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Spatial and Temporal Assessment of Drought in the Northern Prone of Iraq Using Standardized Precipitation Index

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Abstract

Drought becomes a serious issue in Iraq as upstream countries water policies and climate change consequences. It has negative impacts on different sectors, the environment, biodiversity, economy, and water resources. Long periods of severe drought and no rainfall winter are continuing during the last decades and the trend lines of the drought index gravitate toward unrecorded levels. This research studied the drought by using the standardized precipitation index "SPI" by analyzing the rainfall record since 1980 for the northern prone of Iraq which includes Kurdistan Region Governorates "KRG" (Sulaymaniya, Erbil, and Dohuk), Mosul, and Kirkuk to find out the drought pattern, magnitude, and duration, and mapping the results. This index is a very powerful index that is used worldwide when only rainfall data are available. SPI generator is used for more accuracy and confidence. The results show that all governorate has a vital issue and has a drought magnitude passed the thresholds of M = −1.0, −1.5, −2.0, −2.5, −3.0, and −4.0 which means a deficit in the soil moisture content, surface water, and groundwater. In Sulaymaniyah, the record for SPI3, SPI6, and SPI48 respectively is about −3.4, −3.54, and −2.63; in Erbil −2.73, −4.67, and−2.72; in Dohuk −4.22, −4.34, and −2.25; in Mosul −2.57, −2.16: in Kirkuk −3.39, −3.04, and −3.41. It is clear that all governorates have depletion in groundwater except Mosul which has contentious recharge, and in Erbil, both soil moisture and surface water has no huge deficit due to high rainfall and snowpack in the region. The results concluded that the whole region is subject to drought and under threat of water resources depletion; it needs urgent long-term plans in a sustainable manner to manage and conserve those sources and mitigate the climate change consequences.

Keywords

SPI, Drought, Climate Change

1. Introduction

Drought is a complex phenomenon due to insufficient precipitation [1]. It is significant natural hazard that affects the society and economy in the most deteriorating manner compared to other natural disasters [2]. Many regions around the world are affected negatively by the shortage of rainfall which is reflected in the environment, biodiversity, economy, culture, and inhabitant. For many decades, Iraq has suffered from low averages of rainfall and snowfall due to climate change consequences, not only in the middle and south parts but even in the northern part which should receive (400 - 1000) mm of rainfall [3].

Iraq depends on the surface water of rivers and also in many other communities; groundwater is the main source of different activities of human. For many years, it has been noticed that the groundwater level dropped drastically and quality declined as a result of drought. Water management plans should be efficient for the worst conditions that will be a vital issue facing water resources sector. For that, the researches should focus on the drought hazard not only in a specific part of Iraq, but also for the whole country to set forth long terms and sustainable water management plan on the level of meteorology, hydrology, and agricultural levels through using modern techniques of cloud seeding and evaporation control, water harvesting, and changing of land use respectively [4]. In this paper and due to the needs for sustainable management for water resources, we examine the drought events for long time to elaborate the most vulnerabilities sectors which most effected by drought which the government represented by ministry of water resources can set forth a long term plans for water distribution. The main objectives of this paper are to understand the drought behavior and status of soil moisture, surface water, and groundwater storage in the region to evaluate and control agricultural areas, groundwater withdrawal and also urbanization. The method used is worldwide adopted by using the index Standardized Precipitation Index (SPI) which is required less meteorological data, for the next step, authors will focus on other indices and compare the results. The main issue right time is the availability and confidence of data. For drought management, attempts are needed to control events by modifying hydrologic and other natural systems by applying bioengineering measures along with structures to exert some control over extreme drought event. The development of such plans as full understanding of natural hydrologic system and processes [5]. The results obtained in this research reflect some real phenomena in the region like desertification, lowering groundwater level, shrinkage land cover and disappearing of some natural species of plant.

2. Methodology

This research aims to identify the Standardized Precipitation Index "SPI" of the northern prone of Iraq which include Kurdistan Region Governorates (Sulaymaniya, Erbil, and Dohuk) KRG, Mosul, and Kirkuk which have high precipitation income through winter and spring as an endeavor to analyze the drought and understand the consequences of the water scarcity in Iraq accomplished with climate change scenarios. This research analyzed one of drought index to have a general understanding of drought issues by analyzing the data and then move to other approaches which is depends on comparison between indices and choose the best one for future prediction.

SPI represents soil wetness, surface water, and ground and water storage conditions throughout SPI3, SPI6, and SPI48 respectively through a timeline according to the available rainfall records for at least 30 years in specific spatial locations which represent the governorate listed above. Data are collected from reliable sources (governmental meteorological authorization) and utilize the "SPI generator" software to calculate values for analysis [6]. The software is a white box model has all the equation required which embedded in it which make the calculation easier and faster, the results then mapping for specific hydrological periods (10 years) to show the changing in the parameters under study. The results obtained in this research will establish a full drought assessment by comparison with different indices to find comprehensive future plans for water management in Iraq accomplished with climate change effect. For more simplified visual outputs, zoning maps of the drought results generates using ArcGIS software [7]. For the next steps, authors will focus on the comparison of results of different indices which are using different approaches and may give different results. The results obtained are interpreted in Section 4.4.

3. Study Area and Data

In this research, the area to be studied is within the northern region of Iraq which includes the following governorates: Dohuk (6553 km^2 – 7.9%), Mosul (37,323 km^2 – 45.2%), Erbil (12,000 km^2 – 14.5%), Sulaymaniyah (17,023 km^2 – 20.6%), Kirkuk (9679 km^2 – 11.8%) with total area of 82578 Sq·km forming nearly 19% of the total area of the country. It lies between 41˚9' to 46˚5' east longitudes and 33˚11' to 37˚3' north altitudes as shown in **Figure 1**.

The SPI is a powerful, flexible index that is simple to calculate where only rainfall data are required, it is considered the main meteorological drought index that should be used to monitor and follow drought conditions [8]. The results of this index represent the precipitation probability that can calculated at any number of timescales (1 month to 48 months or longer).

Monthly rainfall data for 5 major stations in Erbil, Sulaymaniyah, Dohuk, Mosul, and Kirkuk are available almost from 1980 to 2020. Data are used as

Figure 1. Study area.

input for the software to find the drought pattern according to the categorized values as in **Table 1**. The primary strength of the SPI is that its data can be compared between different climate regions [9]. A drought event occurs any time when SPI is continuously negative and reaches an intensity of −1.0 or less. The event ends when the SPI becomes positive. [6].

