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Published by the Faculty of Engineering, Khon Kaen University, Thailand

Climate change and the behaviour of meteorological drought and its impact on wheat yield

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Received 12 November 2023
Revised 7 February 2024
Accepted 9 February 2024

Abstract

Climate change is the most prominent issue in this decade. The expected impacts of this change have become a reality, with rising sea levels and long, intense heat waves occurring globally. The present study examines the characteristics of drought in Nineveh Governorate and its impact on the wheat crop. Two drought indices were used in the study: (1) the Standardised Precipitation Index (SPI) and (2) the Chinese Z Index (CZI). The study used climate data on rainfall and temperature for the period 1990–2020 from eight meteorological stations distributed in the study area. Results showed a nonsignificant decrease in rainfall and an increase in maximum and minimum temperatures. Results also showed that the highest recurrence rates of drought (recorded at the Tal-Abta) are 51.2% and 56% for SPI and CZI, whereas the lowest rates (recorded at Mosul, Sheikhan and Sinjar) are 45.1% and 50.8% for SPI and CZI, respectively. The two drought indices match in identifying wet and dry periods, with R^2 values ranging from 0.84 to 0.94. Furthermore, a relationship was found between productivity and climatic drought indices and it was concluded that wheat productivity is more significantly influenced by the distribution of rainfall than by drought. The current study can help demonstrate the extent of climate change's impacts on wheat productivity. Thus, the results can contribute to planning and managing agricultural production according to climate change.

Keywords: Climate change, Drought, Trend analysis, Wheat, SPI, CZI

1. Introduction

The increase in demand for food caused by increasing population density and ongoing international conflicts poses a real threat to global food security. Therefore, studying the impact of climatic drought on crops, particularly wheat, which is the most significant food crop, is important, mainly because wheat relies on rainfall for its cultivation in most countries. The importance of wheat remarkably increased with the outbreak of the Russian–Ukrainian war, which led to an increased demand for this crop and a rise in its prices; wheat reached its highest value in March 2022 and surpassed levels not seen in a decade [1]. The wheat production in Nineveh Governorate is a remarkably contributor to Iraqi food security. Wheat is a primary source of human food; one of the main constraints affecting wheat productivity is the lack of soil moisture resulting from drought, which affects crop growth stages and limits yield [2].

Drought is an environmental hazard that occurs because of a lack of rainfall. It cannot be avoided, but we can manage the problems resulting from its impact and reduce its negative effects on human activities [3]. Understanding the occurrence of drought, identifying its risks and assessing its impact on agricultural production are crucial. Therefore, monitoring drought and studying its characteristics using drought indices, are necessary [4].

In regard to the study area, the size of suitable agricultural lands is approximately 7.8 million dunams; the majority of these lands rely on rain-fed agriculture (Ninawa Directorate of Agriculture). A report by the United Nations Office for the Coordination of Humanitarian Affairs stated that vast agricultural lands and drinking water resources in Ninawa Governorate have been depleted, and wheat production is expected to decrease by 70% because of recurrent droughts [5]. Researchers [6] revealed that countries in the Mediterranean and Middle East region suffer from variability in wheat yield because of the impact of climatic drought and because they are exposed to temperatures higher than those in the rest of the world.

In [7] conducted several tests to analyse the time series of rainfall and temperatures annually and monthly from 1980 to 2011 for 28 meteorological stations in Iraq. The results showed a decreasing trend for rainfall except for two stations and an increasing trend for maximum and minimum temperatures; however, for some, the results were not statistically significant at a confidence level of 5%.

In terms of climate drought, researchers [8] conducted several tests to analyse the time series of rainfall and temperatures annually and monthly from 1980 to 2011 for 28 meteorological stations in Iraq. In analysed drought in the northern region of Iraq for the period 1965–2014. The results showed that 68% of the dry months are within moderate drought. Thus, the study area can be considered to fall within mild drought [9]. Finally, confirmed that SPI and CZI can well reflect drought conditions. CZI exhibits high sensitivity in determining severe drought years [10].

The [11] conducted a study in 10 countries to understand the impact of drought on the agricultural production of four strategic crops. The researchers relied on SPI and the crop yield data for the 1961–2016 period. The results showed a strong correlation between drought and crop yield. [6]; highlighted the impact of drought on wheat crop yield in the Mediterranean and Middle Eastern regions.

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doi: 10.14456/easr.2024.24

They considered that these regions have the most suitable climate for growing wheat and are amongst the areas in the world witnessing a temperature rise. In Kazakhstan, studied the relationship between the actual yield of wheat crops and drought. The researchers used two drought indices: SPI and SPEI. The researchers used the Pearson correlation coefficient to find the strength of the relationship between drought and actual production values. The results showed a strong correlation between the drought index and wheat crop yield [12].

The main objective of the present study is to determine the impact of climatic drought on wheat crop productivity in Nineveh Governorate and find a relationship linking the drought index with productivity. Thus, the following steps are conducted in this study: Firstly, climate changes are studied using the Mann–Kendall test and Sen's slope. Secondly, drought characteristics are analysed based on SPI and CZI, and the feasibility of adopting CZI in the study area is investigated. Finally, the impact of climatic drought on wheat crop productivity is investigated after the reference evapotranspiration is determined using the Penman–Monteith equation.

2. Data and study area

We used a set of monthly climate data for the period 1990–2020. These data represent the rainfall for eight climatic stations. The data from six climatic stations (Mosul, Tal-Afar, Rabiah, Sinjar, Ba'aj and Tal-Abta) were obtained from the General Authority for Meteorology and Seismic Monitoring/Iraqi Ministry of Transportation. Those from two other stations (Hamdaniyah and Sheikhan) were obtained from the Nineveh Agriculture Directorate. The maximum and minimum temperature data were available for six climatic stations (Mosul, Tal-Afar, Rabiah, Sinjar, Ba'aj and Tal-Abta). They were obtained from the General Authority for Meteorology and Seismic Monitoring. Figure 1 shows the geographical location of the meteorological stations in Nineveh Governorate. In particular, the climate data underwent homogeneity tests after the missing values were replaced [13].

