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RESEARCH PAPER

Assessment of Future Meteorological Drought Under Representative Concentration Pathways (RCP8.5) Scenario: Case Study of Iraq

Bassim Mohammed Hashim,*[,1] Esam Abd Alraheem,[1] Najm Abdullah Jaber,[1] Mehdi Jamei,[2] and Fredolin Tangang[3]

[1]Environment and Water Directorate, Ministry of Science and Technology, Baghdad, Iraq
[2]Faculty of Engineering, Shohadaye Hoveizeh Campus of Technology, Shahid Chamran University of Ahvaz, Dashte Azadegan, Iran
[3]Department of Earth Sciences and Environment, Faculty of Science and Technology, Universiti Kebangsaan Malaysia, Bangi 43600, Selangor, Malaysia
*Corresponding author. Email: bassim_saa22@yahoo.com

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Abstract

Iraq is one of the countries in the Middle East that suffers from frequent droughts due to severe weather fluctuations. This study analyzed the precipitation data of 14 meteorological stations located in different climatic regions of Iraq for 50 years (1968-2017) to calculate the Standard Precipitation Index (SPI). Future precipitation projected for 2020-2040, 2041-2060, 2061-2080, and 2081-2100 using CCSM4 climate model for RCP 8.5 scenario was also used for meteorological drought projections. The results showed that the SPI for 1968-2017 near-normal (0.99 to -0.99), with the percentage of dry years being 49%. Samawa and Karbala recorded positive SPI values 0.012 and 0.0067, respectively), and Mosul noticed the highest negative SPI (-0.33) for RCP 8.5 in the (mid-21th century, 2041-2060. For 2081-2100, the highest positive SPIs recorded in the northern and western regions, including Kirkuk, Baiji, and Rutba (0.91, 0.893, and 0.857, respectively). In comparison, the highest negative SPIs were recorded in Amara and Baghdad (-0.872, -0.807, respectively). The results confirmed that southern and central Iraq would be most affected by drought in the future. The above results can help policymakers assess future drought risks in Iraq. It may also help to develop appropriate adaptation strategies to combat climate change.

Keywords: Drought analysis; Standard Precipitation Index; Iraq region; Climate change

1. Introduction

Drought is one of the most complex, harmful, and least understood hydrometeorological events [1], [2]. It is anticipated that the severity and frequency of droughts will change in the future due to climate change [3], [4]. Droughts influence the availability of water resources [5] and severely affect different aspects of human life, such as the environment, agriculture, food security, and social harmony, especially in water-limited regions. Its effects are frequently indirect and dispersed over large areas [3], [6]. Drought impacts depend on the exposure and vulnerability of affected societies and can be aggravated by poor land management practices [7], [8]. Droughts are caused by abnormally low precipitation for a period of time [9]. The role of precipitation in climatic conditions is very vital due to the supply of required water resources.

The four main categories used to classify droughts are hydrological drought, soil moisture drought, meteorological drought, and socioeconomic drought. An extended absence of precipitation due to atmospheric circulation normally precedes a hydrological drought, which is frequently followed by a meteorological drought [10].

Precipitation is a complex and highly variable element, which become even more variable due to climate change [11]. Climate change is expected to increase the frequency of extreme climatic events, posing greater risks to society, the environment, and industries that rely on precipitation and water resources [12]. In accord with the Fifth Assessment Report (AR5) of the Intergovernmental Panel on Climate Change (IPCC), dry regions may get drier and wet regions to wetter in the 21st century in many regions of the world due to climate change [13]. This would make droughts more frequent and severe in the dry regions [14].

Drought is different from other extreme events not only regarding its complexity and difficulty in forecasting [15], but also on the exposed assets (e.g., crops, people, water-intensive industries, natural ecosystems) and the economic, spiritual and social harms [16]. The production of food is hampered by drought, which also has a negative effect on the economies of huge regions or entire countries [17].

Drought is a slow-moving phenomenon whose onset, duration, and severity are difficult to quantify. Therefore, it is generally managed for mitigating impacts. Present and future information about variations in climate at the local, regional, and global scale are essential to developing national and international level mitigation approaches for natural disasters (e.g., drought) [18]. Drought prediction is crucial for managing water resources, irrigated agriculture, recreational tourism, environmental monitoring, and the health of the environment [19].

Due to the advancement in modeling and significance of the climate system, the general circulation models have become an essential tool for the climate change processes [12]. A global climate simulation was made by the U.S. National Center for Atmospheric Research (NCAR) using the Community Climate System Model 4 -CCSM4) for the Fifth Assessment Report (AR5) of the IPCC [20]. It simulated the global climate for the Representative Concentration Pathways (RCPs), which is a set of greenhouse gas concentration and emissions pathways designed to support investigating impacts and potential policy responses to climate change [21], [22]. The RCP 8.5 corresponds to a high greenhouse gas emissions pathway, also the baseline scenario that does not consider any specific climate mitigation aim [23]. Therefore, it assumes greenhouse gas emissions and concentrations increase remarkably over time, yielding a radiative forcing of 8.5 W/m2 at the end of the century [24].

Iraq is a country in a semi-arid region where the drought is anticipated to increase in the future. Over the past decade, drought in Iraq has increased in terms of recurrence and severity. The principal cause of these changes is climate variability [25]. Water scarcity, desertification, drought, high temperatures, low precipitation, heat waves, and sea-level rise represent some of Iraq's climate change scenarios in recent years [26]. The temperature rise has influenced the water balance, causing changes in evapotranspiration averages, temperature, and precipitation [27]. Iraq faces a complex water crisis with humanitarian, economic, security, and social implications. These include population movements, losses of agriculture and livelihoods, mass demonstrations, and increased risks of food insecurity and infectious diseases. According to the UN Environment Program, Iraq is the fifth most vulnerable country to climate change. Evidence of growing climate risks deals with extreme heat is becoming more common, drought is becoming more frequent, and dust storms are becoming more intense [28]. Recent studies suggest more severe shortages in the country's surface and groundwater resources [29]. Therefore, the assessment of droughts is very important for the country [30], [31].

Several drought indices have been presented and employed across the globe to assess and monitor droughts. The Standardized Precipitation Index (SPI) is the most widely used drought monitoring and assessment index globally [32], [33]. The SPI only uses precipitation and can monitor dry and wet conditions, and therefore, is less complex [34]. The World Meteorological Organization (WMO) suggested drought early warning system establishment by identifying SPI [35]. A developed SPI considering a decrease in precipitation relative to the average precipitation amount is the primary driver of drought, resulting in a subsequent water shortage for various natural and human needs [36]. The SPI is typically calculated for 3, 6, 9, or 12 months to assess the shortage of precipitation and defines drought intensity [37]. Drought indices, estimated for projected climate, can help project drought caused by global warming [38]. Many previous local and global studies used SPI for drought monitoring [7,8,11, 30–32]. Several global studies also used SPI for monitoring future droughts for RCP 8.5 [28, 33–35]. Other researchers studied the hydrological drought forecasting using machine learning models and their advanced versions, readers could sufficiently explored the following references [45]–[47].