The basic formulas used to calculate the SPI and build-in with SPI generator are as the following [10] and [11]:

1) Mean of the precipitation can be computed as

$$\bar{X} = \frac{\sum X}{N} \tag{1}$$

where N is the number of precipitation observations

2) The standard deviation for the precipitation is computed as

$$S = \sqrt{\frac{\sum \left(X - \bar{X}\right)^2}{N}} \tag{2}$$

3) The skewness of the given precipitation is computed as

$$\text{Skew} = \frac{N}{(N-1)(N-2)} \sum \left(\frac{X - \bar{X}}{S}\right)^3 \tag{3}$$

4) The precipitation is converted to lognormal values and the statistics U, shape and scale parameters of Gamma distribution are computed

Table 1. SPI categories.

SPI	SPI Category
≥2.00	Extremely Wet
1.50 - 1.99	Severely Wet
1.00 - 1.49	Moderately Wet
0 - 0.99	Mildly Wet
−0.99 - 0	Mildly Drought
−1.49 - −1.00	Moderate Drought
−1.99 - −1.50	Severe Drought
≤−2.00	Extreme Drought

$$\log \text{mean} = \bar{X} = \ln \bar{X} \tag{4}$$

$$U = \ln \bar{X} - \frac{\sum \ln(X)}{N} \tag{5}$$

5) Shape parameter α

$$\alpha = \frac{1 + \sqrt{1 + \frac{4U}{3}}}{4U} \tag{6}$$

6) Scale parameter β

$$\beta = \frac{\bar{X}}{\alpha} \tag{7}$$

7) The cumulative probability is given by

$$G(x) = \frac{\int_0^x x^{\alpha-1} e^{\frac{-x}{\beta}} \mathrm{d}x}{\beta^\alpha \Gamma(\alpha)} \tag{8}$$

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

$$H(x) = q + (1-q)G(x) \tag{9}$$

where q is the probability of zero

8) Z with mean zero and variance of one, which is the value of the SPI:-

$$Z = \text{SPI} = -\left(t - \frac{c_0 + c_1 t + c_2 t^2}{1 + d_1 t + d_2 t^2 + d_3 t^3}\right) \quad 0 < H(x) \le 0.5 \tag{10}$$

$$Z = \text{SPI} = +\left(t - \frac{c_0 + c_1 t + c_2 t^2}{1 + d_1 t + d_2 t^2 + d_3 t^3}\right) \quad 0.5 < H(x) \le 1 \tag{11}$$

where

$$t = \sqrt{\ln\left(\frac{1}{H(x)^2}\right)} \quad 0 < H(x) \le 0.5 \tag{12}$$

$$t = \sqrt{\ln\left(\frac{1}{\left(1 - H(x)\right)^2}\right)} \quad 0.5 < H(x) \le 1 \tag{13}$$

$c_0 = 2.515517$, $c_1 = 0.802583$, $c_2 = 0.010328$, $d_1 = 1.432788$, $d_2 = 0.189269$, $d_3 = 0.001308$

The effect of climate change is very clear when rainfall data analyze by SPI generator. Climate change impacts on Iraq have a regional domain which includes all the East Mediterranean countries and the Arabian Peninsula [12], surface water quantity, groundwater levels and water storage in reservoirs are under threat.

4. Results

The northern part of Iraq as the whole country subjected to critical drought events throughout the last 2 decades that have extremely influenced the water resources conditions and the ecosystem productivity. In this regard, the current research aimed to identify and assess the drought events and their consequences during the study period. The results show very clear drought effects on all governorates under study, the value of SPI declared a long and continuous drought period affecting the region. Some separated wet periods are presented but with no huge effect on the trend line of the drought. Some results show long drought duration with ultimate negative values of SPI, while others are in normal state with average values. The results will be focusing on SPI3, SPI6, and SPI48 which represent soil moisture, surface water, and groundwater conditions respectively. The results below show the significance of SPI to understand many critical conditions regarding water in the region, the lower value of SPI3 especially in winter and spring seasons reflect the dry conditions of soil which is effect the germination and flowering process for winter crops which reduce later the value of product. In other hand with less rainfall the water level in stream became lower with time as per SPI6 results which alter supplementary irrigation process needs and put the water resources under pressure. To mitigate water shortage, the groundwater is the unique alternative to meet the demand of water which is already affected by the climate change and misuse as the SPI48 results. The thresholds indicate the minimal values of water condition regarding soil moisture, surface water, and groundwater storage as **Table 1** of drought scenario, the results obtained of SPI values will compare with the thresholds with maximum duration to indicate and evaluate the consequences of drought and find the proper solutions.

4.1. 3 Months SPI (SPI3)

SPI3 measure, reflects short and medium terms of moisture conditions, and also provides a seasonal estimation of precipitation (rainfall). For the areas of primary agricultural, this factor is to be more effective in terms of available moisture conditions than other indices. The results of the analysis of the northern prone show a serious deficit of soil moisture Sulaymaniyah, since 1997 the trend line passed the zero line toward negative values of SPI (M), which alter the pattern of agriculture. This behavior of reflection is the same in Dohuk and Kirkuk with the same behavior of trend line. In Mosul its looks like the status of soil moisture tends to be stable with a very slow changing in the slope of trend line. In Erbil the results show a reassuring state of SPI3 as shown in Figures 2-6 below.

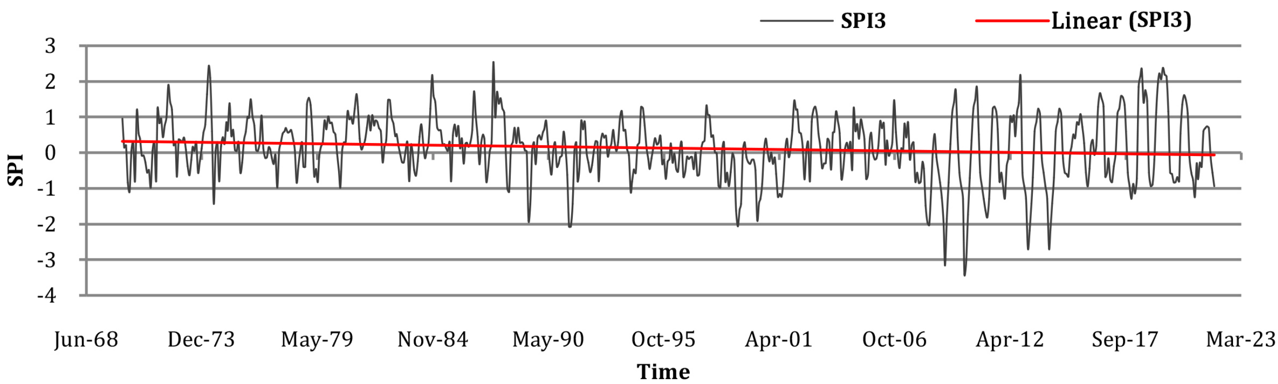

Figure 2. SPI3 for Sulaymaniyah.

