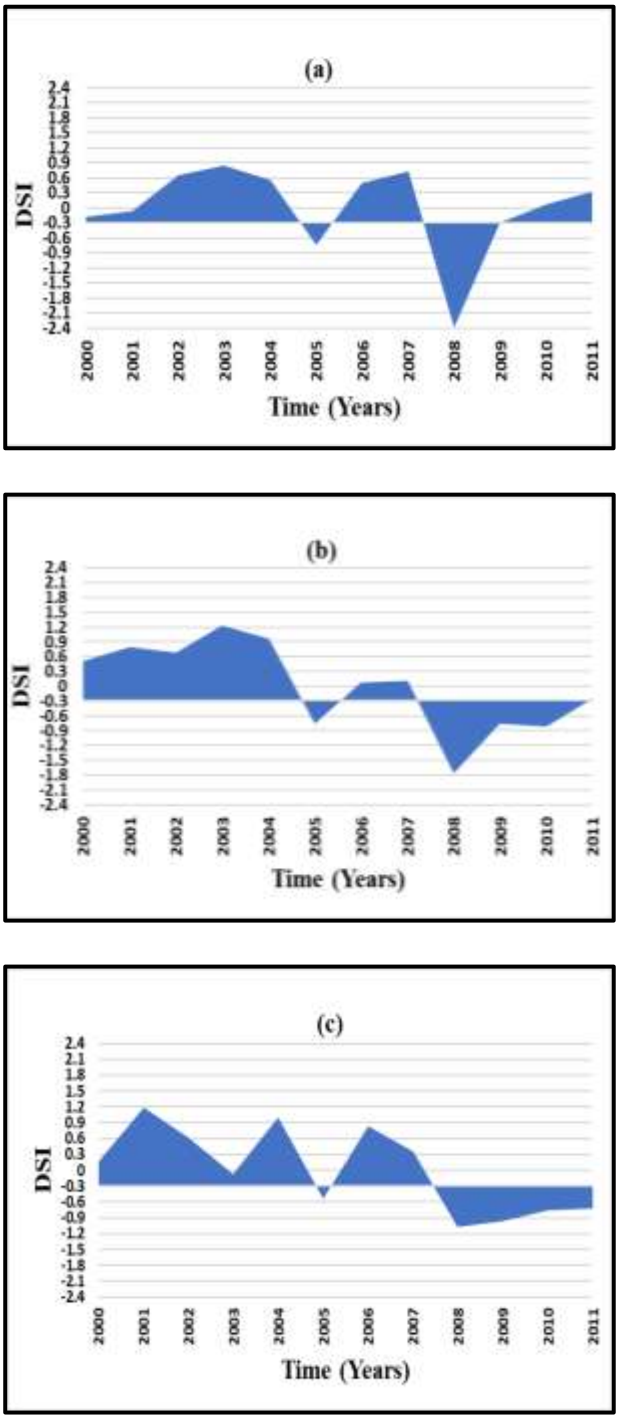


Fig. 9. Annual DSI for Iraq: Arid and Semi-Arid Zone, (b) Steppes Zone and (c) Desert Zone

The daily DSI was extracted for three stations to represent the zones: Sulaymaniyah represent the Arid and Semi-Arid Zone, Mousl represents steppes zone and Baghdad, represents the desert zone for the period (2000-2011), see figure (1). Figure (10) shows the time series of DSI in 2008 at three selected stations. The drought severity of DSI was -38.31 in Baghdad station (Desert Zone) and drought duration 35 time below threshold level with intensity -1.1. Also, the drought severity of DSI in Mousl station (Steppes Zone) was -44.7 and drought duration 40 time below threshold level with intensity -1.12. While the drought severity of DSI was -49.12 in Sulaymaniyah station (Arid and Semi-Arid Zone), and drought duration 36 time below threshold level with intensity -1.36. So, it can be seen the drier zone in 2008 was Arid and Semi-Arid Zone (Sulaymaniyah station), this is clear from values of drought severity and drought intensity in 2008