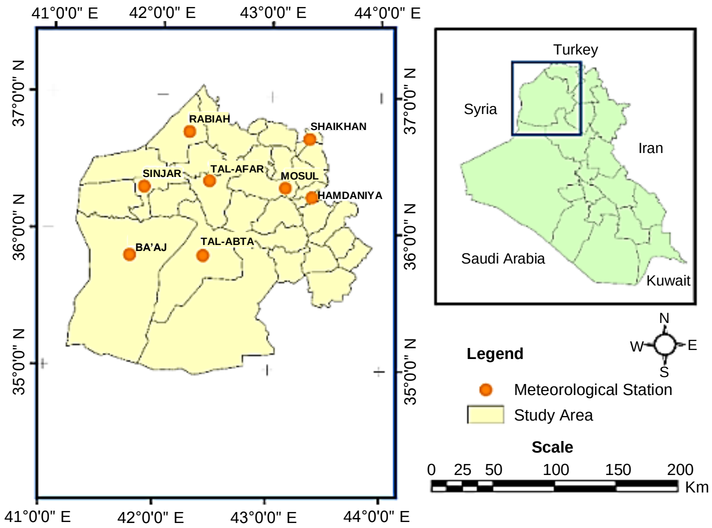

Figure 1 Geographical location and spatial distribution of the meteorological stations in the Nineveh government.

3. Materials and methods

3.1 Mann–Kendall test

Mann–Kendall test is nonparametric, indicating that it does not require a normal distribution of time series. It is widely used to determine whether a trend in a time series is positive or negative and to investigate the presence or absence of a significant change based on the null hypothesis, which assumes it is independently distributed, and the alternative hypothesis, which is that there exists a monotonic trend. The World Meteorological Organization recommends this test [14-16].

$$s = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} sign(x_i - x_j) \quad (1)$$

where

n: is the number of data points or length of the time series. Xi, Xj: Data values in the time series at i and j where (j>i)

$$sign(x_i - x_j) = \begin{cases} 1, if\ (x_i - x_j) > 0 \\ 0, if\ (x_i - x_j) = 0 \\ -1, if\ (x_i - x_j) < 0 \end{cases} \quad (2)$$

The variance is calculated from the following relationship:

$$v(s) = \frac{1}{18}\left[n(n-1)(2n+5) - \sum_{p=1}^{q} t_p(t_p - 1)(2t_p + 5)\right] \quad (3)$$

t_p: Number of times the value is repeated.

$$k = \begin{cases} \frac{s-1}{\sqrt{var(s)}}, if\ s > 0 \\ 0 \qquad if\ s = 0 \\ \frac{s+1}{\sqrt{var(s)}}, if\ s < 0 \end{cases} \tag{4}$$

The direction of the time series is interpreted through the value (k); a positive value indicates the presence of an increasing trend in the time series, while a negative value indicates a decreasing trend in the time series. The null hypothesis of no trend is rejected if the P-value is < 0.05.

3.2 Sen's slope estimator

Sen (1968) proposed the Sen's slope estimator test, which is a powerful tool for developing linear relationships. The method calculates the direction and the amount of slope for the time series. In this method, the errors in the data series and their extreme values do not significantly affect the results [17].

$$Q_i = \frac{X_j - X_k}{j-k} \quad for\ i = 1, \ldots\ldots, n \tag{5}$$

X_j and X_k represent data values at j and k (j> k).

$$Q_{med} = \begin{cases} Q[(n+1)/2], if\ n\ is\ odd \\ \frac{Q_{[n/2]} + Q_{[(n+2)/2]}}{2}, if\ n\ is\ even \end{cases} \tag{6}$$

The positive Sen's slope reveals an increasing trend, while the negative Sen's slope indicates a decreasing trend.

3.3 SPI

SPI is a strong and flexible indicator that effectively determines wet and dry periods. The researcher needs rain data because these data are the required input. Moreover, SPI relies on its calculations to transform the time series data from a gamma distribution to a normal distribution. Thus, the average SPI value for the data equals zero, the positive index results indicate more rain than usual, and negative values indicate a shortage of rain [18].

3.4 CZI

CZI was first used in 1995 by the National Climate Centre in China. It relies on rainfall as the input for its calculation using the Pearson Type III distribution. This index is distinguished by identifying dry and wet periods for monthly durations ranging from 1 month to 72 months [19, 20].

3.5 Water consumption and productivity

The reference evapotranspiration value is estimated from the climate data using the Penman–Monteith equation, which is one of the best mathematical models adopted by the Food and Agriculture Organization. The Penman–Monteith equation for calculating the reference evapotranspiration is as follows:

$$ET_o = \frac{0.408\,\Delta\,(R_n - G) + \gamma \frac{900}{T+273} u_2 (e_s - e_a)}{\Delta + \gamma\,(1 + 0.34 u_2)} \tag{7}$$

The water requirement for winter wheat crop is determined from the crop coefficient (K_c) and the daily reference evapotranspiration (ET_o) using the following equation:

$$ET_c = ET_o * K_c \tag{8}$$

The necessary crop data, which included the crop coefficient, determining the planting date, length of the growing season, the dominant soil, and its moisture content, were according to [21-24]. The behavior and productivity response of winter wheat to water (K_y) were estimated through the following relationship described by [25]. It represents the relationship between the relative yield decrease ($1-Y_a / Y_m$) and the relative evapotranspiration ($1-ET_a / ET_m$). Figure 2 shows the flowchart of the research methodology in a simplified explanation by using climate data: first, the trend analysis using Mann-Kendall and Sen's slope; second, the drought characteristics are tested using the SPI and CZI indices; and lastly, the productivity ratio is computed with how drought affects it.

$$(1 - \frac{Y_a}{Y_m}) = K_y (1 - \frac{ET_a}{ET_m}) \tag{9}$$

Where:

Y_m= Maximum yield (kg).
Y_a= Actual yield (kg).
ET_m= Maximum evapotranspiration (mm/period).
ET_a= Actual evapotranspiration (mm/period).