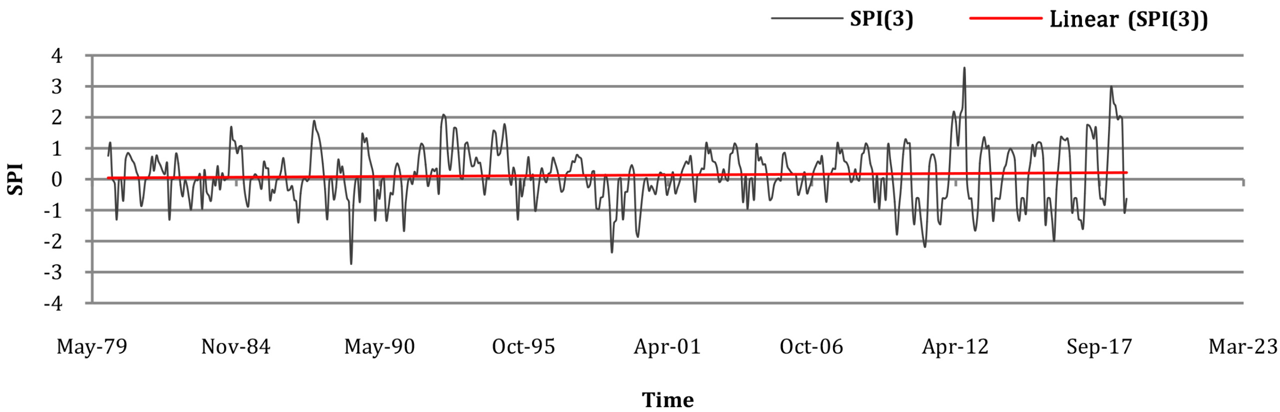

Figure 3. SPI3 for Erbil.

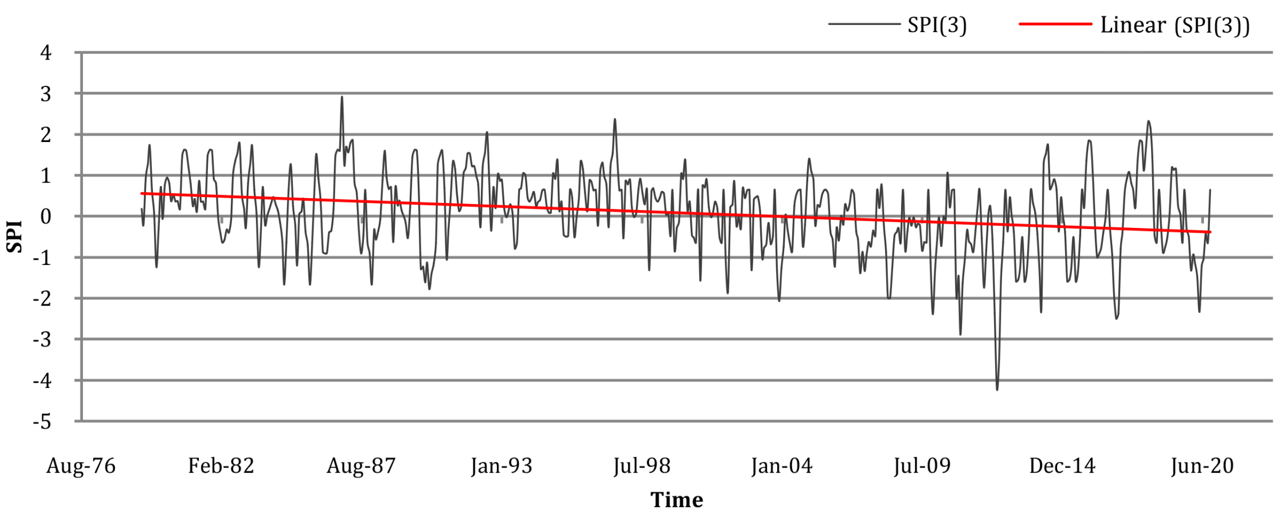

Figure 4. SPI3 for Dohuk.

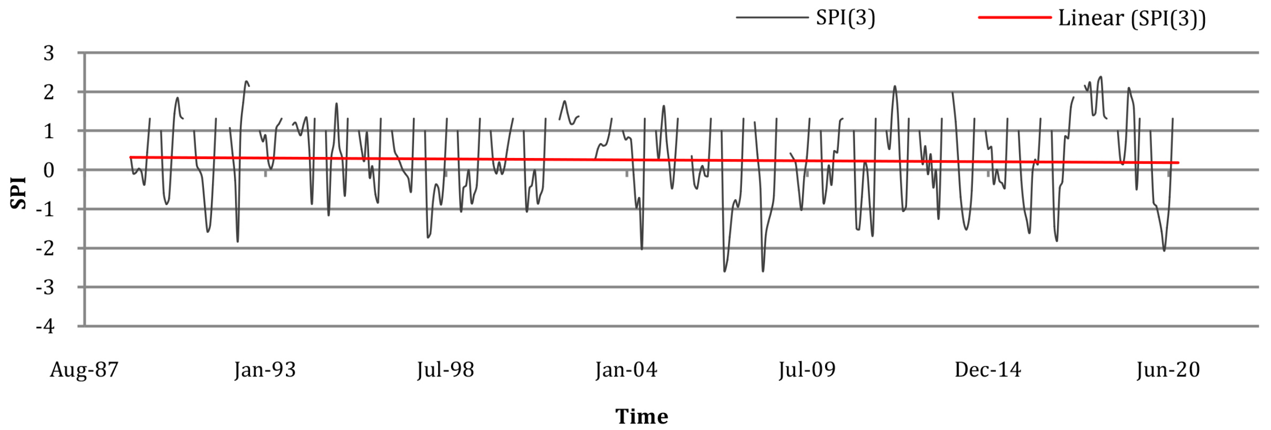

Figure 5. SPI3 for Mosul.

