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Evaluating Water Scarcity Indices for Cultivation Region in Sadat Al-Hindya, Babylon, Iraq: A Case Study

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Abstract

The study evaluated the Water Scarcity Indices for Cultivation Region in Sadat Al-Hindya, Babylon, Iraq. It calculated the reference evapotranspiration, actual evapotranspiration, and amount of precipitation with effective rainfall to estimate the droughts indicators which are the Standard Precipitation Index (SPI), the Standard Precipitation and Evaporation Rain Index (SPEI) and Reconnaissance Drought Index RDI. The study indicated that the greatest decrease in river flow occurred from 2019-2021 to 2020-2021 due to increasing temperature in summer and decreasing precipitation in winter. This research evaluated a wet and drought indicating for planning and management of water resources to face changes in climate of future. The research showed the last years were years of drought according to the three indicators. SPI ranged from 0.5 to 1.5 in the rainy years, but it was −0.5 to −1 as moderately dry because in the middle of Iraq while in the south of Iraq was severely dry or extremely dry. SPEI of the study area ranged from −1.5 to −2.5 which means severely dry. The SPEI measures are negative values meaning the months and years were drier. RDi ranged from 0 to −1 was dry and moderately dry while some months and years are positive and will be wet through rainfall for ten years (2014-2023). From indices showed that the region was a drying study area due to the impact of climate change because of the reduction of precipitation and increase in temperature which caused a rise of evapotranspiration during the last few years.

Keywords

Drought Indices, Evapotranspiration, Precipitation, Climate Change

1. Introduction

Drought is a frequent natural phenomenon, but climate change may increase severity of water scarcity. The researchers compared three commonly utilized meteorological drought indices, which were standardized precipitation index (SPI), standardized precipitation evapotranspiration index (SPEI) and reconnaissance drought index (RDI). All drought indices identify the main droughts; however, the severity of dehydration varies according to the indicator used. SPI and SPEI are flexible and often best correlated with stream flow [1]. The drought indicators improve monitoring and impact assessment. It was using a new methodology, a Bayesian network. There are several advantages to this proposed method: it combines information from multiple drought indices and comes out with a better estimate of drought severity; rather than a deterministic outcome of drought severity from individual indicators, it provides probabilistic estimates of drought severity [2]. This drought index that considers drought impacts on cultivation, hydrological, and stream health categories. Additionally, predictive drought models were developed to capture both categorical and overall impacts of drought. The analysis was performed to find three indices in each category. After that drought indices were averaged in each category to create the drought result. Finally, the drought results were simply averaged to develop the MASH drought indices. The results of this research can assist managers to best the position resources to cope with drought via education drought impacts on various sectors [3]. The Reconnaissance Drought Index (RDI) was applied to assess the properties of the meteorological drought in India. RDI utilized via many researchers to identify the drought properties suited to arid and semi-arid regions. The RDI utilized precipitation and potential evapotranspiration (PET) and analyses the climate change effecting on the drought scenario. The drought found very high [4]. The different of drought indices for the humid, semi-arid and arid areas of India were analyzed using SPI and RDI. In SPI, arid areas had seven droughts. In the case of RDI, the humid and semi-arid regions had eleven drought years. SPI and RDI are different because RDI is considered as potential evapotranspiration, and hence, correlation with plants would be better in case of RDI. SPI and RDI were found to be well correlated with respect to three months rainfall data and SPI values led to prediction of annual RDI [5]. The droughts in the arid region of Iran and assessed via SPI to predict the prediction of precipitation, temperature, and the type of indices. The drought indices showed drier conditions in the future period 2006-2042 [6]. That Fluctuations of rainfall cause drought via various severities that imposes extensive damage on environmental and economic condition of regions. They presented drought indices, and the advantages and disadvantages related to each index discussed enabling policy makers to manage drought effectively [7].

Previous literature and our current study provide a clear picture of the impact of climate change on the regions of Iraq. Drought indicators are evidence of the presence of drought in these regions. They help in researching drought resistance in several ways to resist drought and searching for ways to reduce the impact of climate in these regions. This study and the studies that were mentioned are an indicator or warning of the presence of drought that must Addressing it or researching and studying to address it, which is an evaluation indicator for these areas. The study is unique in its study of drought indicators in Iraqi cities. The aim of this study is to evaluate the water scarcity indices for areas with impact of climate change which caused decreasing of rainfall and increasing of temperatures also comparing with ten years (2014-2023) through twelve months.

2. Material and Methods

2.1. Area of Study

The study was carried out in Sadat Al Hindya town belong to Hilla City at Babylon governorate. The research zone is far away 100 Km South of Baghdad Capital and 30 km from Karbala governorate also 30 km from Babylon governorate. The site is located at 32˚35'33"N and longitude 44˚20'24"E, and altitude: 31 m. **Figure 1** shows satellite image to site of study area by ArcMap.

