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Comparative analysis of NDVI and CHIRPS-based SPI to assess drought impacts on crop yield in Basrah Governorate, Iraq

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ABSTRACT
Drought is a climatological phenomenon that occurs across all climate zones of the world. It causes environmental and economic loss and can negatively affect agricultural profit, especially in dry and semi-arid areas. This study used the Standardized Precipitation Index (SPI) and Normalized Difference Vegetation Index (NDVI) to model drought impacts on agricultural production. The role of meteorological and hydrological parameters was considered simultaneously. The results revealed that: (1) the increase of drought intensity leads to the reduction of crop production, while in the case of high-level drought, the production stays consistent; (2) NDVI could model the impacts of drought on crops production (R^2 = 0.60 and RMSE = 0.42); (3) NDVI had a better ability for showing SPI fluctuations, but in higher drought intensities, it was less sensitive to SPI fluctuations; (4) the spatial pattern of drought in the study area showed that the northern parts of the Basrah Governorate have the highest sensitivity to drought; (5) the temporal pattern of long-term SPI showed a high level of risk for agricultural activities due to drought; and (6) air temperature and humidity are the main meteorological parameters of crops production affecting the interpretation of the impacts of drought on agriculture production in Basrah, Iraq.

Keywords: Basrah, Iraq, Crop yield, Drought, NDVI, SPI.

INTRODUCTION
Drought is a climatological phenomenon that can lead to an environmental disaster with greater consequences than many other disasters (Hagman *et al.* 1984). It is a serious and ubiquitous climatological phenomenon experienced in most of the world's climatic zones. Agriculture is often affected most upon the onset of drought due to its dependency on water resources and soil moisture reserves during crop growth (Narasimhan & Srinivasan 2005). Drought is one of Iraq's main current problems, which leads to erratic water supply and declining agricultural lands (Fadhil, 2013; Gaznayee & Al-Quraishi 2019; Almamalachy *et al*. 2020; Al-Quraishi *et al.* 2020). Consequently, migration from drought-affected agricultural lands, depletion of water in Iraqi rivers, declining marshes, soil degradation, increased salinity of surface water, and groundwater deterioration are intertwined phenomena affecting the agro-economy of Basrah Governorate of Iraq. The obvious symptoms of drought include the low levels of surface water flow, a decline of groundwater levels, drying of shallow wells, salinization of water and soil, deterioration of agricultural production, and increased frequency of sand and dust storms (Yaseen *et al.* 2016; Darvishi Boloorani *et al.* 2020a). For instance, in the hydrological year 2007-2008, there was a continuous high air temperature, and precipitation decreased by approximately 41%, compared to Iraq's long-term average rainfall. These led to a severe drought and land degradation (Fadhil 2011). These two phenomena consequently triggered very harsh dust storms in the subsequent years. Iraq is experiencing severe droughts due to the shortage of rainfall. The condition is exacerbated by non-developed irrigation and agricultural

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activities and water shortage in two main rivers, i.e. Tigris and Euphrates. All of these parameters are substantial drivers of the deficiency of agricultural production. Although drought is the most extreme natural hazard in Iraq, only a few studies have addressed this phenomenon. Several studies have indicated the need to investigate drought impacts on agricultural activities in Iraq (Al-Timimi & Al-Jiboori 2013 Yan *et al*. 2017; Beg & Al-Sulttani 2020). Drought spans wide spatial and temporal ranges from local to regional scales and from a few months to multiple years (Mishra & Singh 2010; Yan *et al.* 2017; Beg & Al-Sulttani 2020). Abdel-Hamid *et al.* (2020) assessed the impact of drought stress on grasslands using multi-temporal SAR data from Sentinel-1. Kibret *et al.* (2020) used MODIS EVI to map crop phenology, identify cropping systems, detect land-use changes, and measures drought risks. They proved the capability of high temporal resolution phenology data to identify the needs for agricultural inputs and emergency support in real-time, assess the drought risk, and monitor land-use dynamics. Numerous remotely-sensed indices have been developed to quantify, monitor, and map drought in relation to climatic factors (Alavipanah *et al.* 2016), e.g. Vegetation Condition Index (VCI) (Kogan 1990), NDVI (Wilhite, 2000), Temperature-Vegetation Drought Index (TVDI) (Sandholt *et al.* 2002), Vegetation Supply Water Index (VSWI) (Carlson *et al.* 1990), Normalized Differential Sand Dune Index (NDSDI) (Fadhil 2009), Temperature Vegetation Dryness Index (TVDI) (Du *et al.* 2017), Water Stress (WrS) (Darvishi Boloorani *et al.* 2020b) and Synthesized Drought Index (SDI) (Du *et al*. 2013). Buddenbaum *et al.* (2015) successfully applied the Photochemical Reflectance Index (PRI) to detect drought-stressed beech seedlings. The literature shows that further study is needed for this region. Therefore, this study aimed to investigate the drought impacts on agricultural activities. The main objective of this study was to model the impacts of drought on agricultural activities, mainly the winter crops, wheat, and barley in the Basrah Governorate of Iraq during 1991-2018, using multi-temporal and multisource datasets.