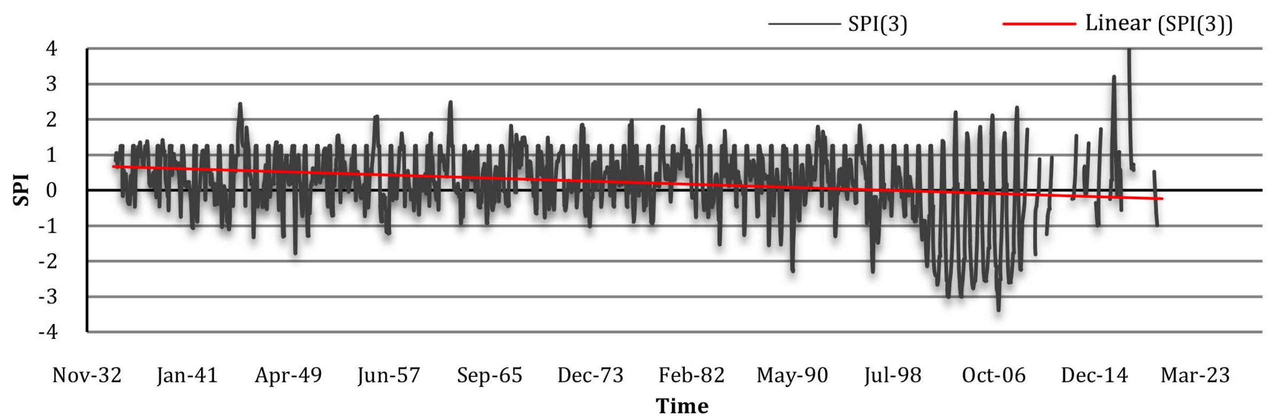

Figure 6. SPI3 for Kirkuk.

4.2. 6 Months SPI (SPI6)

SPI6 measure reflects medium-term trends of precipitation (rainfall) timescale, it is more sensitive to conditions at that scale than other indices and can reflect the precipitation over distinct season. This index usually represents the stream-flow conditions in the study area. The results show a drastic decrease in the value of SPI6 in almost all sites (except Erbil) which indicates the low levels of surface water; and the whole region vulnerable to drought hazards in near future. Values of SPI6 touch the record of M = −5 in Erbil during the late 1990s with consecutive drought periods of SPI6 value of M = −2 and the wet seasons (2012 and 2018) that makes the trend line move upward snow pack and high rainfall incomes make the balance. In Dohuk the same scenario is shown through the analysis results with values passed M = −4. The same values are found in Kirkuk and Sulaymaniyah, in time, normal values of SPI6 are represented in Mosul with no more than −0.5 for the M value as shown in Figures 7-11 for the times scale for Sulaymaniyah, Erbil, Dohuk, Mosul, and Kirkuk respectively. Overall, all trend lines gravitate toward the negative line below zero for the timescale of the study which represents a decrease in the surface water level. Also, long and severe periodic drought events are noticed through the analysis with M values

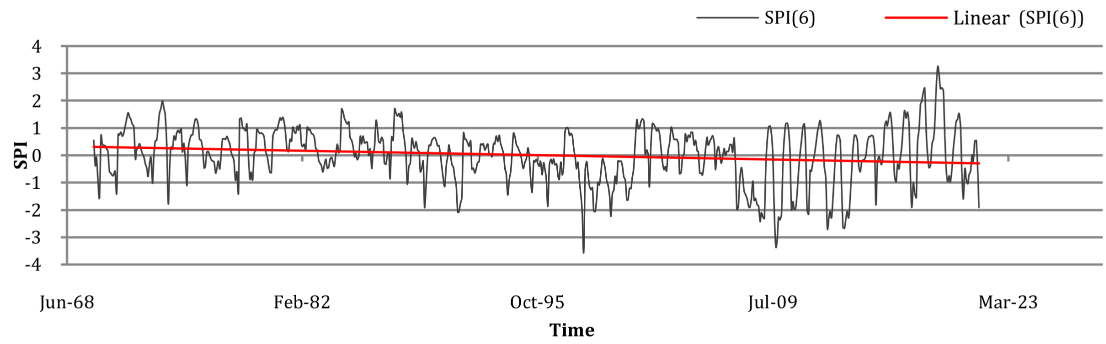

Figure 7. SPI6 for Sulaymaniyah.

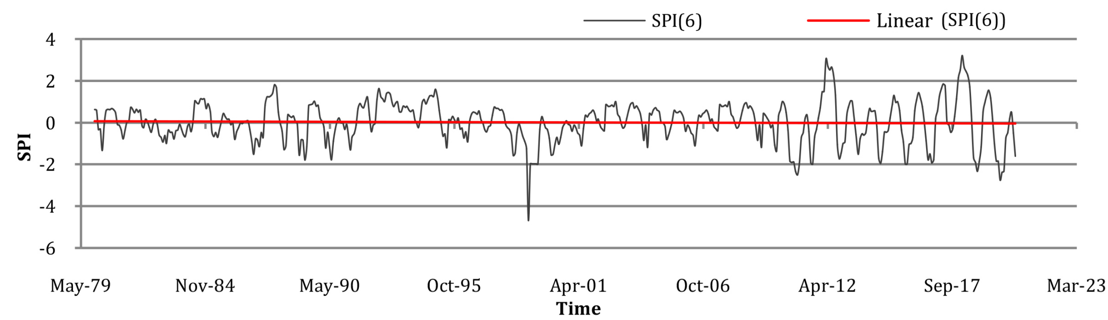

Figure 8. SPI6 for Erbil.

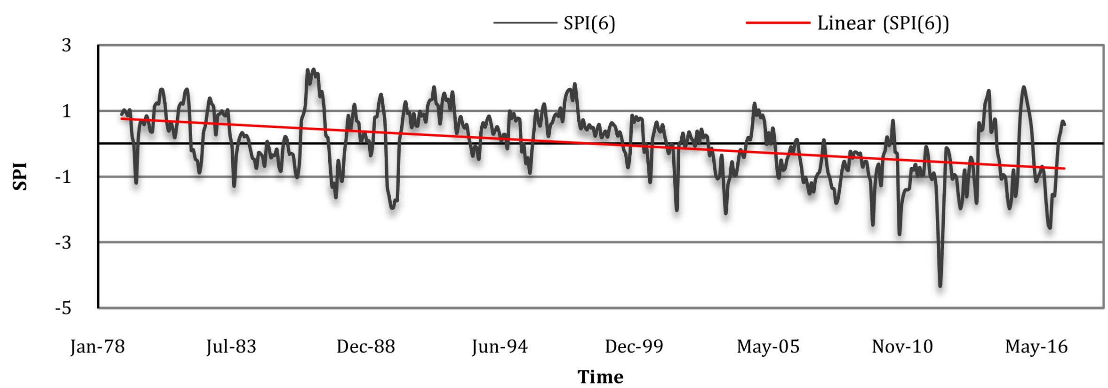

Figure 9. SPI6 for Dohuk.