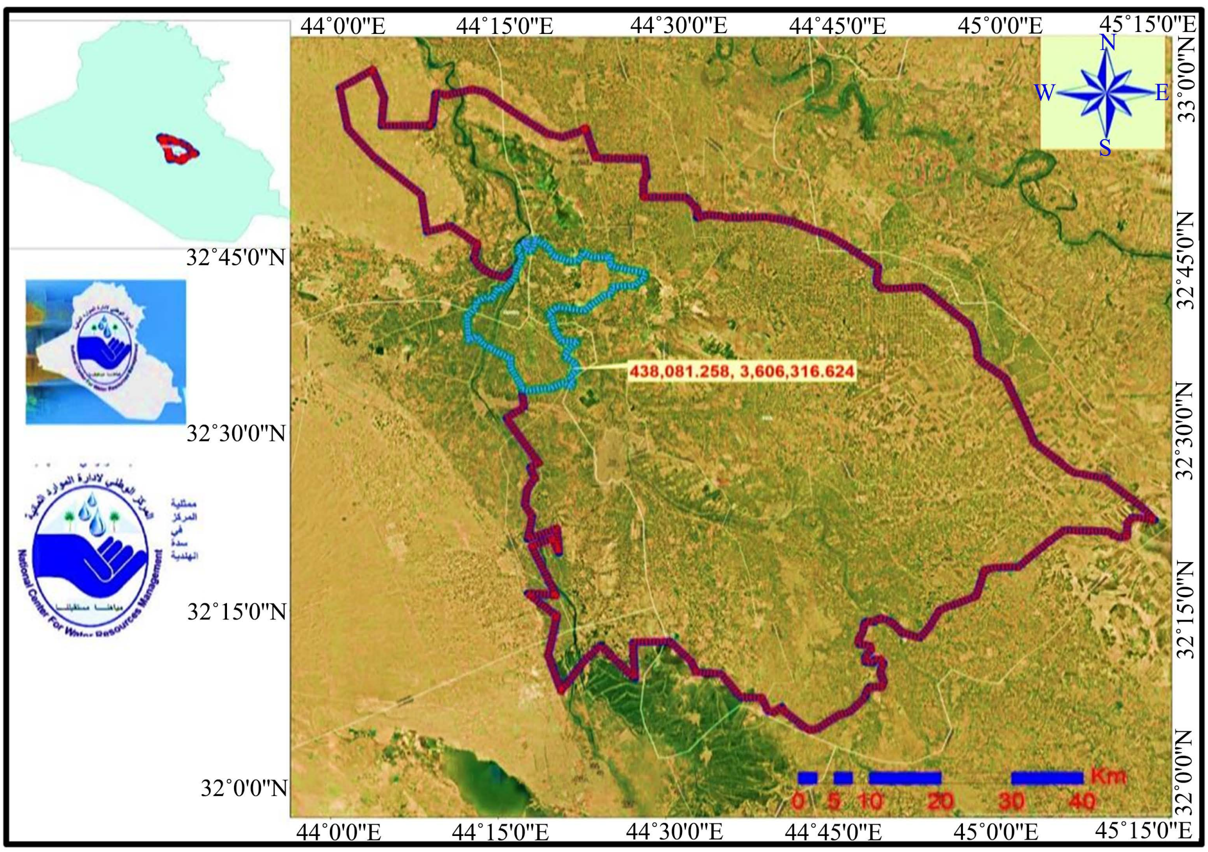

Figure 1. Satellite image of study area by Arc map.

2.2. Methodology of Research

The main drought drivers are temperature, radiation, wind speed and relative humidity/vapour pressure. These drought drivers are associated with meteorological, agricultural and/or hydrological droughts. A few drought indices can be used to identify drought events.

2.2.1. Standardized Precipitation Index (SPI)

The most common drought index is the standardized precipitation index (SPI) and has been widely studied [2] [8]. The SPI index represents the deviation of precipitation from the long-term average; negative values indicate below average "dry periods and positive values indicate above average precipitation," wet periods. The index helps to find different types of droughts, as precipitation is the key climatic variable upon which SMD, stream flow and groundwater recharge depend. Therefore, it could easily be used to quantify the severity of both dry and wet events. The SPI index scale values are above 2.0 extremely wet, 1.5 - 1.99 very wet, 1.0 - 1.49 moderately wet, −0.99 to 0.99 near normal, −1.0 to −1.49 moderately dry, −1.5 to −1.99 severely dry and −2.0 and less, extremely dry [8]:

$$\text{SPI} = \frac{Xi - \mu}{\sigma} \tag{1}$$

where, xi is the precipitation of the selected period during the year i, is the long term μ is mean precipitation and σ is standard deviation for the selected period.