MATERIALS AND METHODS

Study area

Basrah Governorate is situated in the southern part of Iraq. It is located (Fig. 1) at the west bank of the Shatt Al-Arab (also called Arvand Rud in Iran, Fig. 1), consisting of the Tigris and Euphrates rivers confluence. It is located to the northwest of the Persian Gulf (Douabul *et al.* 2013). The study area covers the southern part of a sedimentary plain characterized by broad and low slope plains extending from north to south. Basrah has a continental and dry climate, with slight differences noticed in some areas. Normally, rainfall in the study area begins in October, increasing until May (Ismail 2019). In summer times, this area is under the control of tropical high-pressure systems leading to rain retention. Surface water is the leading available water resource for agricultural activities in the eastern parts of Basrah Governorate (sedimentary plains). Euphrates, Tigris, and Shat-Al-Arab are the main rivers of Basrah. Groundwater within the western plateau in this Governorate is the leading water resource for agricultural activities. The amount of water surplus varies from one season to another, while the crops' water requirements during the hot seasons are higher due to high evaporation and transpiration. For instance, in December and June, wheat water requirements are 39.4 and 299 (mm dec^{-1}), respectively. Similarly, in April and July, the tomato water requirements are 110.9 and 353 (mm dec^{-1}), respectively (Ewaid *et al.* 2019). Basrah has agricultural areas where cereals, palm trees, fruit, and vegetables are planted. Other types of vegetables and field crops are also cultivated (Hameed 2013). The agricultural sector is a vital component of Iraq’s economy in general and especially in Basrah. It is particularly the main source of livelihood for the sparse population, especially those who are experiencing food insecurity. The increase in the agricultural sector's contribution to Gross Domestic Product (GDP) from 4% in 2008 to 8.1% in 2010 shrunk to 7.6% in 2011 (Al-Haboby *et al.* 2014). Agricultural activities are still responsible for recruiting about 20% of the workforce, even after the decline of the GDP in 2008 (Al-Haboby *et al.* 2014). Droughts of the last decades have led the marshes to decline to the same size area recorded in 2003 (Mohamed *et al.* 2012). Iraq’s population increased by 77%, from 22 million in 1997 to 40 million in 2021, which has worsened the impacts of drought on agricultural activities in this country. This very sharp population growth is expected to exacerbate the effects of drought on food security in the future. It will result in more saline groundwater, migration, and agricultural land degradation (UNESCO 2014).

Datasets

Agricultural data

Annual cultivated wheat and barley crop areas and productions of each district of Basrah Governorate during 1986-2018 were obtained from the Ministry of Agriculture of Iraq. The total land area suitable for agriculture in

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Basrah is 67,411 hectares. Box plot test showed that the data from 1986 to 1990 are outliers and were eliminated from the next data analysis steps and the study focus on the 1991-2018 period. Wheat and barley were the major crops for 1991-2018, covering 66% (44,550 hectares) of the entire agricultural lands. Therefore, we selected wheat and barley as the representative crops to investigate drought impacts on the agricultural sector.