The specific objectives of this study are (i) assessing meteorological drought in Iraq based on precipitation using SPI at 14 meteorological stations for 1968-2017, (ii) investigating the climate change impacts on future precipitation and droughts for four future periods: 2020-2040, 2041-2060, 2061-2080 and 2081-2100 under RCP 8.5 and (iii) find the trend of drought under RCP8.5 climate change conditions.

2. Materials and Methods

2.1 Study Area

Iraq, a semi-arid country, ranked as the fifth most vulnerable country in the world to the consequences of climate change [48]. It is located at a latitude between 29^o 02′ N and 37^o 23′ N and longitude between 38^o 47′ E and 48^o 35′ E. The total area of Iraq is 437,049 km2 [49]. Iraq's middle and southern regions have varying climates, as shown in Figure 1, ranging from continental and subtropical to arid and semi-arid. In contrast, the mountainous northern and northeastern regions have a Mediterranean climate [50]. Precipitation is mainly experienced from December to February but can extend to 6 months (November–April) in the northern and northeastern regions [51]. The mean annual precipitation is 154 mm, but it ranges from less than 100 mm in 60% of the country in the south and up to 1200 mm in the northeast [29]. Precipitation season also changes from year to year. Sometimes, precipitation is within the normal limit and does not represent a severe threat. In contrast, it is severe in some seasons and causes erosion for some soft-land and cause damages in the social and agricultural [41]. Summers are dry, hot in the northern parts, and extremely hot (higher than 48 C) across the rest of Iraq. Spring and fall are very short in Iraq [52].

2.2 Available Data

Details of the data used in this study are given below:

i. Monthly averages of precipitation recorded in meteorological stations across Iraq, were obtained for 1968-2017 for 14 meteorological stations (Baghdad, Basra, Kirkuk, Rutba, Mosul, Naseriya, Najaf, Dewaniya, Amara, Samawa, Baiji, Kerbala, Sinjar and Hai), as shown in Figure 2 and Table 1. The source of these data is the Iraqi Ministry of Transport (Iraqi Meteorological Organization and Seismology/ IMOAS) [53]. There are some gaps in the observed data in some stations in 2003 and 2014-2017; due to the second Gulf War and ISIS occupation of Sinjar, Baiji and Mosul in 2014.
ii. Global climate model data: The CCSM4 is one of the climate models participated in CMIP5 [54]. The NCAR maintains it with a spatial resolution of 1.4^o × 1.4^o. This database was prepared for IPCC to implement AR4 and AR5 in 2007 and 2013. Precipitation data were downloaded from the (http://gisclimatechange.ucar.edu/). The current study used the monthly mean precipitation

Figure 1: *Climatic zones in Iraq.*

for 14 Iraqi stations for 2020–2100. The MDM (Meteorological Drought Monitoring) software package was used for calculating SPI from monthly mean precipitation [40]. The ArcGIS software was used to produce drought maps.

Table 1: *Information of 14 meteorological stations.*

City	Latitude	Longitude	Elevation (m)	Climate
Baghdad	33.23	44.23	32	Arid
Basra	30.57	47.78	2	Arid
Kirkuk	35.46	44.41	331	Semi-arid
Rutba	33.03	40.28	615	Arid
Mosul	36.31	43.15	223	Semi-arid
Naseriya	31.08	46.23	3	Arid
Najaf	31.98	44.32	32	Arid
Dewaniya	31.98	44.98	20	Arid
Amara	31.85	47.17	9	Arid
Samawa	31.30	45.27	6	Arid
Baiji	34.60	43.48	115	Semi-arid
Kerbala	32.62	44.02	29	Arid
Sinjar	36.31	41.83	465	Semi-arid
Hai	32.08	46.03	17	Arid

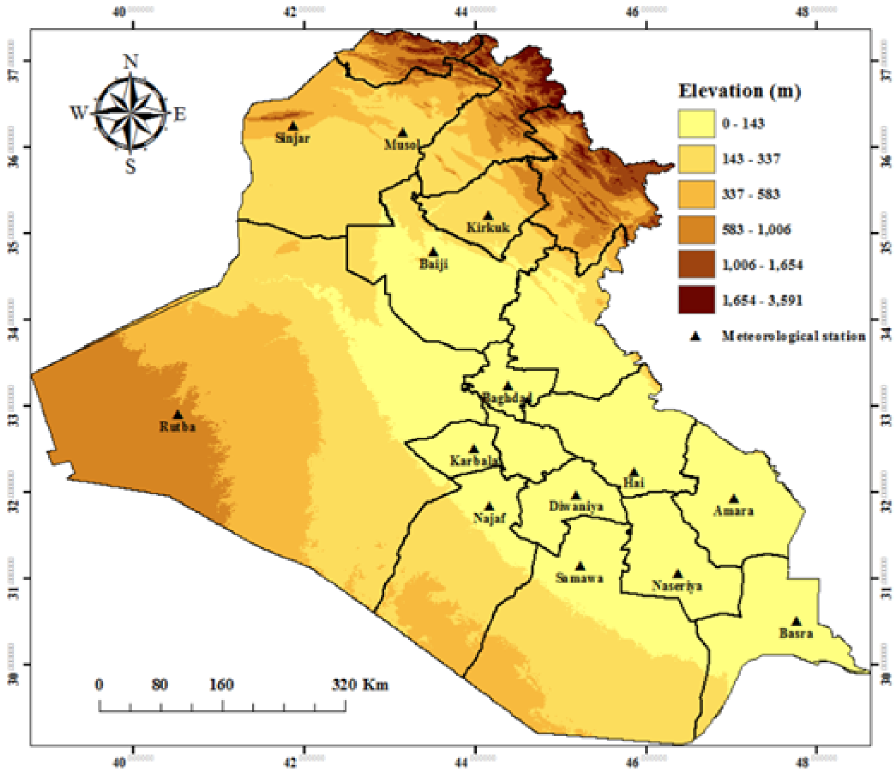


Figure 2: *Locations of 14 meteorological stations in Iraq.*

2.3 SPI (Standardized Precipitation Index)

SPI is one of the most commonly used drought indexes designed by McKee at Colorado University [44]. It is a widely recognized index for characterizing meteorological droughts [55]. Mckee defined SPI suitable for different timescales (1, 3, 6, and 12 months), but it is flexible according to the period chosen [36]. The output SPI values ranged from (−2.0 to 2.0) [40], as shown in Table 2.