In this research, SSbop pyithon code was used and ETa was extracted via Arc-GIS 10.8 Program as working by the researcher about carrot crop in reference [9].

2.2.2. Standardized Precipitation Evapotranspiration Index (SPEI)

Another drought index is the standardized precipitation evapotranspiration index (SPEI) which is a multi-scale drought index, sensitive to global warming. This index has been widely applied in different parts of the world [10] [11] to study meteorological and agricultural droughts also impacts of drought on vegetation health. The equation used to calculate SPEI is based on the study by [12] Thornthwaits (1948):

$$\text{Di} = \text{Pi} - \text{PETi} \tag{2}$$

where Di is the difference between the precipitation (P) and the potential evapotranspiration (PET) for a particular month. The SPEI drought index takes both precipitation and PET, therefore unlike the SPI, this drought index captures the impact of increased temperature on water demand including irrigation. The aim of applying this index was to measure the water surplus or deficit for the analyzed period. Like the SPI, a negative value shows dryness and a positive value shows wetness, relative to the long-term average (Thornthwaits 1948). This drought index has been applied in several studies later [13] [14].

2.2.3. Reconnaissance Drought Index (RDI)

A third key drought index used in this study was the reconnaissance drought index (RDI) which is based on the studies of [15] Tsakiris *et al.* (2007) and [14] Mahmoudi *et al.* (2019). The standard RDI is calculated using the ratio of total precipitation (mm) to total potential evapotranspiration (mm) over a certain period. It is a good indicator for describing agricultural, hydrological, and meteorological droughts. The RDI was calculated as:

$$a_0^{(i)} = \frac{\sum_{j=1}^{12} Pij}{PRT \text{ or } AEij} \quad (3)$$

$$RDI_n^i = \frac{a_0^{(i)}}{\bar{a}} - 1 \quad (4)$$

$$RDI_n^i = \frac{y_k^{(i)} - \bar{y}_k}{\sigma yk} \quad (5)$$

$$Pe = 0.8 * P - 25 \quad \text{for } P > 75 \text{ mm/month} \quad (6a)$$

$$Pe = 0.6 * P - 10 \quad \text{for } P < 75 \text{ mm/month} \quad (6b)$$

a_0 is a value of dividing the precipitation and evapotranspiration (potential or actual) with P = rainfall or precipitation (mm/month), Pe = effective rainfall or effective precipitation (mm/month) NOTE: Pe is always equal to or larger than zero; never negative, Brouwer and Heibloem 1986 (FAO 86) [16].

Where Pij and $PETij$ are the precipitation and potential evapotranspiration or $AEij$ actual evapotranspiration of the jth month of the ith hydrological year (starting from October) respectively, and $\bar{a}$ in Equation (4) is the arithmetic means of the a_0 calculated for the number of years. In the above equation y_k is the ln($a_0^{(i)}$), $\bar{y}_k$ is its arithmetic mean and σyk is its standard deviation. This method is widely accepted and applied, as it calculates the aggregated deficit between precipitation and atmospheric evaporation demand. The method is directly linked to the climate conditions of a region and is comparable to the aridity index [15] [17]. In addition to the conventional way of calculating RDI, an adjusted RDI was calculated using the net rainfall (gross rainfall minus rainfall interception losses by the canopy cover) and actual evapotranspiration.

- Calculation the SPEI by site and model of SPEI Global Drought Monitor (https://spei.csic.es/map).
- Estimation of the Eta by two methods (one method is using SSebop to energy balance and second method by WAPOR method) also ETp and rainfall were quantified by WAPOR method. Some data of rainfall collected from Al-Hindya barrage project to 2 years. And collection of all types of data to estimate the drought indices.
- Compare the result with ten years and twelve months to all indicators to find the values which drier in the study area and more drier.

3. Result and Discussion

Monthly Actual evapotranspiration (Eta) values were measured by using a remote sensing by two methods. The ETa, potential monthly evapotranspiration (ETP) and rainfall we used of WAPOR by downloaded the data We have downloaded Raster images of (ETo) product from WAPOR also the second method via the SSEBop model is based on Python language code, and we used the IDLE Version 3.1.10 to utilize the code. Monthly ETa calculated were used from available ETf values to satellite over pass date also calculation the effective rainfall from precipitation as well as from Sebop we can calculate (Normalized Difference Vegetation Index) NDVI and land surface temperature (LST) as shown in **Figures 2-5** shows the SSbop pyithon code with and extraction the ETa via Arc-GIS 10.8Program as working by the researcher about carrot crop in reference. The Penman-Monteith equation [18] predicts the rate of total evaporation and transpiration using commonly measured meteorological data (solar radiation, air temperature, vapor pressure and wind speed) [18].