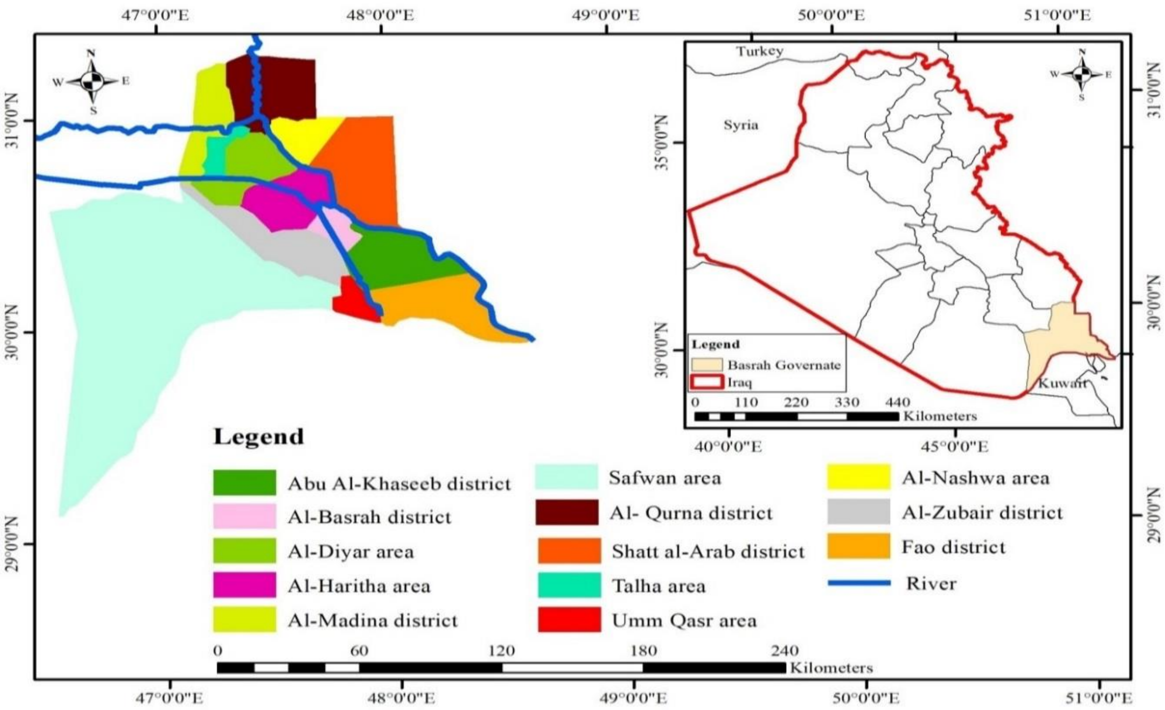

Fig. 1. Map of the study area in Basrah Governorate, Iraq.

Meteorological and hydrological data

Meteorological and hydrological data were obtained from the Ministry of Transport and Communications of Iraq. The meteorological data included monthly air temperature, relative humidity, and precipitation from Basrah station during 1991-2018. Air temperature in 2003 and precipitation in 2003-2004 were not recorded. The Tigris and Euphrates river discharge data were also collected during 1991-2018. Discharges in 2008-2014 and 2018 were not recorded.

CHIRPS precipitation

Due to the lack of well-distributed meteorological stations, satellite-based monthly rainfall data with a spatial resolution of 0.05 degree were obtained from the CHIRPS data (Funk *et al*. 2015). Using the Thiessen method, the study area was divided into 20 geographical polygons (as shown in Fig. 3, eight stations are located inside and 12 stations outside of the study area). The center of each of them (as the representative of the whole polygon) was used for collecting the CHIRPS precipitation data.

LANDSAT-NDVI

The 228 monthly-NDVI products of Landsat TM, ETM+, and OLI sensors (30 m of spatial resolution) were obtained from 1991 through 2018 (Chander *et al.* 2009). Band-specific gap mask files of Landsat 7 Level-1 images were used to eliminate the gap areas of the Landsat ETM+ images with the Scan Line Corrector (SLC-off) problem from 2003 to 2012 (Fig. 3A).

MCD12Q1 product

Yearly land cover products of MODIS with a 500-meter spatial resolution (Friedl *et al*. 2002) were obtained from 2001 to 2018. The MCD12Q1 product was used to determine the agricultural lands. World Geodetic System 1984 (WGS84) datum, UTM Zone 38N projection system, and GeoTIFF format were selected for all images and maps of this study. Table 1 shows the list of the research data.

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Table 1. Time-series data used in this study, including meteorological, hydrological, agricultural, and satellite base rainfall and Landsat-NDVI.

Data	Temporal resolution	Spatial resolution	Period	Description
Meteorological and hydrological data	Monthly	Governorate	1991-2018	Hydrological data during 2008-2014 were not available
CHIRPS-based rain data	Monthly	0.05 degree	1991-2018	20 stations for SPI calculation
Landsat-based NDVI	Monthly	30 m	1991-2018	The used ETM+ data of 2003-2013 had an SLC-off problem. We masked the gap areas of the images.
Census agricultural statistics	Annual	District	1991-2018	Data for the period of 1990-1991 were not reliable for data analysis.
MODIS product of MCD12Q1	Annual	500 m	2001-2018	Code 12: At least 60% of the area is cultivated cropland

Method

Fig. 2 describes the stepwise procedure used to model drought impacts on the agriculture sector in Basrah Governorate of Iraq, includes six steps: (1) identification of agricultural field by MCD12Q1 product of MODIS and NDVI of Landsat; (2) Collection of time-series data (from 1991 to 2018), including ground climatologic, and hydrological data, NDVI of Landsat remote sensing, CHIRPS rainfall data, and census agricultural statistics; (3) calculation of monthly SPI as drought indicator using CHIRPS data; (4) preparation and pre-processing of the monthly and yearly average of Landsat-NDVI for agricultural areas; (5) calculation of the production of wheat and barley for agricultural fields; and (6) analysis of the impacts of drought, hydrological, and meteorological parameters on agriculture production.