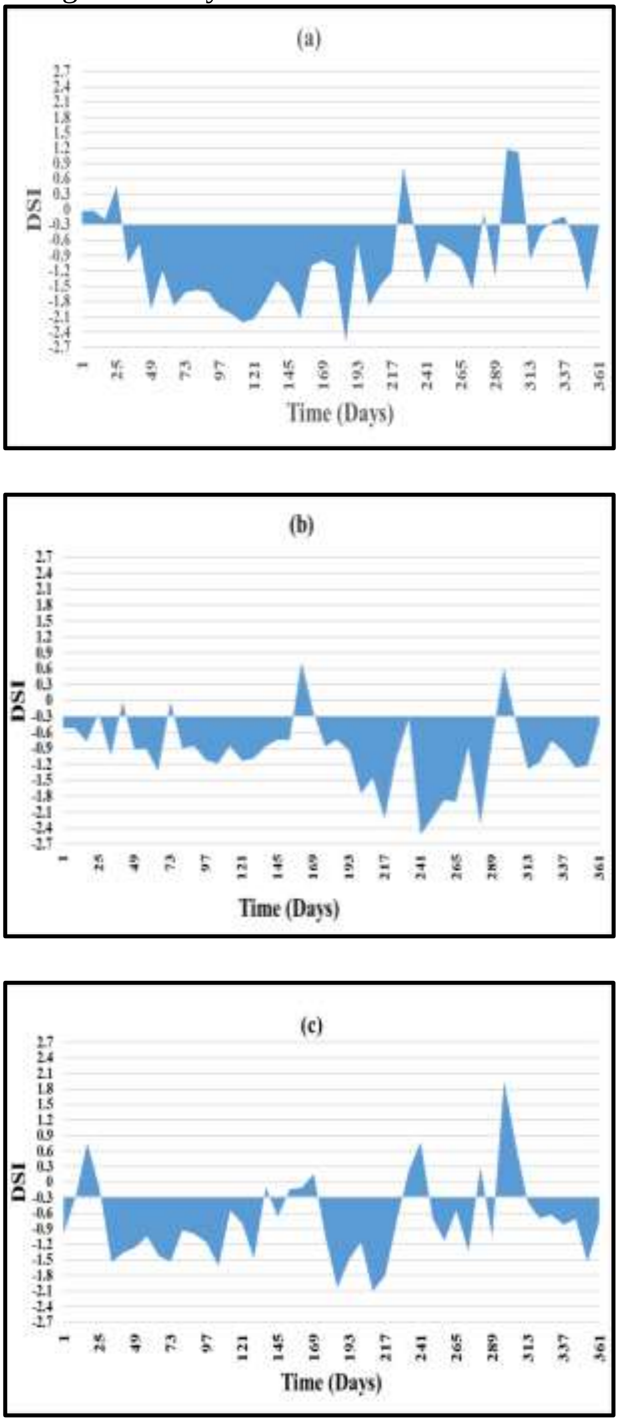


Fig. 10. Annual DSI for selected stations in 2008
Sulaymaniyah, (b) Mousl and (c) Baghdad.

CONCLUSIONS

Depending to the results obtained through this study for the two study periods (2000-2011) and (1980-2015), following are the conclusions: ===The correlation of annual DSI and annual precipitation shows a generally significant relationship at all Zones, which demonstrating that the DSI has strong efficiency for drought monitoring at annual level. The correlation between DSI-ET, DSI-PET and DSI-PRE shows, the annual DSI has a strong relationship with all indicators in all Zones. The relationships between DSI-ET are positive correlation while between DSI-PET inverse correlation. There is a significant fluctuation in precipitation from the average, in seasons: (1999-2000), (2000-2001), (2001-2002), (2002-2003), (2003-2004), (2004-2005), (2005-2006), (2007-2008) and (2008-2009) at all zones, and the greater fluctuation in Arid and Semi-Arid Zone because it has greater standard deviation value. The drier year is 2008 in all zones and the wetter year is 2001 in Desert zone and 2003 in steppes and Arid and Semi-Arid Zone zones. The drier Zone is Arid and Semi-Arid and the most susceptible areas to dry spell is desert zone and the wetter Zone is steppes during study period. Soil kept amount of water a result of the high amount of precipitation during a season, which lead to high value of Evapotranspiration in next year**.** During long-term study period 1980-2015, the drier year also 2008 in all zone.

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