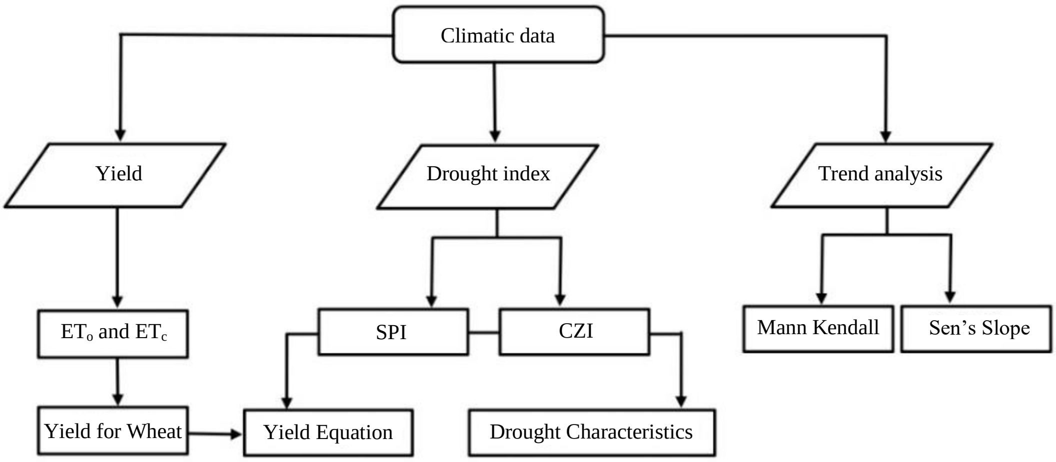

Figure 2 A flowchart shows the methodology.

4. Results and discussion

4.1 Climate changes

Rainfall and temperatures are amongst the most prominent climate elements directly affecting the Earth's surface. Therefore, any fluctuation in them significantly impacts human life. Mann–Kendall and Sen's slope tests were performed on the time series of climate data (rainfall and maximum and minimum temperatures) to detect seasonal and annual data trends and understand the direction of climatic changes, whether positive or negative.

4.1.1 Trend analysis

As shown in Table 1, the analysis of the annual rainfall trend by the Mann–Kendall test revealed a noticeable negative trend that was not statistically significant (P-value > 0.05) in all stations except Al-Sheikhan and Al-Hamdaniyah, which was a positive trend. This observation occurred in the winter and spring seasons. However, the results in the fall season showed an increase for the stations (Sinjar, Tal-Abta, Ba'aj and Al-Hamdaniyah), and a decrease for the other stations.The annual trend analysis for maximum temperatures showed a statistically significant increase at level 0.05 for all stations except for Tal-Abta. Also, the increase was statistically significant in the winter, excluding Tal-Abta. In the summer, the increase was evident but not statistically significant, excluding Mosul. However, this increase was observed across the spring and summer but varied between significant and insignificant (Based on P-value), except for Tal-Abta. Regarding minimum temperatures, the results of the annual study indicated a statistically significant increase with a p-value less than 0.05 for all stations. In terms of seasons, the increase was statistically significant in winter, except for Tal-Abta and Ba'aj stations, and in summer, excluding Mosul, Tal-Afar and Ba'aj. In autumn, the increase was statistically significant for all stations. In spring, there was a varied increase between significant and insignificant in all stations, as shown in Table 2 and 3.

As shown in Table 4, The results of Sen's slope test showed a strong agreement with those of the Mann–Kendall test in detecting the trend for the time series. The test revealed that the highest rate of annual rainfall decline was in Tal Afar, reaching −2.900 mm/year and that the highest increase was at the Al-Hamdaniyah station, reaching 1.867 mm/year. Regarding the quarterly tests (winter, spring and autumn), the lowest values were determined from Sinjar, Sinjar and Mosul stations (−1.460, −1.500 and −0.1 mm/year, respectively). These values resulted in increases for Sheikhan, Hamdaniyah and Hamdaniyah stations (0.556, 0.345 and 0.677 mm/year, respectively). The increase in the trend analysis for maximum and minimum temperatures was predominant in the results. The highest temperature increases (annually, winter, spring, summer and autumn) were determined from Mosul, Ba'aj, Tal-Afar, Tal-Afar and Mosul stations (0.067, 0.076, 0.083, 0.063 and 0.074 °C/year, respectively). For the minimum temperature, the highest increase was recorded from Mosul and Sinjar stations, reaching 0.046.

Table 1 Results of the Mann-Kendall test for rainfall over the period 1990-2020.

Station	Winter		Spring		Autumn		Annual	
	K	*P-value*	*K*	*P-value*	*K*	*P-value*	*K*	*P-value*
Mosul	decrease	0.443	decrease	0.669	decrease	0.915	decrease	0.498
Tal-Afar	decrease	0.432	decrease	0.454	decrease	0.887	decrease	0.269
Sinjar	decrease	0.486	decrease	0.254	increase	0.592	decrease	0.432
Tal-Abta	decrease	0.803	decrease	0.372	increase	0.748	decrease	0.544
Rabiah	decrease	1	decrease	0.498	decrease	0.858	decrease	0.748
Ba'aj	decrease	0.335	decrease	0.83	increase	0.498	decrease	0.544
Sheikhan	increase	0.83	increase	0.943	decrease	0.943	increase	0.915
Hamdaniyah	increase	1	increase	0.708	increase	0.192	increase	0.592

Table 2 Results of the Mann-Kendall test for Max temperature over the period 1990-2020.