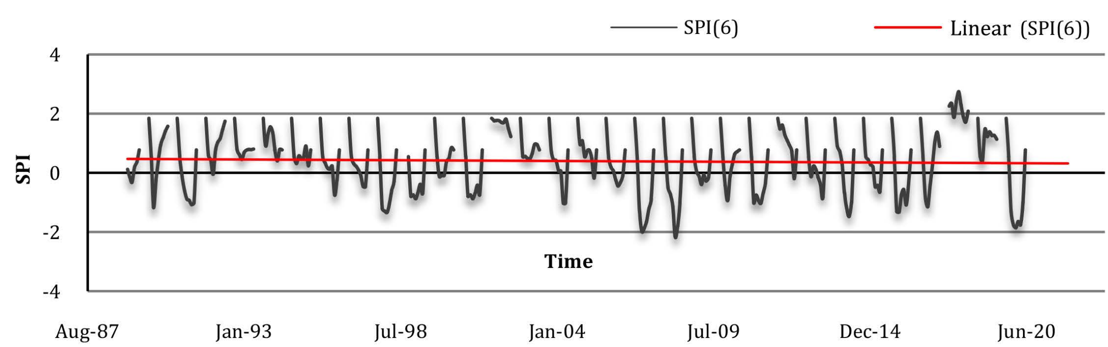

Figure 10. SPI6 for Mosul.

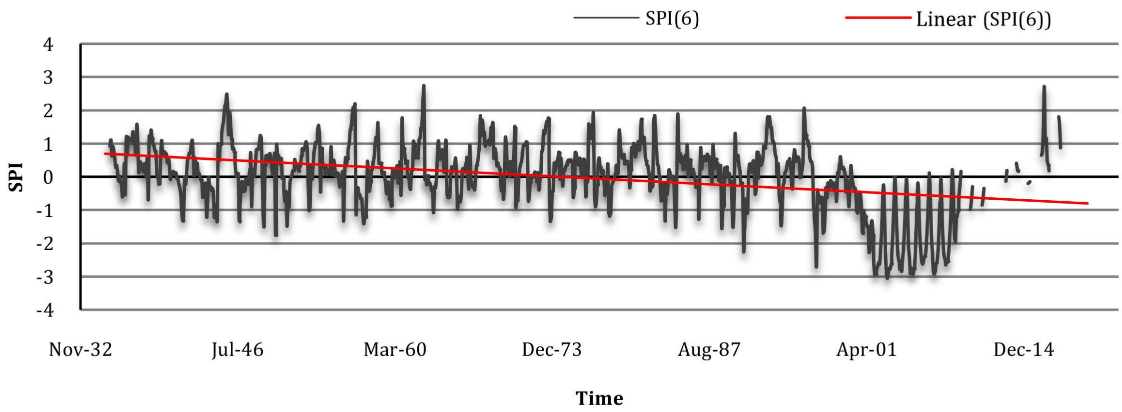

Figure 11. SPI6 for Kirkuk.

ranging from −1.5 to −4. The maximum drought events with their duration and magnitudes for the study area are shown except for Mosul and Erbil which has no drought event on the level of surface water.

4.3. 48 Months SPI (SPI48)

SPI (12, 24, and 48) represent the long-term pattern of precipitation, the SPI48 which this study adopted, tends to move toward (zero) unless a detective dry or wet trend is taking place. It is a cumulative scale for the short periods above or below normal values, and it represents the water level in reservoirs and groundwater conditions in the study area for a long timescale. The results show through Figures 12-16 that Sulaymaniyah, Dohuk, Mosul, and Kirkuk are the most affected by the decrease of surface water with M values ranging from (−2 to −3.5) far of Erbil which is also vulnerable to drought but with mild slop trend line. Kirkuk hit the ultimate value of drought in 2005 and so on with an M value of −3.5 after a long and stable condition before which reflects the need for an urgent plan to mitigate the impact of drought.

4.4. Drought Mapping

For drought mapping of both severity and duration, the hydrological period of (1990-2010) is taken into consideration for SPI6 and SPI48 plotting purposes, we had many timescale periods where dry conditions are experienced as the index value fell below the threshold of −1, but this era has the maximum drought magnitude and duration; also, such dry periods should be consistent in their occurrences for all governorates. Severe drought events hit the region and cause serious negative impacts. Figures 17(a)-(c) represent the maximum magnitude of SPI3, SPI6, and SPI48 on the study area.

Drought become a serious issue in Iraq which has vital negative consequences. This study aimed to assess the spatial and temporal drought hazard for the north of Iraq by analyzing historical rainfall data using the powerful index “SPI” which effecting by climate changes and misuse and waste of water. From the results above, it is clear that the northern prone of Iraq is subjected through the last 3

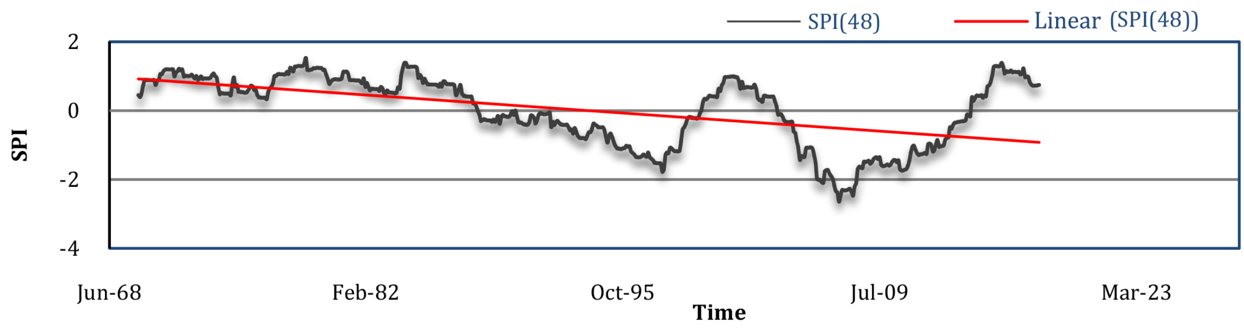

Figure 12. SPI48 for Sulaymaniyah.