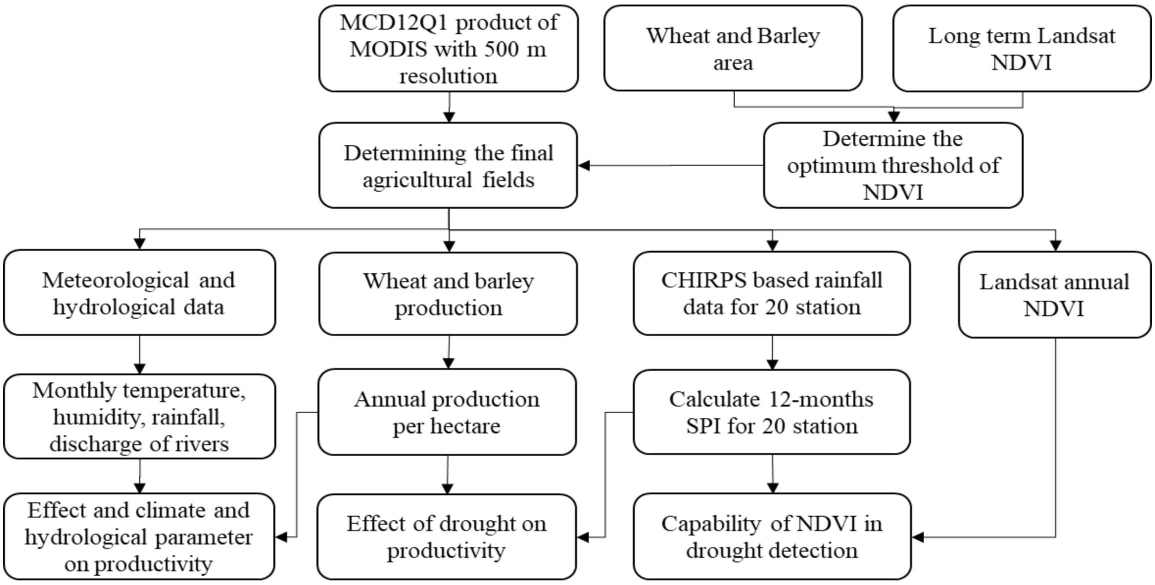

Fig. 2. Stepwise methodology procedure for analysis of drought impacts on agricultural activities.

Agricultural area determination

Cropland classes of MCD12Q1 yearly time-series were used as the base map for the demarcation of agricultural fields. In the first step, those pixels with negative values in NDVI extracted from Landsat images were eliminated as non-agricultural lands.

Then, pixels undergoing land-use changes from agriculture to other classes from 1991 to 2018 were also eliminated. Sensitivity analysis was carried out to test the robustness of the best performed NDVI for cultivated area determination, and the best result was reached at a threshold of 0.2 NDVI. Finally, the remained pixels (67,500 hectares) were labeled as agricultural fields. NDVI (Fig. 3A) and agricultural field map (Fig. 3B) show that there are no agricultural activities in the west and southwest of Basrah Governate. Therefore, these parts were not considered in SPI investigations for drought impact analysis.

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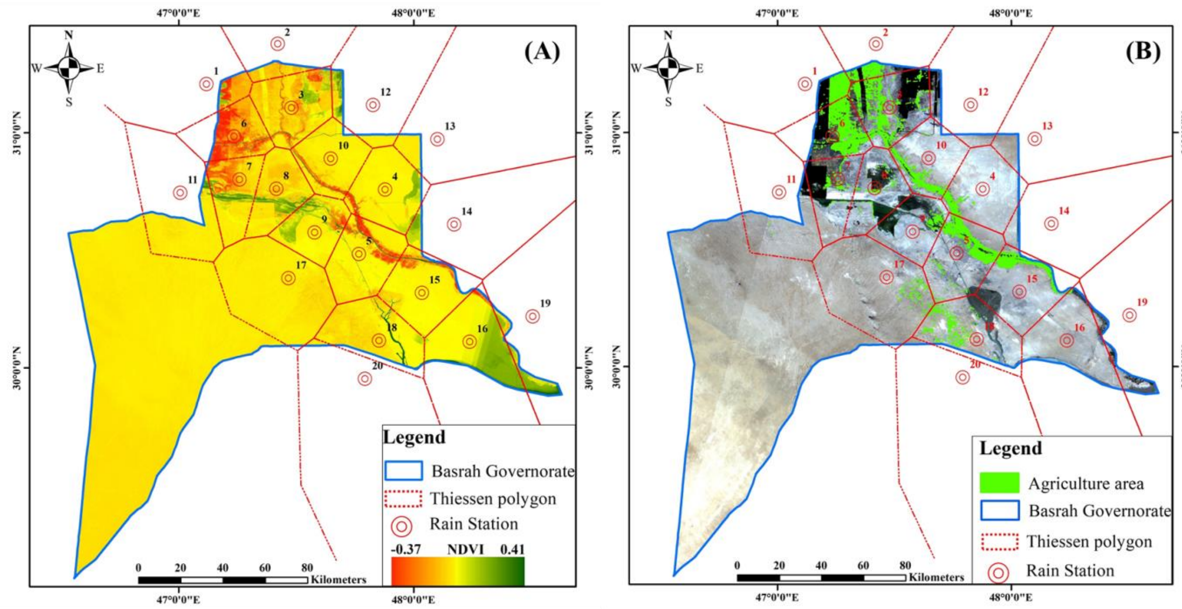

Fig. 3. (A) 28-year average of NDVI (1991-2018) and (B) selected agricultural fields.

Standardized precipitation index (SPI)

There are several drought indices based on ground data and satellite images. The Palmer drought index (Palmer 1965) and the SPI (McKee *et al.* 1993) are most often used in the USA, the Deciles index (Gibbs & Maher 1967) prevails in Australia, and Z-index in China (Wu *et al.* 2001). Other methods include the threshold level method (Yevjevich 1967), rainfall anomaly index (Van Rooy 1965), and the simplest method based on precipitation anomaly or percent of normal precipitation.