SPI determines periods of positive or negative precipitation anomalies over a given region using precipitation data for a selected timescale. Simply, meteorological drought is the strong decrease in precipitation over a period in a specific region relative to the long-term average precipitation of that region. Finally, this difference is standardized by dividing it by standard deviation [56].

The SPI is generally calculated using the following formula [8]:

$$\mathrm{SPI}_i = \frac{P_i - \overline{P}}{\delta},$$

where SPI_i represents the drought index, P_i is the precipitation value in the period P_t, and δ are the averages of precipitation and standard deviation of precipitation, respectively. A positive SPI represents a surplus of precipitation compared to the long-term average for the region where it is assessed, whereas negative values represent precipitation [7]. SPI calculation requires at least 20–30 years of monthly precipitation data, and 50–60 years or more is ideal [57], [58]. In 2009, the World Meteorological Organization (WMO) recommended the SPI as a standard drought index and suggested to use for drought early warning [46].

Table 2: *Drought category according to SPI value [47].*

SPI values	Category
≤ 2.0	extremely wet
1.5 to 1.99	very wet
1.0 to 1.49	moderately wet
-.99 to .99	near normal
-1.0 to -1.49	moderately dry
-1.5 to -1.99	severely dry
≥ 2.0	extremely dry

3. Results

3.1 Precipitation Analysis from 1968 - 2017

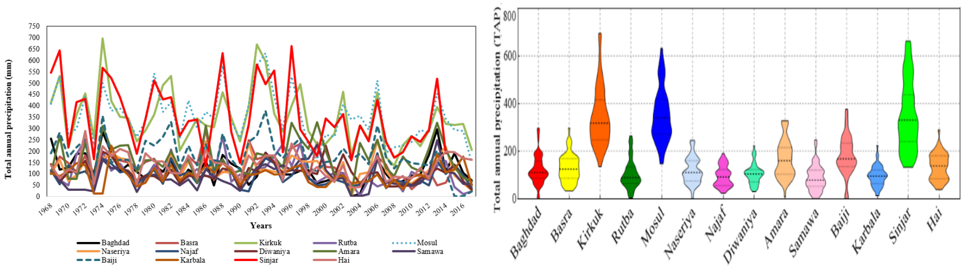


Figure 3: *The total annual precipitation variation at 14 meteorological stations in Iraq during 1968-2017 (a) trend curve plot; (b) violin plot.*

Figure 3 shows the total annual precipitation at 14 meteorological stations used in the current study in Iraq for 1968-2017 using trend curve and violin plots (i.e., Figure 3a and Figure 3b), the exception of Baiji and Sinjar, which missing precipitation data for 2015-2017, due to ISIS occupation. There is an evident fluctuation in the annual precipitation in all stations depending on the geographical location. The Sinjar, Mosul, and Kirkuk stations in northern Iraq recorded the highest total annual precipitation during the study period due to the Mediterranean climate prevailing in northern Iraq. The highest annual precipitation was recorded in Sinjar, 663 mm, in 1996. The total precipitation was characterized by fluctuation during the study period, but it declined during 1997-2017. The general trend of precipitation in Sinjar has been decreasing due to the scarcity of rain since the end of the last century. Kirkuk recorded the highest annual precipitation in 1974, reaching about 696 mm. This highest annual value in Kirkuk was recorded in the mid-70th and early 90th of the 20th century. The annual precipitation began to fluctuate and decrease and reached 135 mm in 2008. In Mosul, the annual precipitation fluctuated and decreased during 1968-2017. The highest annual value of precipitation reached 633 mm in 1993. The highest annual precipitation in Baiji was recorded in 1993, about 377 mm. An evident fluctuation in precipitation values led to a decrease of trend during the current study. The general trend of precipitation recorded in the four meteorological stations in northern Iraq (Sinjar, Kirkuk, Mosul and Baiji) was characterized by a decrease and the presence of severe drought, which became clear since the end of the 90th.

The total annual precipitation in Baghdad was mostly below 150 mm during 1968-2017, except in some years. The highest value was recorded, 297 mm, in 2013. However, the general trend in precipitation was decreasing and fluctuating. The pattern of precipitation in Rutba is characterized by evident fluctuation. Its highest value was 264 mm in 1988. In addition, the annual precipitation values decreased from 1998 to 2017, which confirms the existence of a significant decline in precipitation over the past twenty years. The annual precipitation in Karbala was the highest, 244 mm, in 1975. A slight decrease characterized the general trend in precipitation in Karbala during the study period. Najaf characterized that the total annual precipitation below 150 mm during the study period, except for some years, such as 2006, which recorded 191 mm, the highest total annual. The general trend was decreasing in Najaf, compared to other cities in central Iraq, such as Baghdad, Rutba, and Karbala.

Dewaniya is one of the cities in middle Iraq that recorded total annual precipitation mostly below 150 mm during 1968–2017. The highest precipitation value was recorded, 223 mm, in 2000. These values decreased below 50 mm during2007–2010 and reached to lowest value at 30 mm in 2017. A decrease and fluctuation characterize the general annual precipitation trend throughout the study period. Hai, like other cities in central Iraq characterized by fluctuation in annual precipitation amounts, but it increased significantly after 2012. However, it did not exceed the highest value of precipitation recorded in 1972 at 290 mm. A decrease marked the general trend of precipitation during the current study. Samawa, in southern Iraq, is one of the rarest cities with precipitation. The recorded precipitation amounts are scarce and did not exceed 100 mm in most years of study, especially in recent years. However, the highest annual precipitation recorded was 248 mm in 2013. The general trend of rain showed a slight increase accordingly. The annual precipitation values in Amara showed a rise in different years, exceeding 300 mm per year, for example, 1974, 1986, 1996, 1999, and 2013. Accordingly, the general trend of annual precipitation showed a slight decrease during the study period in Amara. In Naseriya, southern Iraq, the annual precipitation values exceed 200 mm in a few years along the study period. The highest precipitation values were recorded at 246 in 2006. The amount of precipitation decreased significantly after 2015, to reach only a minimum level of 27 mm in 2017. Also, the general trend is marked by a decrease. Although Basra is affected by the climate of the Arabian Gulf, the total annual precipitation during most of the years of the current study did not exceed the threshold of 150 mm/year. It is clear that the amounts of precipitation in Basra are characterized by significant fluctuation and decrease, especially after 2008. The general trend of precipitation also shows a decrease during 1968–2017 in Basra. The spatial distribution of total annual precipitation in 14 meteorological stations in Iraq during 1968–2017, as shown in Figure 4.