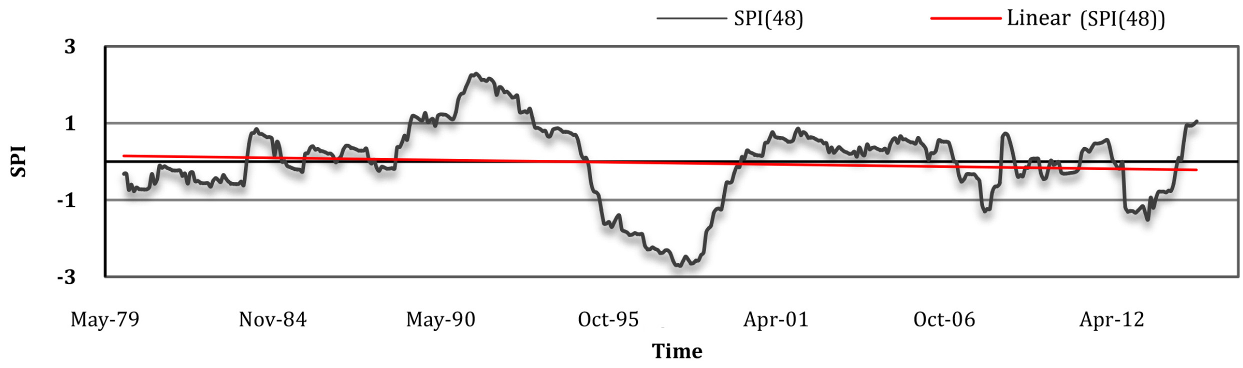

Figure 13. SPI48 for Erbil.

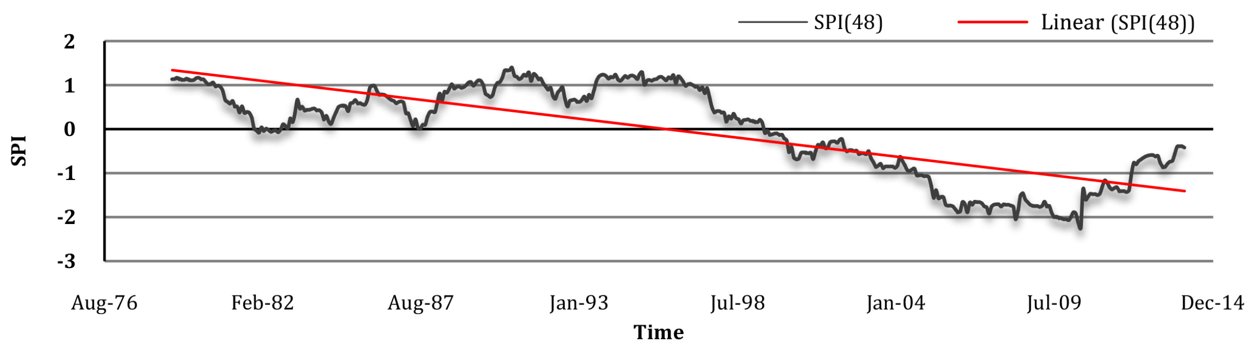

Figure 14. SPI48 for Dohuk.

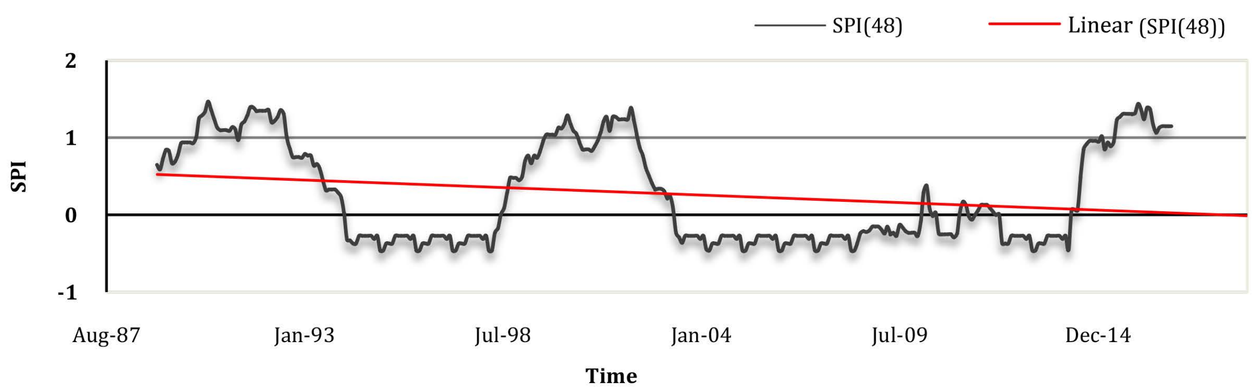

Figure 15. SPI48 for Mosul.

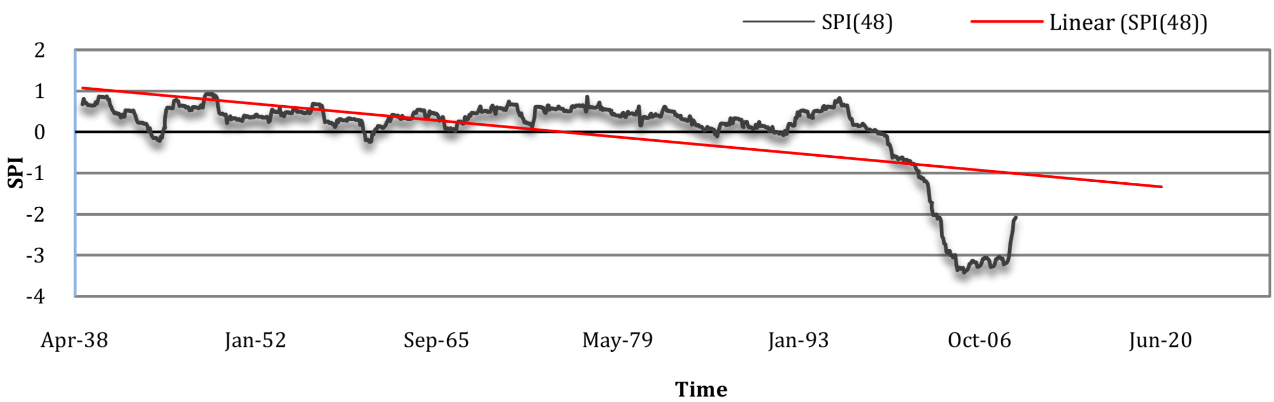

Figure 16. SPI48 for Kirkuk.