SPI is a widely used index to characterize meteorological drought in different timescales. The SPI is closely related to soil moisture on short timescales, while at more extended periods of time, it might be related to groundwater and reservoir storage (McKee et al. 1993). SPI expresses the actual rainfall as a standardized departure with respect to rainfall probability distribution function, and hence the index has gained importance in recent years as a potential drought indicator allowing comparisons across space and time (Abhilash *et al.* 2019). SPI values can be interpreted as the number of standard deviations by which the observed anomaly deviates from the long-term mean. McKee *et al.* (1993) used SPI to develop a classification system to define drought intensities. A drought event occurs when the SPI is continuously negative and reaches an intensity of -1.0 or less. The event ends when the SPI becomes positive. The positive sum of the SPI for all the months within a drought event can be termed the drought's "magnitude". In the present study, the DrinC software Ver. 1.71(91) (https://drought-software.com/) was used to calculate SPI values. Kriging interpolation was used to create the annual SPI maps (30-meter pixel size) for 20 meteorological stations to be used in the next steps of analysis.

Statistical analyses

The normal distribution of the yearly averages of agricultural meteorological and hydrological data was checked by Kolmogorov-Smirnov test. Pearson correlation was used to investigate the relationship between variables. Because of the small number of samples for validation, the Leave-one-out cross-validation was adapted. R^2 (Coefficient of Determination) and RMSE (Root Mean Squared Error) were used to evaluate the accuracy of the regression model to assess the drought from Landsat NDVI.

RESULTS

SPI

The SPI basic statistics for 20 stations were calculated from 1991 to 2018 (i.e. min -2.49; mean -0.024; max 2.42; StDev 0.337; range 4.91). Results showed high SPI differences across the study area. The long-term SPI average (i.e. 1991-2018) was -0.024; where, 1987, 1997, 2001, 2004, 2006, 2009, 2014, and 2018 showed the highest levels of SPI. Based on the classification system of McKee *et al.* (1993), the study area has a near-normal status

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of SPI. The analyses of long-term climatic, hydrological, drought-SPI, NDVI, and agricultural production revealed that 2008 was the driest and 2014 the wettest years in the Basrah Governorate during 1991-2018 (Fig. 4).

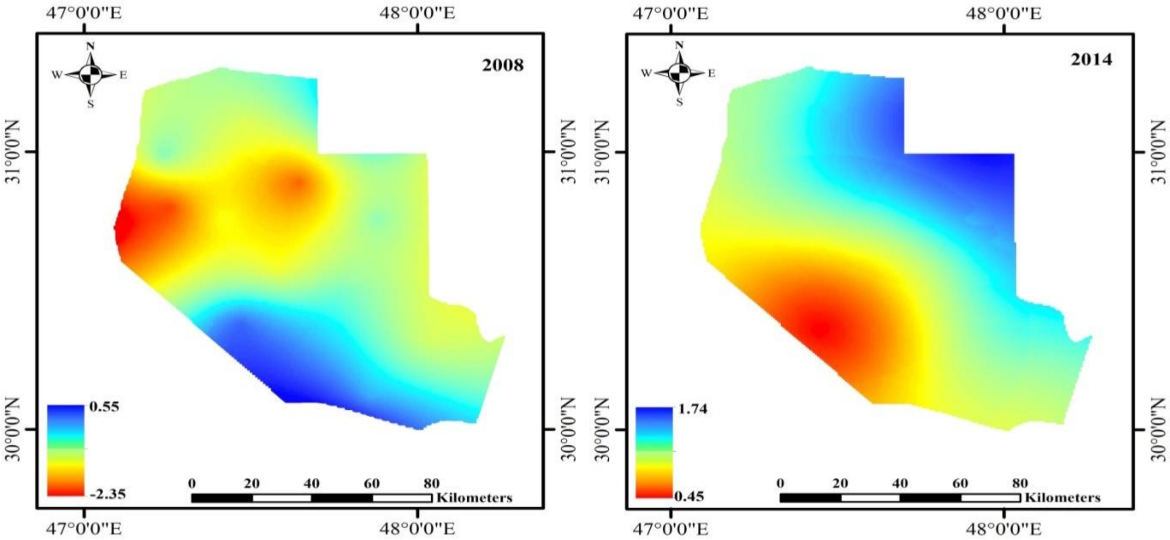

Fig. 4. SPI maps of Basrah Governorate in 2014 as wet and in 2008 as dry years (interpolated by Kriging).

Agriculture products

Annual croplands for wheat and barley and the amounts of crop productions of the study area are represented in Fig. 5. The wheat cultivation areas and productions in 1997, 2003, and 2014 experienced sudden increases. The statistical analysis results showed a very high deviation in the wheat planted area, which may be related to external parameters like drought on agricultural activities in the study area (Table 2).