3.2 Temporal Variation in the SPI from 1968 - 2017

Figures 5 and 6 showed the temporal changes in SPI for 12 months at 14 meteorological stations in Iraq for 1968–2017. The annual SPI value is indicated for December each year. Some dry, wet years and seasons were recorded in Sinjar for the period 1968–2014. The dry years and seasons were represented by the years (1977–1979), (1983–1986), (1998–1999), (2006–2009), and (2013–2014). SPI in 1986 was classified as extremely dry (-2.1). On the other hand, wet years and seasons in Sinjar are the most important (1968–1969), (1974–1976), (1980–1982), (1990–1997), which recorded the longest wet season, finally (2010–2012). Due to the high annual precipitation, the number of wet years is more than the dry years in Sinjar. In Kirkuk, dry, wet years and seasons were recorded for the period from 1968–2017. The dry years and seasons were (1976–1979), (1983–1987), (1998–2012), which represent the longest dry series in Kirkuk. 2008 was classified as an extremely dry year (-2.08). Wet years and seasons were recorded in Kirkuk, the most important of which are (1980–1982), (1988–1997), and (2013–2016), which is the weakest wet series. It is clear that the number of dry years is more than the wet years, especially since the end of the last century and the beginning of the 20th century.

The temporal variation of the SPI value in Mosul showed several dry and wet years and seasons from 1968–2017. The dry years and seasons recorded in (1970–1974), (1978–1980), (1998–2001), (2007–2012) represent the longest dry time series. Finally, (2015–2017), 2017 was classified as a

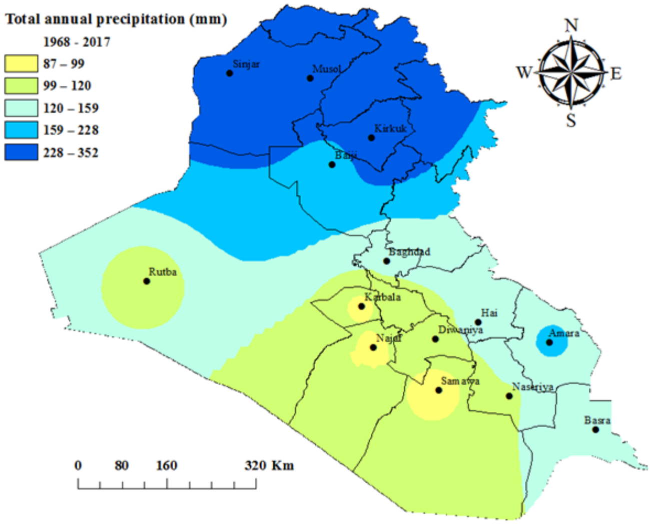


Figure 4: *The spatial distribution of total annual precipitation in 14 meteorological stations in Iraq during 1968-2017.*

severely dry year (-1.96). Seasons and wet years recorded in Mosul, the most important of which are (1975-1977), (1981-1983) and (1987-1997), which is the longest wet series, and (2002-2006). The dry years have been repeated, especially since 1998, except for a few wet years.

The SPI in Baiji is characterized by the length of the dry seasons, especially in the last years of the 20th century until 2014. Fig. 5 shows that the dry years and seasons in Baiji represented (1973-1974), as 1973 was classified as an extremely dry year (-2.42), then 1978-1980, and 1983-1990; except for a few years. Finally, from (2007-2014), which represents the longest dry time series. Wet years and seasons were recorded in Baiji, the most important are during 1979-1982 and 1991-1997, which is the longest wet chain. The number of dry years has been repeated, especially since 1998, except for a few wet years. In Rutba, the dry years and seasons were recorded in 1977-1978 and 2002-2009, which represents the longest dry series in Rutba in 2004, which is classified as extremely dry (-2.93). The last years, 2015-2017, also recorded a series of dry years. On the other hand, wet years and seasons were recorded in Rutba, the most important of which were during 1971-1976, 1990-1997, and 2010-2013, which are the weakest of the wet series. It is clear that the number of dry years is slightly less than the wet years, but the drought seems clear from the year 2002. The temporal variation of the SPI value in Baghdad showed several wet years and seasons during 1976-1986, except for 1982, 1977, and 1985. 1983 was classified as a severely dry year (-1.95). The dry years were also recorded in Baghdad during 1999-2004 and 2007-2011. Wet seasons and years were recorded in Baghdad, the most important of which are during 1971 -1975 except for 1973, during 1988 -1990 and finally during 2012 - 2016, which represents the longest wet series. The year 2013 was classified as an extremely wet (2.39). It is clear that the drought years have repeated, especially since 1999, except for a few wet years.

The drought years and seasons in Najaf were represented by the separate years, 1969-1991, where 1991 was classified as severely dry (-1.95). The years 1999-2005 and then 2007-2012, also characterized by drought. On the other hand, the wet years and seasons in Najaf are the most important for 1974-1977, 1986-1989, and 2013-2016. The year 2006 was classified as a very wet year in Najaf (1.84). It is clear that the number of wet years is equal to the dry years in Najaf during the study period. In Karbala, the dry years and seasons were recorded in 1973 -1974, which represented the driest season in Karbala (-2.33 and - 2.36), respectively, and during 1978 -1983, except for a few years between them. The period 1998-2012 represents the longest drought series recorded in Karbala.