Station	Winter		Spring		Summer		Autumn		Annual	
	K	*P-value*	*K*	*P-value*	*K*	*P-value*	*K*	*P-value*	*K*	*P-value*
Mosul	increase	0.002	increase	0.061	increase	0.015	increase	0.04	increase	0.001
Tal-Afar	increase	0.001	increase	0.014	increase	0.003	increase	0.175	increase	0.001
Sinjar	increase	0.011	increase	0.012	increase	0.006	increase	0.509	increase	0.011
Tal-Abta	increase	0.335	decrease	1	decrease	0.748	increase	0.83	increase	0.803
Rabiah	increase	0.02	increase	0.069	increase	0.027	increase	0.309	increase	0.022
Ba’aj	increase	0.002	increase	0.034	increase	0.101	increase	0.205	increase	0.009

Table 3 Results of the Mann-Kendall test for Min temperature over the period 1990-2020.

Station	Winter		Spring		Summer		Autumn		Annual	
	K	*P-value*	*K*	*P-value*	*K*	*P-value*	*K*	*P-value*	*K*	*P-value*
Mosul	increase	0.019	increase	0.002	increase	0.175	increase	0.007	increase	0.012
Tal-Afar	increase	0.032	increase	0.225	increase	0.134	increase	0.006	increase	0.05
Sinjar	increase	0.009	increase	0.009	increase	0.017	increase	0.035	increase	0.015
Tal-Abta	increase	0.164	increase	0.066	increase	0.022	increase	0.019	increase	0.025
Rabiah	increase	0.015	increase	0.069	increase	0.035	increase	0.02	increase	0.009
Ba’aj	increase	0.363	increase	0.181	increase	0.139	increase	0.025	increase	0.046

Table 4 Results of the Sen's slope test for rainfall, Max and Min temperature over the period 1990-2020.

Station	Climatic elements	Winter	Spring	Summer	Autumn	Annual
		Slope	*Slope*	*Slope*	*Slope*	*Slope*
Mosul	Rainfall	-1.252	-0.652	-	-0.1	-2.122
	Max temperature	0.071	0.065	0.054	0.074	0.067
	Min temperature	0.066	0.055	0.034	0.067	0.046
Tal-Afar	Rainfall	-1.205	-0.683	-	-0.082	-2.9
	Max temperature	0.067	0.083	0.063	0.046	0.061
	Min temperature	0.051	0.034	0.032	0.074	0.036
Sinjar	Rainfall	-1.46	-1.5	-	0.48	-1.976
	Max temperature	0.056	0.066	0.054	0.017	0.042
	Min temperature	0.057	0.078	0.046	0.058	0.046
Tal-Abta	Rainfall	-0.539	-0.518	-	0.131	-1.3
	Max temperature	0.029	-0.003	-0.024	0.008	0.014
	Min temperature	0.029	0.042	0.074	0.07	0.045
Rabiah	Rainfall	-0.053	-0.744	-	-0.027	-1.147
	Max temperature	0.051	0.048	0.046	0.021	0.042
	Min temperature	0.031	0.046	0.039	0.056	0.037
Ba’aj	Rainfall	-1.42	-0.233	-	0.414	-1.134
	Max temperature	0.076	0.071	0.038	0.025	0.041
	Min temperature	0.02	0.039	0.044	0.052	0.03
Sheikhan	Rainfall	0.556	0.147	-	-0.077	1.143
Hamdaniyah	Rainfall	0.167	0.345	-	0.677	1.867

4.2 Drought index

The use of drought indicators for identifying wet and dry periods and analysing results helps understand the climatic nature of the study area. SPI, widely used in Iraq and globally as a main indicator for describing climatic drought and detecting dry and wet periods experienced by the study area [26], was adopted. Moreover, the calculations were performed on CZI to detect dry and wet periods for the same period (SPI and CZI). Drought indices for the 1-month time scale were used because they represent the meteorological drought. However, it is important to note that choosing any time scale greater than one may reflect the hydrological impact. Therefore, the current study is related to studying the effect of a meteorological drought on wheat productivity. The simplicity of the calculations demonstrated the potential for adopting and integrating CZI in Nineveh Province and Iraq.

4.2.1 Analysis of the climatic drought indicators SPI and CZI

An analysis of the rainfall time series for the period 1990–2020 based on SPI was conducted. Given the simplicity of CZI’s calculations, the results based on SPI were compared with those based on CZI to study the possibility of adopting the latter for the study area in describing drought. The comparison results between SPI and CZI for the period of 1 month indicated that the R^2 values reached 0.88, 0.94, 0.85, 0.89, 0.89, 0.91, 0.84 and 0.86 for Ba’aj, Hamdaniyah, Mosul, Rabiah, Sheikhan, Sinjar, Tal- Afar and Tal-Abta stations, respectively. These values fall within the ratios mentioned by [27], as shown in Figure 3. The results also showed that the highest recurrence rate for drought in SPI was 51.2% for the Tal-Abta station, and the lowest was 45.1% for the Mosul station. For the CZI, the highest drought recurrence rate was also determined from the Tal-Abta station, reaching 56%, whereas the lowest was determined from Sheikhan and Sinjar stations, reaching 50.8%, as shown in Table 5 and 6. Finally, the time series of drought indicators shown in Figure 4 indicates that a very strong match existed during the wet months, with a slight difference in the dry months. This finding agrees with the results found by [28].

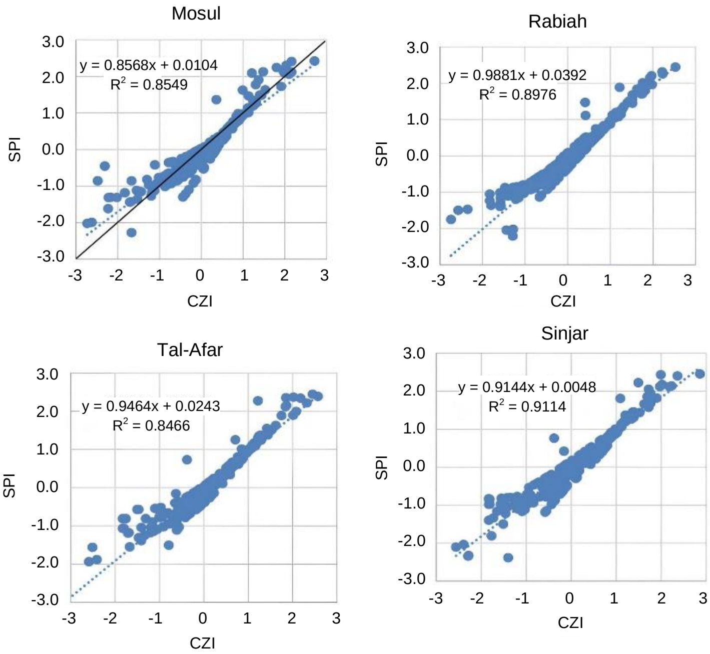

Figure 3 Scatter diagram for the SPI and CZI at (1M) time scale for the metrological stations.