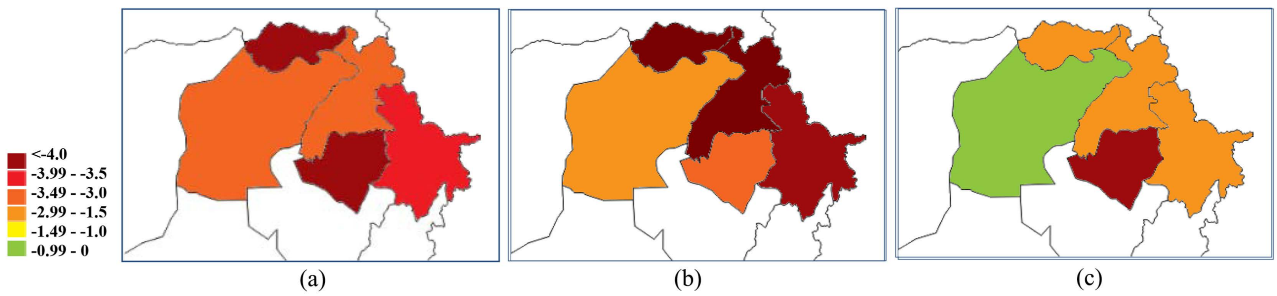

Figure 17. Drought mapping.

decades to drought on the levels of soil moisture, surface water, and groundwater conditions, which will alert the water resources decision-makers to initiate serious steps toward drought hazard mitigation. The drought event analysis shows that the M magnitude passed the specific level underlined. The following finding of the 3 types of SPI index (3, 6, and 48) summarized the drought hazard in numbers as per individual governorate: -

1) Sulaymaniya

In all cases related to soil moisture content, surface water, and groundwater conditions the governorate is subjected to a serious hazard of drought due to long duration event, the slope of trend lines hit for the last 2 decades' negative values with a very steep slope regarding SPI48 which is mean the ground storage depleted and lowering levels with time. The drought event analysis shows that the M magnitude passed the specific level underlined. Drought magnitudes for SPI3 and SPI6 for threshold M = −1.0, −1.5, −2.0, −2.5, −3.0 which are the worst conditions reached −3.4 and −3.54 respectively for maximum duration of 4 and 37 days in winter season (January) which is mean the soil is extremely dry and surface water is under threat of low level. For SPI48 for threshold M = −1.0 and −1.5 reached −2.63 for 100- and 111-days (Table 2), which is reflection water income to Dokan and Derbendikhan dams and groundwater level depletion.

2) Erbil

The results show more positive values regarding SPI3 and SPI6. An extensive deficit in groundwater levels is began since middle of 1990s' continue to the mid of 2000s' with periodic drought events, which overburdened the surface water resources in Erbil despite the good condition for soil moisture due to snowpack and high levels of rainfall which lasted for long period through the year and supply stream flow. Less severe drought events are here even with longer duration. The drought magnitude for SPI3 for threshold M = −1.0, 1.5, and −2.0 are −2.17, −1.86, and −2.36. For SPI6 even though the drought magnitude reached −4.67 for most the thresholds but the duration didn't pass 7 days which makes a relief of drought impact, whereas 55 days with −2.72 magnitude are presented in SPI48 as shown in **Table 3**. In Erbil, the best condition occurs due to minimum duration of drought event.

3) Dohuk

The results show more positive values regarding SPI3 and SPI6. An extensive deficit in groundwater levels is began since the middle of 1990s' which overburdened the surface water resources in Erbil despite the good condition for soil moisture due to snowpack and high levels of rainfall which lasted for long period through the year and supply stream flow. Less severe drought events are here even with longer duration. Drought magnitudes for SPI3 and SPI6 for threshold M = −1.0, 1.5, −2.0, −2.5, −3.0, and −4.0 reached −4.22 and −4.34 of maximum durations of 5 and 39 days respectively. For SPI48 −2.25 of M = −1.0, −1.5, and −2.0 for 114 and 73 days as shown in **Table 4**.

Table 2. Drought events in Sulaymaniyah.

Cat.	Threshold	start date	end date	Max. duration	Max. M
SPI3	M = −1.0	01/01/2010	06/01/2010	5	−3.4
	M = −1.5, −2.0, −2.5, −3.0	02/01/2010	06/01/2010	4	−3.4
SPI6	M = −1.0	10/01/1998	12/01/2001	38	−3.54
	M = −1.0	02/01/2009	05/01/2018	111	−2.63
SPI48	M = −1.5	01/01/2010	05/01/2018	100	−2.63

Table 3. Drought events of Erbil.

Cat.	Threshold	start date	end date	Max. duration	Max. M
SPI3	M = −1.0	11/01/2010	06/01/2011	7	−2.17
	M = −1.5	06/01/1992	09/01/2000	5	−1.86
	M = −2.0	05/01/1999	09/01/1999	4	−2.36
SPI6	M = −1.0	11/01/1998	02/01/2000	15	−4.67
	M = −1.5	11/01/1998	02/01/2000	15	−4.67
	M = −2.0, −2.5, −3.0, −3.5, −4.0	07/01/1999	02/01/2000	7	−4.67
SPI48	M = −1.0, −1.5, −2.0, −2.5	07/01/1999	02/01/2004	55	−2.72

4) Mosul

The results in Mosul differ from others, SPI3 and SPI6 show very simple slope toward negative values, in times SPI48 reflect the fluctuation of groundwater level with a long duration of drought that cause a drop in the trend line slope. This definitely has a negative impact on the water storage in the reservoir. Drought magnitude for SPI3 for threshold M = −1.0, 1.5, −2.0, and −2.5 reached −2.57 for 7 days. for SPI6 even the drought magnitude reached −2.16 for 4 days, but no drought for SPI48 due to the contentious recharge of groundwater as shown in Table 5.