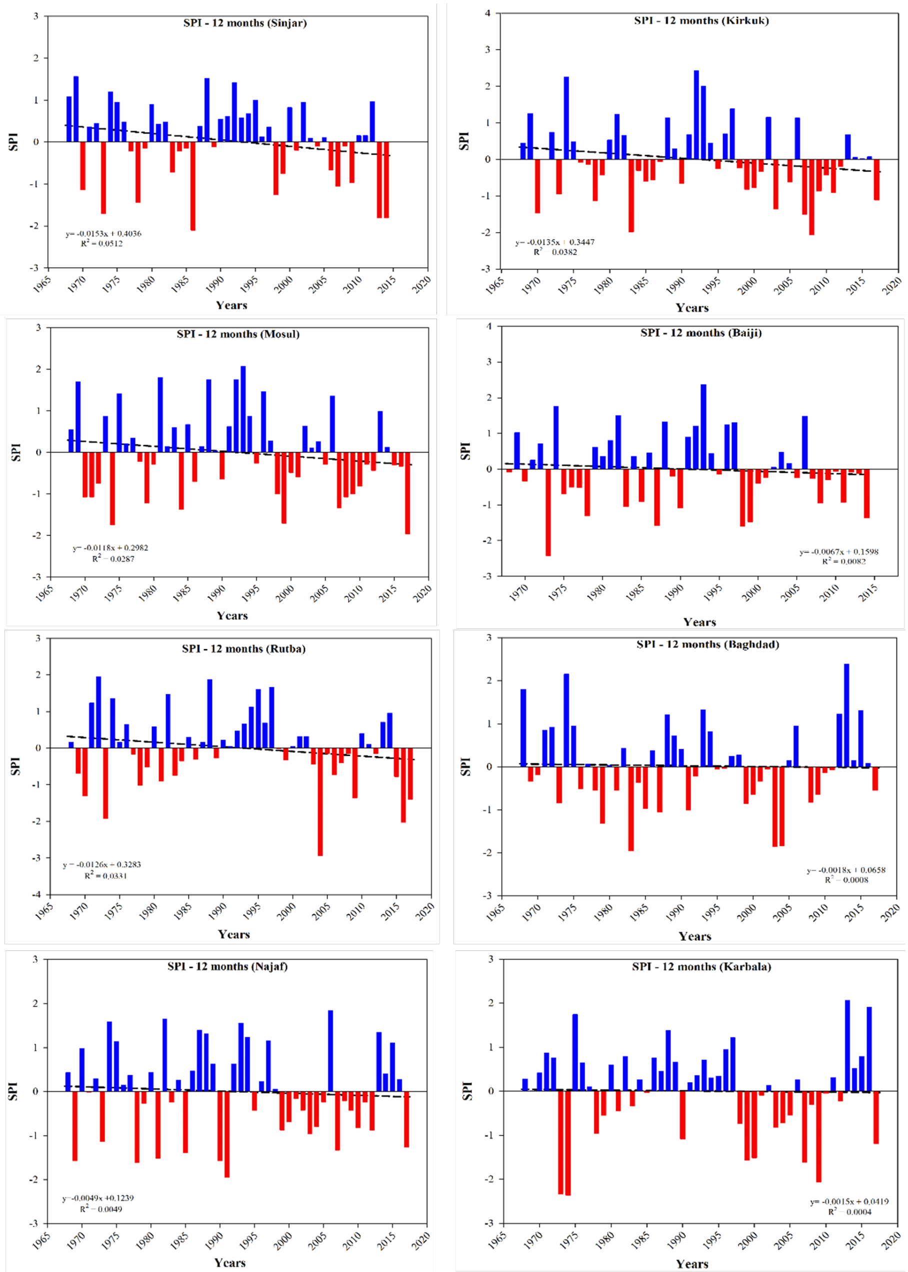


Figure 5: *The temporal changes of the SPI for 12 months at the 8 out of 14 meteorological stations in Iraq during 1968-2017.*

On the other hand, wet years and seasons were recorded in Karbala, the most important of which are 1968-1972, 1975-1977 and 1986-1997, and 2013-2016. The year 2013 recorded the highest

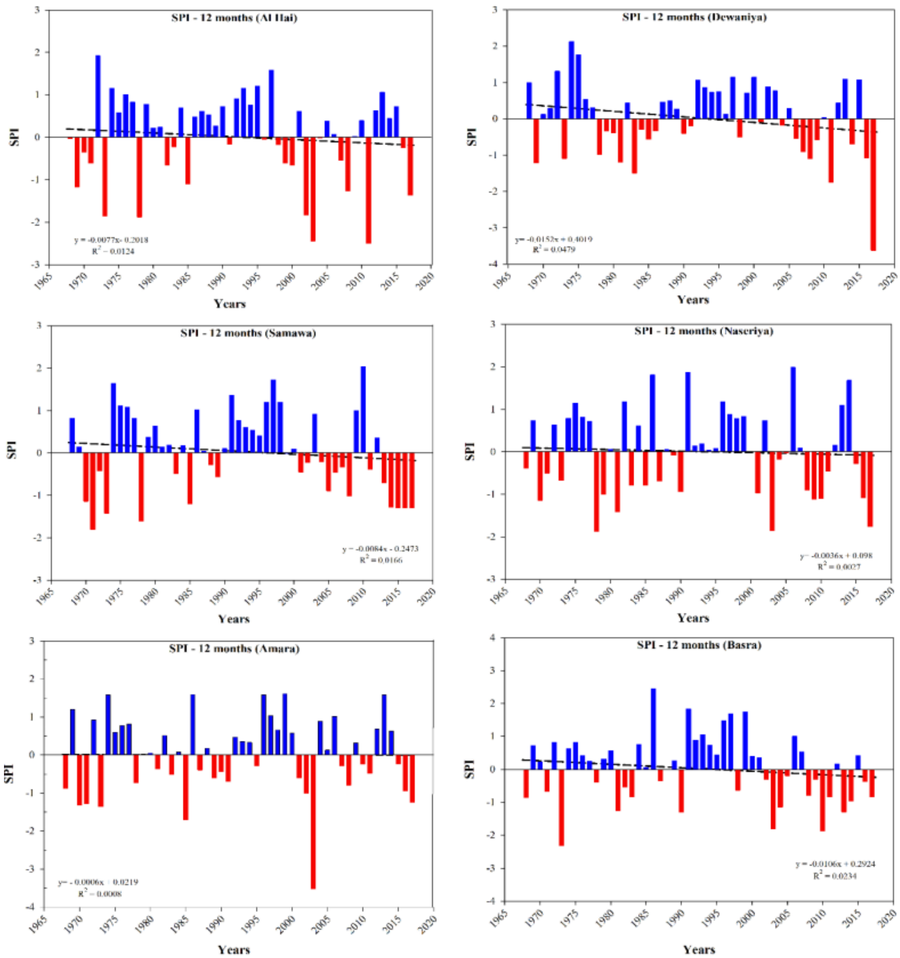


Figure 6: *The temporal changes of the SPI for 12 months at the 6 out of 14 meteorological stations in Iraq during 1968-2017.*

value of the SPI as extremely wet (2.06). Some dry years are slightly less than the wet years, but the drought is evident from the end of the last century. The dry seasons in Hai city were distinguished by their divergence during the study period, such as 1968 -1971, 1998-2003, 2007-2008 and 2016-2017. The highest value of SPI was recorded in 2011 as severely dry (-1.79). The wet years were recorded during 1973-1977, 1979-1981, 1986-1990, 1992-1997, and 2012-2015.

The wet seasons in Hai were characterized by their length and frequency during the study period. In Dewaniya, the years and seasons of drought were recorded in 1977-1986, 2006-2011 and 2015-2017. The year 2017 is classified as the highest value of the SPI as extremely dry (-3.62). On the other hand, wet years and seasons are recorded in Dewaniya, the most important of which are during 1970-1972, 1974-1977, 1992-1997, and 1999-2013. It is clear that the number of dry years is slightly less than the wet years, but the drought seems to be evident since 2002. The drought years and seasons in Samawa represented 1970-1973, 2004-2008 and 2013-2017. On the other hand, the wet years and seasons in Samawa were (1974-1977), (1979-1982), (1990-2000), considered the longest wet series recorded in Samawa. 2010 was classified as an extremely wet year in Samawa (2.03).