Table 5 The percentage of SPI drought recurrence.

Station	Drought Recurrence %				
	Drought	Mild Drought	Moderate drought	Severe Drought	Extreme Drought
Mosul	45.1	32.25	5.64	3.22	4
Tal-Afar	45.9	32.66	6.45	5.24	1.6
Sinjar	48.7	35.48	6.45	5.24	1.6
Rabiah	47.9	33.06	9.67	3.62	1.6
Tal-Abta	51.2	38.71	6.04	4.03	2.42
Ba'aj	47.5	35.6	5.7	3.7	2.5
Sheikhan	49.5	34.67	9.27	5.24	0.4
Hamdaniyah	48.3	37.4	6.45	3.22	1.2

Table 6 The percentage of CZI drought recurrence

Station	Drought Recurrence %				
	Drought	Mild Drought	Moderate drought	Severe Drought	Extreme Drought
Mosul	53.2	44.3	7.6	0.5	0.8
Tal-Afar	51.2	40.32	7.25	2	1.6
Sinjar	50.8	42.74	5.24	0.81	2
Rabiah	55.6	45.3	6.9	0.9	2.42
Tal-Abta	56	47.17	7.66	1.2	0
Ba'aj	55.2	47.58	4.83	1.61	1.2
Sheikhan	50.8	39.8	7.3	2.82	0.81
Hamdaniyah	53.2	43.8	6.9	2	0.5

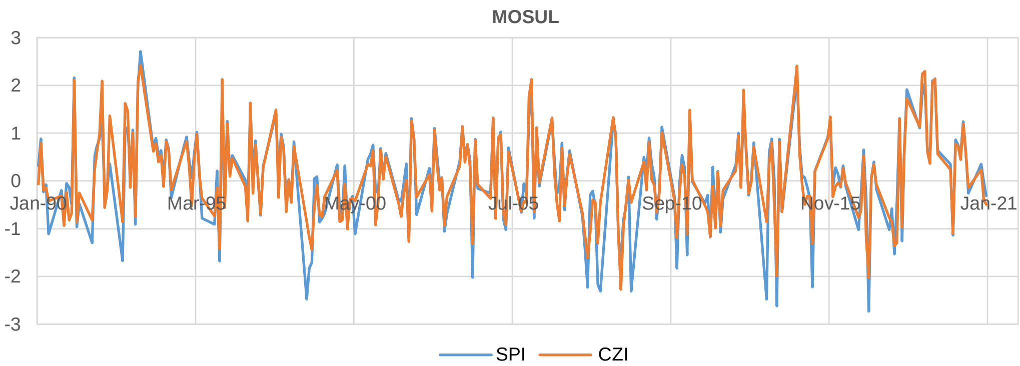

Figure 4 SPI and CZI time series for drought at (1M) time scale in the study stations