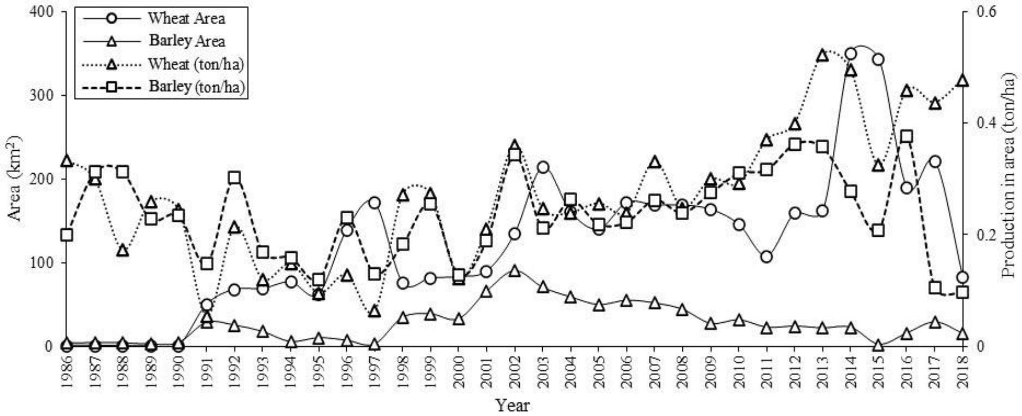

Fig. 5. The wheat and barley planted areas and production per area (ton ha^{-1}) from 1991 through 2018 in Basrah Governorate.

Table 2. Basic statistics of wheat and barley planted areas and productions in Basrah Governorate during 1991-2018.

Parameter	Species	Min	Mean	Max	StDev	Range
Area (km^2)	Wheat	62.01	147.93	350.16	72.48	288.14
	Barley	7.29	36.29	91.28	19.53	83.99
Production (ton)	Wheat	2367	18403.91	69467	14922.84	67100
	Barley	119	3188.37	12518	2570.94	12399

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Climate and hydrology

The Pearson correlation coefficient was calculated to investigate the relationship between the agriculture total productions and the average relative humidity, air temperature, precipitation, and river discharge in the study area (Table 3). The results showed negative (R = -0.42) and positive (R = 0.63) relationships between air temperature and relative humidity versus crop production. Air temperature and relative humidity were essential parameters affecting crop production and agricultural areas across the whole governorate.

Table 3. Pearson's correlation between crop production and land areas versus climate and hydrological parameters.

Parameter	Statics	Precipitation (mm)	Discharge ($m^3 s^{-1}$)	Temperature (°C)	Humidity (%)
Production (ton)	Pearson correlation	-0.268	-0.231	-.420*	.626**
	sig. (2-tailed)	0.186	0.357	0.033	0.001
Cultivated area (km^2)	Pearson correlation	-0.161	-0.154	-.426*	.642**
	sig. (2-tailed)	0.432	0.541	0.030	0.000

** Correlation is significant at the 0.01 level (2-tailed).

* Correlation is significant at the 0.05 level (2-tailed).

NDVI

The average monthly and annual NDVI for agricultural lands is shown in Fig. 6. The study area has a dry to semi-arid condition; the NDVI saturation did not reveal limitations in the present study. The minimum NDVI values were observed in 2008, while the highest was in 2014. The annual NDVI in 2008 and 2014 are shown in Fig. 7.

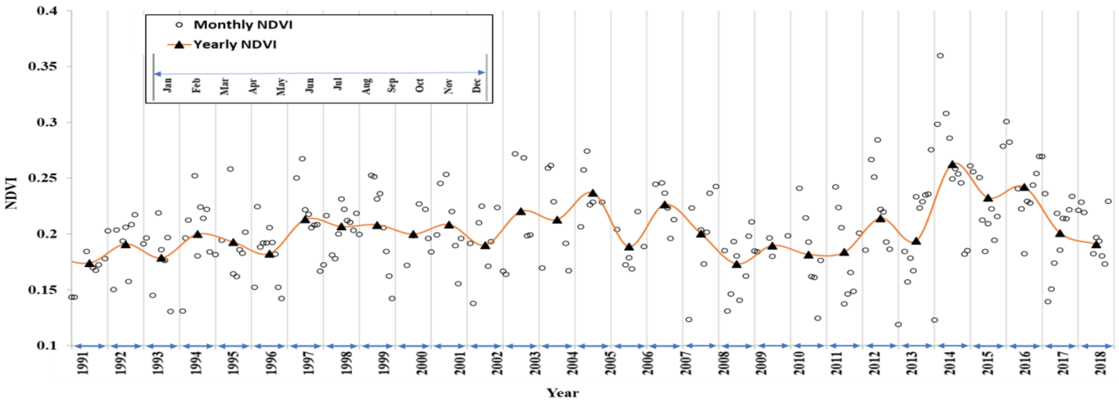

Fig. 6. Average annual and monthly NDVI for the agricultural areas in Basrah Governorate.