The SPI values recorded in Naseriya were characterized by fluctuation during the study period, and a clear dry series was not recorded except in (2002-2004), (2007-2011) and (2015-2017). On the other hand, wet years and seasons are more visible, such as (1973 -1976), (1991-1999) and (2012-2014). As in Amara, the SPI values recorded in Amara characterized by fluctuation during the study period, and a clear dry series was not recorded except in (1989-1991), (2001-2003), as the highest value of the SPI recorded in 2003 as extremely dry (-3.52). As well as (2007-2011), finally (2015-2017). On the other hand, wet years and seasons are more evident such as (1974-1977), (1991-1999), (1996-2000), (2004-2006), and (2012-2014). In Basra, the far south of Iraq, the dry years and seasons were marked by divergence during the study years up to 2000. After that, a dry series appeared at the beginning of the current century from (2001-2005) and (2008-2017), representing the longest series of dry years in Basra, except for 2012 and 2015. The wet years in Basra were characterized by continuity, such as (1974-1980) except for 1978. Also, (1984-1986) and (1991-2001) except for 1998.

Figure 7 shows the annual average of the SPI values for 14 meteorological stations in Iraq from 1968-2017. It appears from the figure that the 90th of the last century was the boundary between positive and negative SPI values. The existence of scattered dry years and seasons was evident from (1970–1990), offset by several wet years and seasons, especially from (1973-1977) and (1991 -1997). However, severe and persistent drought cases began from (1998-2005), (2007-2011) and (2016-2017), as the year 2017 recorded the highest negative value of SPI as moderately dry (-1.47).

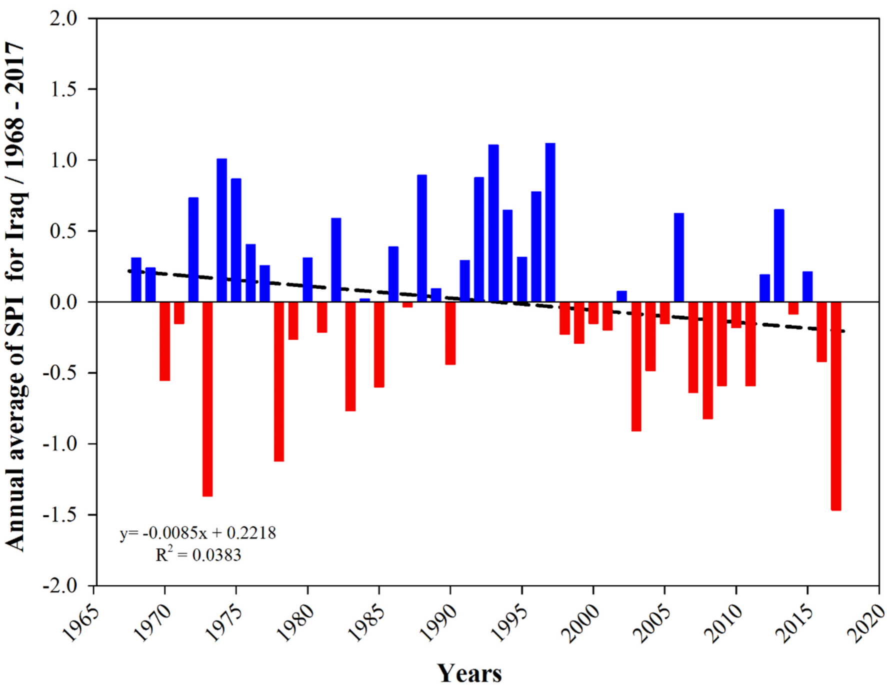


Figure 7: *The annual average of the SPI values for 14 meteorological stations in Iraq from 1968-2017.*

The decadal variations of SPI values in Iraq for 1968 - 1977, 1978 -1987, 1988 -1997, 1998 -2007, and 2008 -2017, as shown in Appendix A.

Table 3 shows a detailed analysis of SPI results at 14 meteorological stations and the number of occurrences of each category of SPI categories indicated in Table 2. The SPI classification ranges in a near-normal category between (0.99 to – 0.99). Also, note that the percentage of dry years amounted to 49%, while the percentage of wet years about 51%, which confirms that the wet years are slightly higher and close to the dry years during the current study.

Table 3: *A detailed analysis of the results of SPI for each 14 meteorological stations.*

Station	Years	extrer wet	very wet	mode wet	near nor-mal	mode dry	severe dry	extrer dry	Dry years	Wet years	Proport of dry years	Proportion of wet years
Baghdz	50	2	1	4	37	3	3	0	27	23	54%	46%
Basra	50	1	3	3	36	4	2	1	23	27	46%	54%
Kirkuk	50	3	0	6	34	4	2	1	28	22	56%	44%
Rutba	50	0	4	5	34	4	1	2	24	26	48%	52%
Mosul	50	1	4	3	31	8	3	0	25	25	50%	50%
Naseriy	50	0	4	4	33	6	3	0	23	27	46%	54%
Najaf	50	0	4	7	30	4	5	0	25	25	50%	50%
Dewan	50	1	1	6	34	6	1	1	23	27	46%	54%
Amara	50	0	5	3	35	5	1	1	23	27	46%	54%
Samaw	50	1	2	7	30	8	2	0	23	27	46%	54%
Baiji	47	1	2	6	30	5	2	1	29	21	62%	38%
Kerbala	50	1	2	2	37	2	3	3	21	29	42%	58%
Sinjar	47	0	2	3	34	4	3	1	20	27	43%	57%
Hai	50	0	2	5	34	4	3	2	22	28	44%	56%

3.3 Calculation and Analysis of SPI under RCP 8.5 scenario

Figure 8 shows the annual precipitation values under RCP 8.5 in the trend curve and violin plots (i.e., Figure 8a and Figure 8b) from 2020–2100 of 14 meteorological stations of Iraq. According to Figure 8b, the highest values of precipitation recorded in Mosul, Sinjar, and Kirkuk, located in northern Iraq from 2020–2080, as 1st period. For the 2nd period, 2081–2100, Kirkuk, Mosul, Baghdad, Baiji, Sinjar, and Rutba recorded the highest precipitation values. Other stations recorded about 200 mm of annual precipitation for the 1st period and equal to or less than 100 mm in the 2nd period.