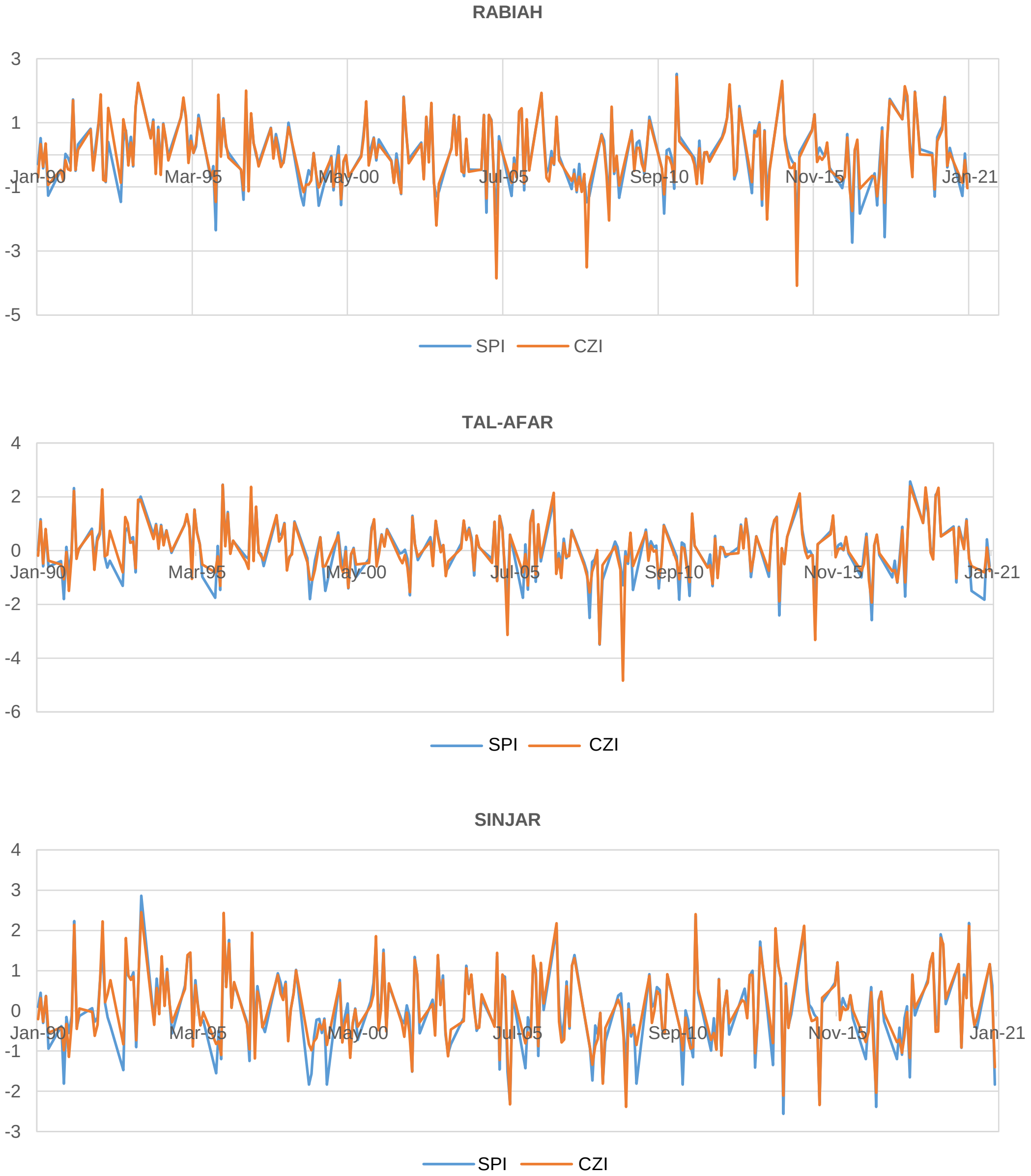

Figure 4 (continued) SPI and CZI time series for drought at (1M) time scale in the study stations

Given the importance of drought characteristics in defining harsh and severe periods, the drought characteristics for SPI and CZI indicators were summarised in Table 7. The highest value of drought was determined from the Tal-Afar station, reaching −4.8 and −3.5 for CZI and SPI, respectively. In addition, the maximum drought quantity was determined from Tal Abta station, reaching −14.3 for SPI, and from Tal-Afar station, reaching −14.7 for CZI.

4.3 Impact of climatic drought on productivity

The natural hazard of drought, the effects of which have become apparent in the study area, is now affecting human activities, the economy, and the environment, threatening food security. Winter wheat is the predominant crop in the study area, and rainfed agriculture accounts for 93% of wheat cultivation (Nineveh Agriculture Directorate, 2022). Climate factors such as maximum and minimum temperatures, humidity, wind speed, and sunlight hours were used to calculate the crop's evapotranspiration, in addition to rainfall and wheat-related characteristics to estimate crop yield. The relationship between drought indices and productivity during dry and wet years was established. The results showed that the relationship between the SPI and CZI drought indices and productivity was strong for four provinces (Mosul, Rabiah, Sinjar, and Tal Afar) in Nineveh Province.

The planting date in mid-November was determined to be the optimal time to achieve the highest crop yield, as indicated [23, 24]. Figure 5 shows that the 2007-2008 season was dry, with productivity reaching only 41% of the normal conditions. In contrast, the 2018-2019 season was extremely wet, with productivity at 97% of the normal conditions. It was also observed that the agricultural seasons of 2010-2011 and 2014-2015 received almost the same amount of rainfall, 306.6 mm and 309.4 mm, with crop yields of 83% and 62%, respectively. This difference was due to rainfalls in April, with 118.8 mm in 2011 and only 0.7 mm in 2015 (General Authority for Meteorology and Seismic Monitoring, 2022). Thus, the distribution and timing of rainfall have a significant impact on productivity. The intensity, depth, and timing of rainfall greatly affect productivity, as emphasised [21], Delaying the planting date can negatively affect or increase productivity, and April rains are crucial in increasing crop yield, with the maximum wheat crop requirement in April

[22], which is approximately the same for all selected stations. Thus, changes in the rainfall pattern in Nineveh Governorate and the uneven distribution of rainfall have a clear impact on wheat productivity.

From the results obtained, it is clear that in some years, dry years have better productivity than wet years with above-average rainfall, as shown in Figure 5. For example, the Mosul station for the year 2011-2012 was a dry year with a drought severity of -0.07, and productivity was 83% of the total production. In contrast, the years 2005-2006, 2009-2010, 2012-2013, and 2015-2016 were wet years with humidity severity and productivity of 0.82 (82%), 0.03 (71%), 0.78 (76%), and 0.24 (80%) respectively. Thus, there are moderately dry years with better productivity than some years with moderate or average humidity. For stations like Rabiah and Sinjar, they have moderately dry years with moderate drought severity and better productivity than some wet years with moderate humidity, as shown in Figures 6 and 7. Therefore, rainfall distribution plays a crucial role and has a significant impact on productivity.

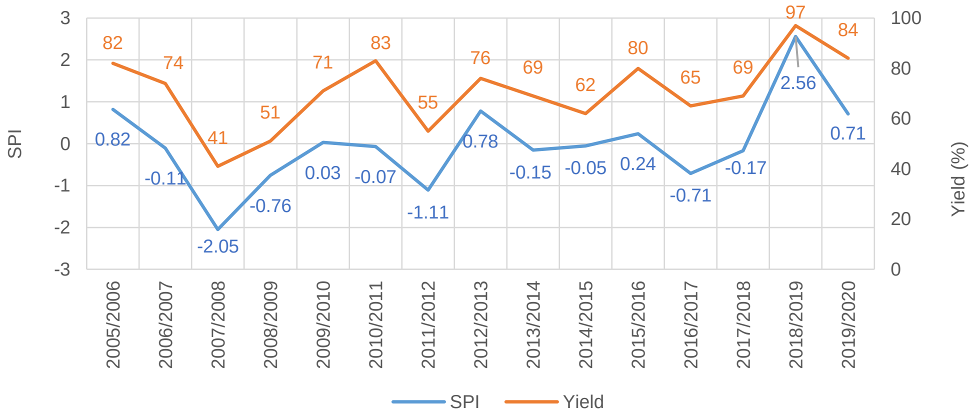

Figure 5 Relationship between the drought index and the productivity of the Mosul station