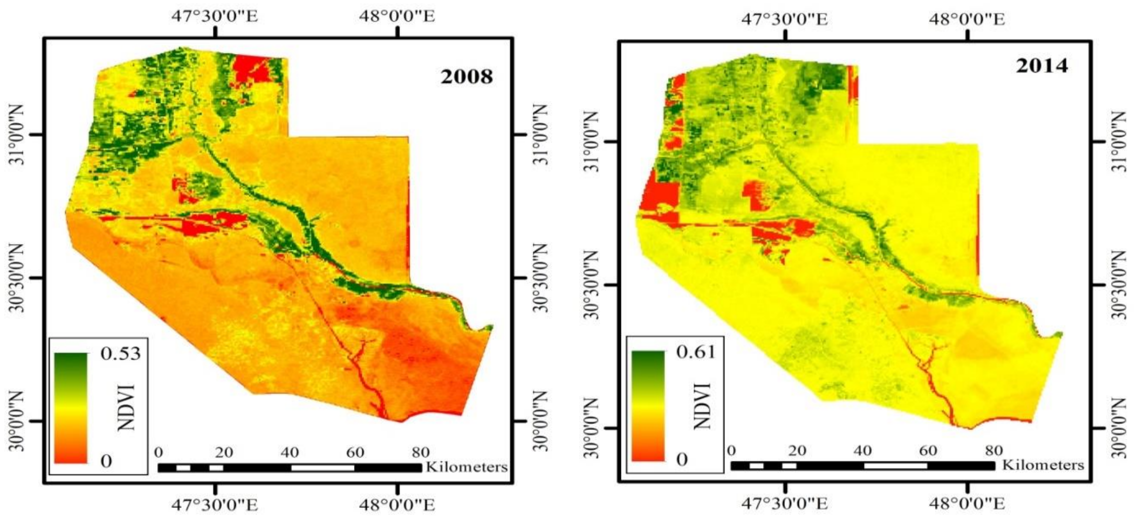

Fig. 7. Averaged annual NDVI in 2014 as a wet (high NDVI) and in 2008 as a dry (low NDVI) years.

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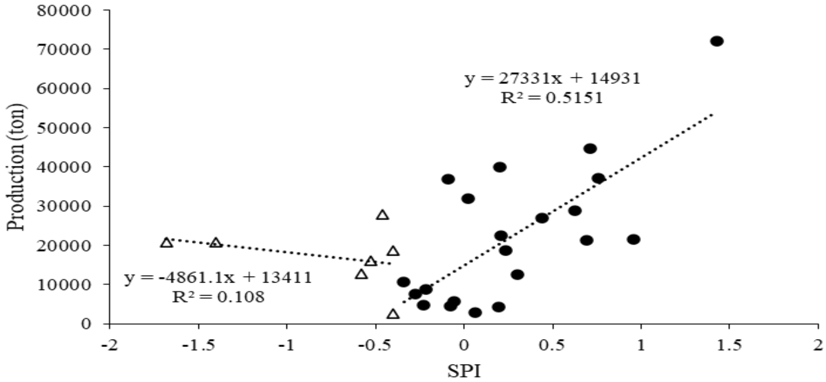

Fig. 8. The statistical relationship between crop production and SPI of Basrah Governorate during 1991-2018.

The annual mean of NDVI for agricultural fields and SPI for 20 stations during 1991-2018 are shown in Fig. 9-A. Using the Cross-Correlation sequence method (Bracewell, 1965), the similarity of NDVI and SPI temporal patterns was estimated at 60%. The SPI maximum values were obtained for 2014 and minimum values in 2008 and 2010, as an obvious indication of the drought harshness in those years. Fig. 9-B shows the relationship between annual NDVI and SPI for agricultural lands, where in the areas with low NDVI, there is a strong linear relationship between them. However, the SPI behavior is saturated for the areas with higher NDVI and shows a non-linear relationship between them. Therefore, a non-linear regression curve was fitted for these cases.

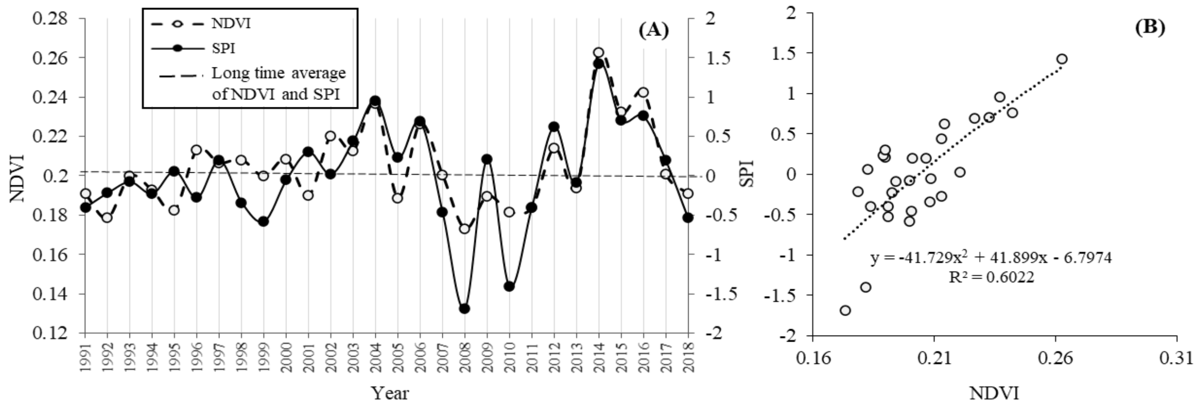

Fig. 9. (A) Averaged annual NDVI and SPI for agricultural areas of Basrah Governorate during 1991-2018; (B) The statistical relationship between NDVI and SPI for agricultural areas of Basrah Governorate during 1991-2018.