5) Kirkuk

It has the worst case in all three indices, soil moisture content and surface water are affected by the deficit of precipitation, some missing data could affect the result but in general, the trend line passed the zero level and drought has a long duration. Climate change is reflected as SPI48 with a sudden drop of the trend line after 1999 where it shows a positive value for the timescale. Drought magnitude for SPI3 for threshold M = −1.0, 1.5, −2.0, −2.5, −3.0 is −3.39 for 7 days maximum. For SPI6 even the drought magnitude reached −3.04 for maximum duration of 76 days. The worst scenario with SPI48 hit the record of −3.41 for threshold −1.0, −1.5, −2.0, −2.5, −3.0 of 89 days' duration which buzzed the alert of serious hazards accomplished with surface water deficit in this governorate where one of the largest agriculture projects (Hawija Irrigation Project) is located as shown in Table 6.

Table 4. Drought events for Dohuk.

Cat.	Threshold	start date	end date	Max. duration	Max. M
SPI3	M = −1.0, −1.5, −2.0	07/01/2012	12/01/2012	5	−4.22
	M = −2.5, −3.0, −3.5, −4.0	08/01/2012	12/01/2012	4	−4.22
SPI6	M = −1.0, −1.5, −2.0, −2.5	03/01/2011	06/01/2014	39	−4.34
	M = −3.0, −3.5, −4.0	11/01/2012	06/01/2014	19	−4.34
SPI48	M = −1.0	09/01/2008	03/01/2018	114	−2.25
	M = −1.5	04/01/2009	03/01/2018	107	−2.25
	M = −2.0	02/01/2012	03/01/2018	73	−2.25

Table 5. Drought events for Mosul.

Cat.	Threshold	start date	end date	Max. duration	Max. M
SPI3	M = −1.0, −1.5, −2.0, −2.5	03/01/2007	10/01/2007	7	−2.57
SPI6	M = −1.0	07/01/2008	11/01/2008	4	−2.16
	M = −1.5, −2.0	08/01/2008	11/01/2008	3	−2.16

Table 6. Drought event for Kirkuk.

Cat.	Threshold	start date	end date	Max. duration	Max. M
SPI3	M = −1.0	11/01/2006	07/01/2007	8	−3.39
	M = −1.5, −2.0	12/01/2006	07/01/2007	7	−3.39
	M = −2.5	01/01/2007	07/01/2007	6	−3.39
	M = −3.0	03/01/2007	07/01/2007	4	−3.39
SPI6	M = −1.0	06/01/2000	10/01/2006	76	−3.04
	M = −1.5	12/01/2000	10/01/2006	70	−3.04
	M = −2.0	07/01/2001	10/01/2006	63	−3.04
	M = −2.5	12/01/2001	10/01/2006	58	−3.04
	M = −3.0	02/01/2003	10/01/2006	44	−3.04
SPI48	M = −1.0	03/01/2002	08/01/2009	89	−3.41
	M = −1.5	01/01/2003	08/01/2009	79	−3.41
	M = −2.0	05/01/2003	08/01/2009	75	−3.41
	M = −2.5	12/01/2003	08/01/2009	68	−3.41
	M = −3.0	09/01/2004	08/01/2009	59	−3.41

5. Conclusions

In this research, the drought has been assessing for 30 years in the northern prone of Iraq, it is an initial step to identify the consequences of water deficit in the whole country as per the other parts will be studied in the future. SPI is used to find the status of soil moisture, surface water, and groundwater conditions. It is clear that the region is subject to a serious drought hazard, SPI passed the threshold of different types of indices. This research is an endeavor to start doing general research about drought in Iraq using different indices according to the available data.

The results come with many facts in the region, the deficit in surface water and depletion of groundwater with a long dry period of topsoil. SPI3 show degradation in all governorate which affects agriculture and overburden the surface water. The worst case is about SPI48 steep slope of trend lines reflecting the extensive groundwater withdrawal.

The results in all governorates are similar except in Erbil which has normal SPI3 and SPI6 due to high rainfall events through the last 2 decades and snowfall over the region, also in terms of surface water, Mosul has normal values due to contentious recharge from the upper catchment. The extreme magnitudes of drought are the results of climate change over Iraq and the region. Long drought duration of more than 100 days has some vital consequences for the water sector.

The research is taking into consideration the SPI index only, it is a powerful index and is used in general. For more accuracy, we need to compare these results with other indices. The only limit is the lack of data, not all the weather station has the full record of data that other indices require.

The results alert to finding new methods and techniques to modify the hydrological and natural systems and use the modern techniques for high water use efficiency and bioengineering for crops of less water use, also using the modern irrigation system to mitigate the misuse of surface water resources as a pre-step for conserve water adopted by ministry of water resources. Set plans to relieve the pressure on groundwater; control well digging by establishing national regulations to manage this source of water. It is important to start national and international talks and take action to mitigate the consequences of climate change by ensuring Iraq's fair share of water from neighbors along with a national sound and comprehensive water strategy.

6. Discussion

This paper summarized the drought events in the study area by analyzing the rainfall data for 5 major meteorological stations in Iraq using the SPI generator to find the drought index as mentioned above. Drought becomes a serious issue facing the water resources sector in Iraq and affects all the linked fields. As per the results, the whole study area is subjected to more than 2 decades of drastic deficit in soil moisture, surface water, and depletion of ground water taking into consideration the area receiving the heights amount of precipitation during winter and spring seasons.

This kind of research is very important especially in Iraq due to the climate change consequences as the fifth-most vulnerable country to climate breakdown [13] and the water policies of the neighboring countries. The water strategies plan should take the results of such research as a start for sustainable long term plans. The area is insecure in terms of "water security" and it had water misuse as long as the past 25 years, the future of water is about to be fuzzier if there are no active plans for water conservation.

The results show there is a serious soil moisture deficit hazard along with a surface water decrease which overburdens the ground and stored water in the reservoir which needs to answer the question; is groundwater storage the escape? The area needs to establish a plan to conserve this depleted resource and control its uses by agriculture, industries, and domestic. Also, find new technologies which involve conserving surface water.

The drought had a serious impact on multi sectors in Iraq, including agriculture and size of lands shrinkage during the last decades due to shortage of water, some crops limited cultivation areas despite their importance as per ministry of water resources and agriculture plans. Many communities were they depend on wells left the lands and houses and shifted to another places due to lowering groundwater levels and they started to seek another sources of water which caused a social issue, the quality of ground water degraded due to extensive withdrawal and insufficient recharge. All these issues should be taken in consideration for the long term future plan.

This research depends only on the SPI due to the limitation of different meteorological parameters and the need to establish platforms for data collection and analysis with cooperation of other agencies. It's highly recommended that other researchers proceed with other indices recommended and compare the results for a full assessment of drought in Iraq for much more sustainable water management plans.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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