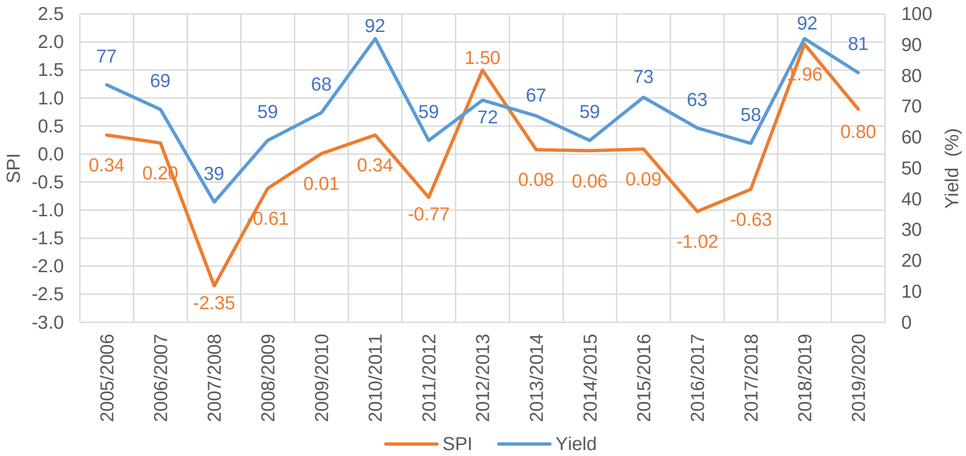

Figure 6 Relationship between the drought index and the productivity of the Rabiah station

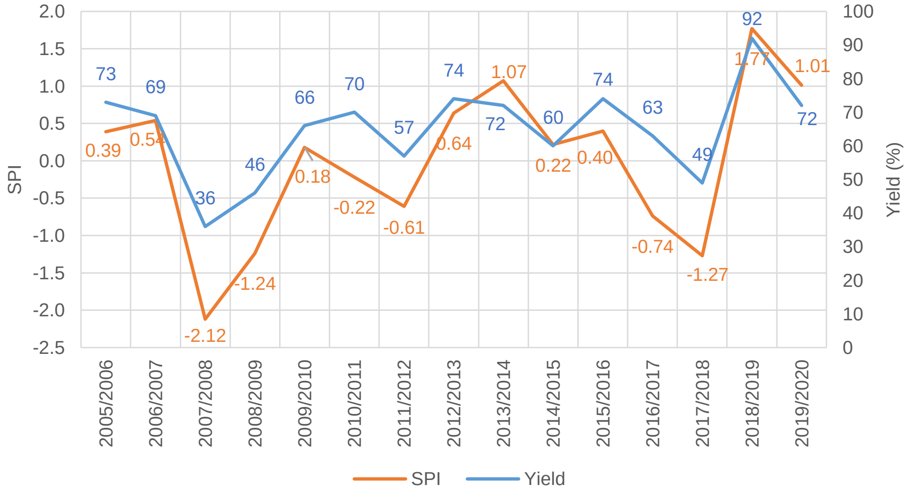

Figure 7 Relationship between the drought index and the productivity of the Sinjar station

Table 7 Drought Characteristics of the SPI and CZI at the time scale of 1 Month

Station	Drought Index	Smax	Duration M M/Y	Speak	M/Y
Mosul	SPI	-9.93	8 10/2007-05/2008	-2.73	Feb-17
	CZI	-9.46	16 10/1998-05/2000	-2.27	Jan-09
Rabiah	SPI	-8.5	11 10/1998-12/1999	-2.74	Feb-17
	CZI	-10.5	17 10/1998-10/2000	-4.08	Apr-15
Tal-Afar	SPI	-9.12	8 10/2007-05/2008	-3.5	Apr-08
	CZI	-14.7	14 10/2007-03/2009	-4.8	Jan-09
Sinjar	SPI	-7.1	8 10/1998-05/1999	-2.56	Feb-14
	CZI	-6.6	8 10/2007-05/2008	-2.4	Jan-09
Hamdaniya	SPI	-10.95	11 10/1998-12/1999	-2.29	Dec-98
	CZI	-11.47	15 02/1998-12/1999	-2.24	Jan-09
Shikhan	SPI	-11.43	13 04/1998-12/1999	-2.65	Oct-96
	CZI	-9.58	13 04/1998-12/1999	-3.45	Mar-04
Tal-Abta	SPI	-14.3	14 10/2007-03/2009	-3.06	Feb-14
	CZI	-11.5	13 10/2007-02/2009	-1.99	Jan-09
Ba'aj	SPI	-10.9	16 10/1998-05/2000	-2.66	Feb-14
	CZI	-8.8	14 10/2008-03/2000	-3.64	Apr-15

A relationship was established to estimate wheat production based on climate drought indices (SPI and CZI). The results indicated that the second-degree equation ($Y=a+bx+cx^2$) was stronger than the first-degree equation ($Y=a+bx$) in terms of statistical tests. The determination coefficient values for the first-degree equation Mosul station were 0.82 and 0.71 for the SPI and CZI indices, respectively, and for the second-degree equation, they were 0.85 and 0.83 for the SPI and CZI indices, respectively, as shown in Table 8. Also, it can be observed that the values of "a" ranged between 0.507 and 0.72, "b" ranged between 0.109 and 0.154, and the value of "c" varied between positive and negative values. Also, the stations in Table 8 represent rainfed agricultural areas (based on rainfall without irrigation), whereas the remaining regions rely on supplementary irrigation. As a result, the Calculations regarding the impact of climate droughts did not include these regions.

Table 8 Shows the productivity equation with drought.