DISCUSSION

Statistical analyses (Table 2) show that crop production in Basrah Governorate had witnessed a high standard deviation (about 80% from average). One or more effective elements causing this variation and drought were hypothesized as the present study's effective elements. Furthermore, to understand the role of meteorological and hydrological parameters in agricultural production, these parameters were considered simultaneously. Agriculture in Basrah with a hot and dry climate (Salman *et al.* 2017) is susceptible to the effects of temperature changes. The optimal ecological temperature for growing wheat and barley are 20°C and 25°C, respectively (Al-Saadi 1998). Temperature and relative humidity showed a significant relationship with production (Table 3). Between 1991 and 2013, the temperature and relative humidity witnessed increasing and decreasing trends, respectively, both of them relating to the decreased crop production. On the contrary, from 2014 to 2017, the entire governorate witnessed higher relative humidity and lower temperature compared to the long-term means of both parameters. Consequently, a simultaneous increase in crop production and relative humidity was observed. When the SPI was below -0.5, no specific changes were observed in crop production, whereas, when the SPI was positive, increased SPI led to increased production. The results showed that drought would linearly reduce crop production. There are exceptions at the severe droughts (like in 2008) that a minimum crop production always exists in the study area. This could be interpreted in relation to the use of river and ground waters for agriculture production. Comparing NDVI values with SPI showed a high temporal correspondence (60%) for the whole study period. The years 2008 and 2010 were cases of concurrent low NDVIs and SPIs. In these years, the temporal pattern of NDVI

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was not normal. For instance, the maximum and minimum NDVIs in 2008 were observed in November and March, respectively, which does not match the crop cultivation calendar (Fig. 6). In the years with SPI lower than -0.5, the NDVI reduction was not evident (Fig. 9B). Since the Basrah agricultural lands were not equally distributed in the entire Governorate, spatial analysis of drought impacts on agriculture is also important but more complicated than the temporal analysis of the phenomenon. Most of the agricultural lands are located in the north and northeast of Basrah (Fig. 3B). Therefore, drought impacts were more observable in these regions. For instance, based on SPI analysis, the study area experienced extreme drought in 2008 (Fig. 9A), where the entire Governorate and especially the northern parts experienced severely dry and extremely dry conditions, where the main agricultural activity was undertaken.

CONCLUSIONS

In this study, NDVI-SPI analysis was used to model the effect of drought on agricultural activities. Furthermore, to understand the role of meteorological and hydrological parameters in agricultural production, these parameters were used simultaneously. In conclusion, the main experimental results of this study state that (1) air temperature and humidity are the main influential meteorological parameters of crops production, while the discharge of rivers had a constant role for the minimum level of agriculture production in the study area; (2) the increased drought intensity led to reduction of crop production, but in the severe droughts (SPI < -0.5), the production rate was constant; (3) using a non-linear relationship, the NDVI temporal analysis could model the impacts of drought on crops production; (4) in the cases with high SPI (i.e. lower drought intensities), NDVI had a better ability for showing SPI fluctuations, but in higher drought intensities, it was less sensitive to SPI fluctuations; (5) The Basrah long-term SPIs showed a high level of risk for agricultural activities due to drought, while the northern parts of the governorate had the highest sensitivity to the phenomena. Based on the obtained results of this work, NDVI time-series data is recommended for monitoring drought impacts (with SPI > -0.5) on agriculture in a dry and semi-arid region like Basrah, Iraq.

Authors' contribution

The study conceptualization and methodology were developed by Ali Darvishi Boloorani, Ayad M. Fadhil Al-Quraishi, and Farshad Amiraslani. The software analyses were implemented by Raheem Attafi and Ayad M. Fadhil Al-Quraishi. Results validation was performed by Raheem Attafi, Ali Darvishi Boloorani, Ayad M. Fadhil Al-Quraishi. The investigation was done by Raheem Attafi and Ali Darvishi Boloorani. Resources were prepared by Raheem Attafi. Data curation was done by Raheem Attafi and Ayad M. Fadhil Al-Quraishi. The original draft of the paper was prepared by Raheem Attafi, Ali Darvishi Boloorani, and Ayad M. Fadhil Al-Quraishi. The manuscript was edited and reviewed by the team. Visualization was done by the team, and Ali Darvishi Boloorani was the project manager and supervised the group.

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