The current study conducted a future meteorological drought analysis for RCP 8.5 using SPI of 12 months at 14 Iraqi meteorological stations during 2020-2100. The future study period for the SPI values is divided into four periods: 2020-2040, 2041-2060, 2061-2080, and 2081-2100, as shown in Figure 9. The SPI average for the first period, 2020-2040, shows the cities of Samawa and Karbala recorded the only negative values of SPI (-0.02 and -0.01), respectively. In contrast, the highest positive value of the SPI was recorded in Mosul (0.36). The SPI values under the second period (2041-2060) reversed from the first period, such as Samawa and Karbala recorded positive SPI values (0.012 and 0.0067), respectively. In comparison, Mosul recorded the highest negative value of the SPI (-0.33). During the third period (2061-2080), the cities of northern and western Iraq, Kirkuk, Baiji, and Rutba, recorded the highest negative values of the SPI (-0.91, -0.89, and -0.86), respectively. In contrast, Amara recorded the highest positive value of SPI (0.871). The results show that southern and central Iraq cities achieved positive values for the SPI, especially Amara, Naseriya, Basra, Baghdad, and Hai. At the end of this century (2081-2100), the highest positive values of the SPI were recorded in the cities of northern and western Iraq, such as Kirkuk, Baiji, and Rutba (0.91, 0.893, and 0.857), respectively. In contrast, the highest negative values of the SPI were recorded in Amara, Baghdad, Naseriya, and Hai (-0.872, -0.807), respectively. The results of future projections of SPI values under RCP 8.5 from 2020-2100 confirmed that southern and central Iraq is the region most affected by drought and low rainfall. 8.5 scenario assumptions.

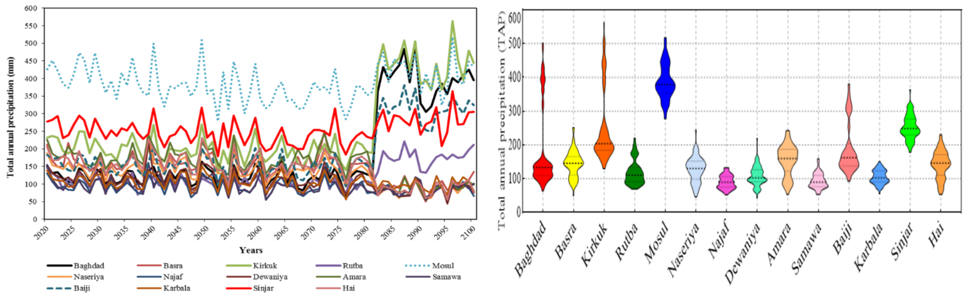


Figure 8: *The annual precipitation values under RCP 8.5 for 14 meteorological stations in Iraq from 2020-2100, (a) trend curve plot; (b) violin plot.*

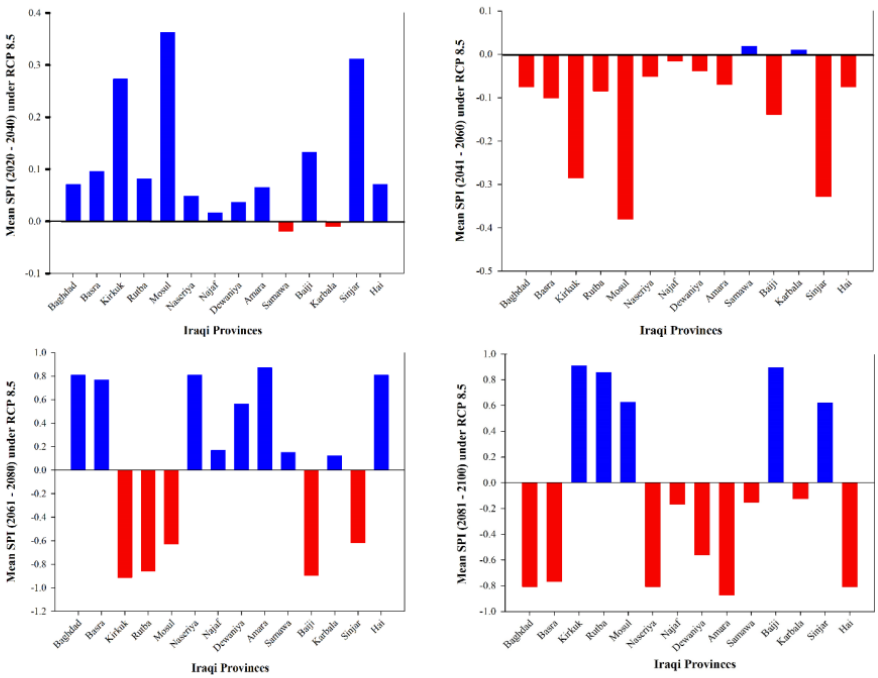


Figure 9: *The SPI values at 14 Iraqi meteorological stations during 2020-2040, 2041-2060, 2061-2080 and 2081-2100 under RCP 8.5.*

4. Discussion

The projection of annual precipitation changes (%) for the four future periods (2020–2040, 2041–2060, 2061–2080, and 2081–2100), in relation to 20 years historical period (1998–2017) under the RCP 8.5 scenario, is shown in Table 4. The results show the most significant decrease (-24%, -30%, and -32%) for periods (2020-2040, 2061-2080, and 2081-2100), respectively, in Kirkuk. Sinjar recorded

2nd rank by (-6%, -12%, and -17%) for the same periods above. Other cities, Samawa, Dewaniya, Hai, Naseriya, and Amara, that recorded negative values in 2081-2100, such as (-7%, -16%, -22%, -24%, and -44%) in 2081-2100. On the other hand, the greatest increase (266%, 146%, and 120%) was recorded in Baghdad, Rutba, and Baiji, respectively, for the fourth period (2081-2100). The results of the RCP 8.5 scenario show that there is not any specific pattern in precipitation change over different periods but, for some cities, the largest increase/decrease occurs in different periods (e.g., Kirkuk and Sinjar). Precipitation changes are expected to exhibit different behavior in all stations at different periods when RCP 8.5 becomes more pessimistic at the end of the current century.