	Y	Error	R^2	RMSE	MSE
Mosul	$0.72+0.13SPI-0.013\ SPI^2$	0.042	0.85	0.053	0.0028
	$0.69+0.11CZI+0.011\ CZI^2$	0.049	0.83	0.057	0.0032
Tal-Afar	$0.511+0.128\ SPI+0.001\ SPI^2$	0.135	0.65	0.095	0.009
	$0.507+0.154\ CZI-0.001\ CZI^2$	0.135	0.65	0.095	0.009
Sinjar	$0.65+0.122\ SPI-0.005\ SPI^2$	0.033	0.87	0.047	0.0022
	$0.66+0.129\ CZI-0.016\ CZI^2$	0.037	0.86	0.05	0.0025
Rabiah	$0.696+0.109\ SPI-0.0096\ SPI^2$	0.07	0.72	0.069	0.0047
	$0.707+0.123\ CZI-0.02\ CZI^2$	0.07	0.72	0.069	0.0047

Figure 8 shows spatial distribution maps illustrating the relationship between SPI and CZI drought indices in estimating productivity during mild, severe, and extreme drought conditions. For estimating productivity based on drought equations, three drought classifications (mild drought = -0.75, severe drought = -1.5, and extreme drought = -2.5) were selected from the Standard Precipitation Index and the Chinese Z index, according to [18, 19]. These values were used in the equations in Tab. 8. The results show that there is alignment between the drought indices in estimating productivity during mild and severe droughts, while the gap widens during periods of extreme drought, as shown in Figure 8. Finally, this relationship can contribute to planning and monitoring to estimate productivity and, thus, reduce crop yield losses in drought conditions.

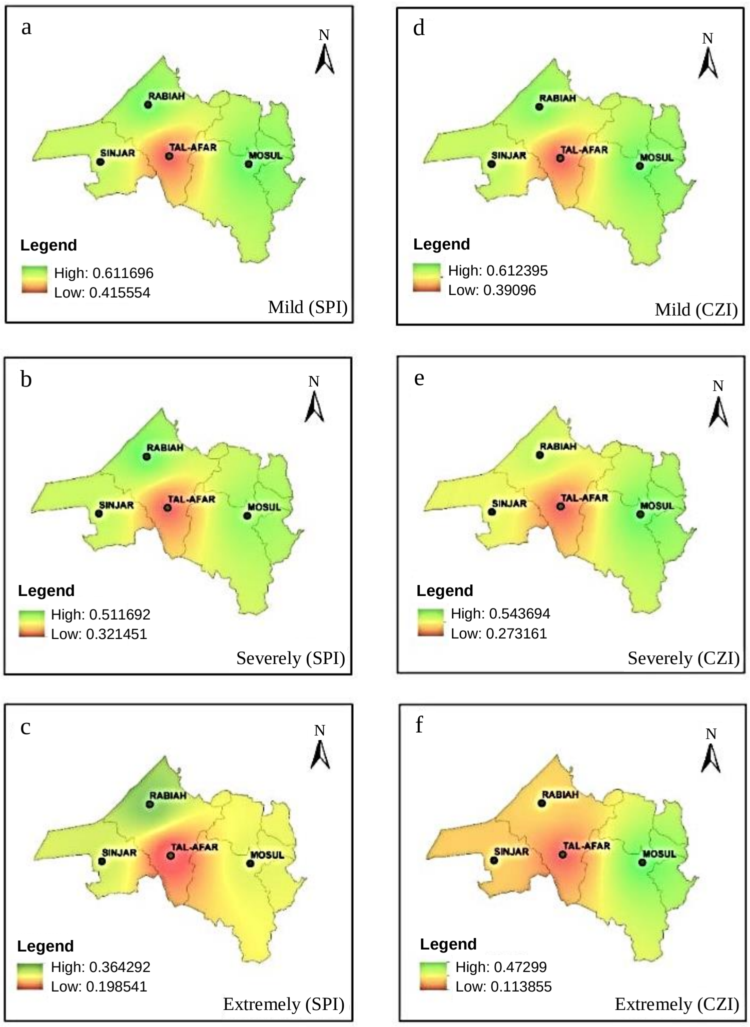

Figure 8 Spatial distribution of wheat yield, a: Mild dry (SPI), b: Severely dry (SPI), c: extremely dry (SPI), d: Mild dry (CZI), e: Severely dry (CZI), f: extremely dry (CZI).

5. Conclusion

This study explained that climatic drought affected the study area. A drought assessment was conducted for the period 1990–2020. The trend analysis results for climatic elements showed a nonsignificant decrease in rainfall at all climatic stations except for Shaikhan and Hamdaniyah. In addition, an ascending and significant trend was observed for maximum and minimum temperatures at most stations. The drought indices SPI and CZI showed that approximately half of the study months were dry and that the SPI and CZI matched well, particularly in determining the wet periods, with a slight difference in dry months, as shown in Figure 4. This finding agrees with the results of [28]. In addition to the determination coefficient, the R^2 values ranging from 0.84 to 0.94 between the two indices for 1 month falls within the percentages mentioned by [27]. It also showed that the highest recurrence rates of drought (recorded at the Tal-Abta) are 51.2% and 56% for SPI and CZI, respectively, whereas the lowest rates (recorded at Mosul, Sheikhan and Sinjar) are 45.1% and 50.8% for SPI and CZI, respectively. The highest value of drought was determined from the Tal-Afar station, reaching −4.8 and −3.5 for CZI and SPI, respectively. In addition, the maximum drought quantity was determined from Tal Abta station, reaching −14.3 for SPI, and from Tal-Afar station, reaching −14.7 for CZI. According to the drought indices, the study area experienced severe drought periods in the years 1998, 1999, 2000, 2007, 2008, and 2017. The climatic changes that Nineveh Governorate is going through and the suffering from poor rainfall distribution suggest that it is one of the most important agricultural areas and an important source of wheat crops in Iraq. The equations listed in Tab.8, illustrating the relationship between the two drought indices and productivity, are included in the first scientific studies that have established these relationships to determine crop yield.

Finally, the results showed that the general trend of rainfall and temperatures indicates the possibility of a decrease and increase in rainfall and temperatures, respectively. This finding means an increase in the likelihood of drought and, therefore, its impact on wheat productivity. Thus, efforts should be intensified to take proactive steps for mitigating the effects of climate change and environmental and agricultural degradation by increasing green spaces, adopting modern irrigation methods and using clean energy.

6. Acknowledgments

The authors express their gratitude to the College of Engineering at the University of Mosul for their assistance in carrying out the current study.

7. References

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