Table 4: *The projection of annual precipitation changes (%) for the future periods (2020–2040, 2041–2060, 2061–2080, and 2081–2100), concerning the historical period (1998–2017) under RCP 8.5.*

Station	RCP 8.5			
	2020-2040	2040-2061	2061-2080	2081-2100
Baghdad	19	18	13	266
Basra	72	65	61	0
Kirkuk	-24	-30	-32	54
Rutba	54	49	39	146
Mosul	41	29	21	43
Naseriya	39	37	26	-24
Najaf	23	23	13	5
Dewaniya	28	26	13	-16
Amara	12	9	17	-44
Samawa	12	13	-1	-7
Baiji	14	9	5	120
Kerbala	33	34	24	17
Sinjar	-6	-12	-17	1
Hai	44	42	32	-22

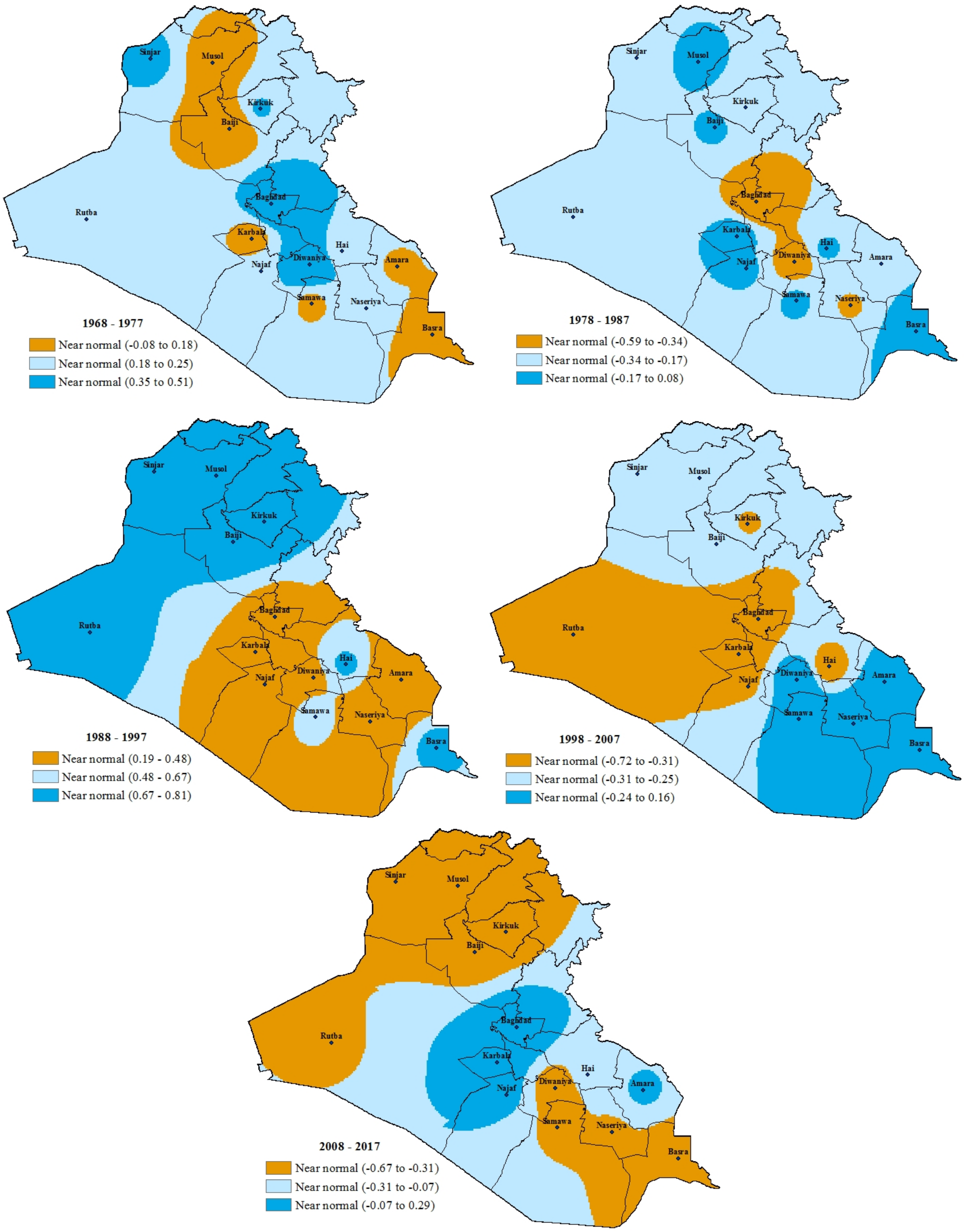
5. Conclusions

This study uses historical precipitation data from 1968 to 2017 and future RCP 8.5 projections for 2020-2100 to estimate the meteorological drought using SPI for monitoring drought at 14 synoptic stations over Iraq. According to the SPI values estimated in Iraq from 1968 to 2017, Iraq experienced drought 15 out of 20 years after 1997. Some of 4 to 5 dry years continue 1997-2000, 2020-2004, 2006-2010 and 2016-2017. The last year recorded the highest negative value of the annual SPI average (-1.47). The results showed that Baiji, Kirkuk, and Baghdad were among the cities where the dry years were most frequent with a percentage, 62%, 56%, and 54%, respectively. However, the most frequent category of the SPI is near normal during the historical period (0.99 to -0.99), as shown in Table 3. However, this does not prevent the presence of strong indicators of drought in Iraq. This mainly due to the lack of precipitation due to climate change. Analysis of the SPI indicated that meteorological drought frequency would increase in Iraq in the end of the 20th century. While population and water demand would increase, average rainfall would decrease by approximately 50% over the last two decades, attributed to climate change.

According to [39], a significant drought occurred in Iraq during 1998–2009. Two significant drought periods of 1998–1999 and 2007–2008 were identified, during which severe to extreme droughts covered about 87% and 82% of Iraq, respectively. For RCP 8.5, the SPI average during 2020-2040 showed Samawa and Karbala with negative values of SPI (-0.02 and -0.01, respectively).

At the same time, the highest positive value of the SPI was recorded in Mosul (0.36). During 2081-2100, the highest negative values of the SPI were recorded in Amara, Baghdad, Naseriya, and Hai. The future changes (%) of precipitation values for RCP 8.5 compared to the historical period (1998-2017) showed an apparent decrease in Kirkuk and Sinjar. However, it recorded high precipitation values for the RCP 8.5. In comparison, the significant rise was recorded in Baghdad, Rutba, and Baiji at the end of the current century. Future drought impacts maybe even worse, as model projections suggest an overall drying trend for much of the Middle East region [48].

Appendix


Sinjar
Musol
Kirkuk
Baiji
Rutba
Baghdad
Karbala
Hai
Diwaniya
Najaf
Amara
Samawa
Naseriya
Basra
1968 - 1977
Near normal (-0.08 to 0.18)
Near normal (0.18 to 0.25)
Near normal (0.35 to 0.51)
1978 - 1987
Near normal (-0.59 to -0.34)
Near normal (-0.34 to -0.17)
Near normal (-0.17 to 0.08)
1988 - 1997
Near normal (0.19 - 0.48)
Near normal (0.48 - 0.67)
Near normal (0.67 - 0.81)
1998 - 2007
Near normal (-0.72 to -0.31)
Near normal (-0.31 to -0.25)
Near normal (-0.24 to 0.16)
2008 - 2017
Near normal (-0.67 to -0.31)
Near normal (-0.31 to -0.07)
Near normal (-0.07 to 0.29)

Conflicts of Interest: The authors have no conflict of interest to any part.

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