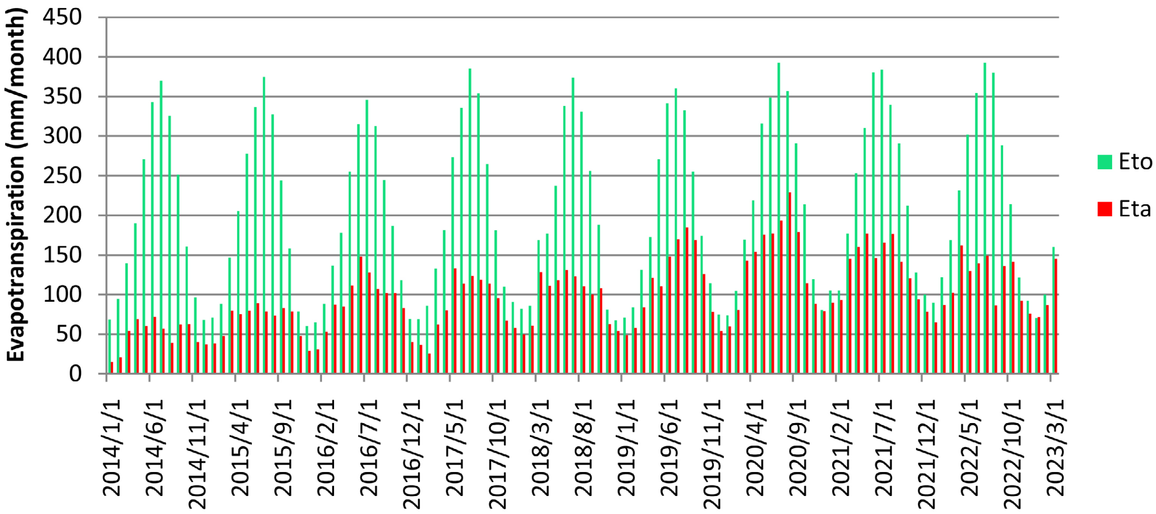

Figure 2. Calculation monthly ETo and ETa from 2014 to 2023.

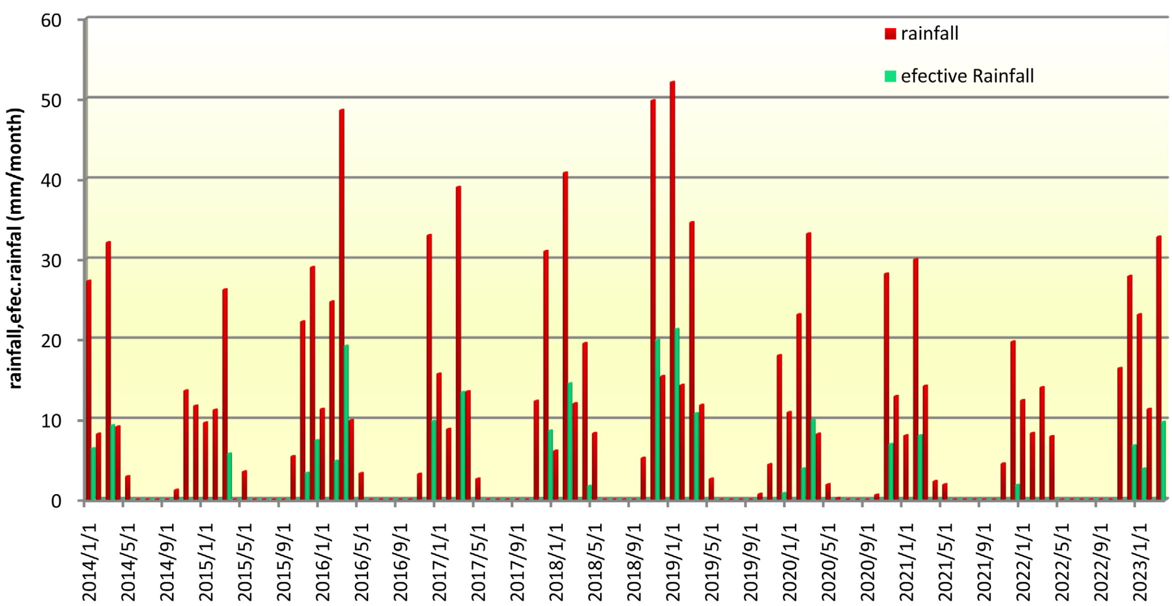

Figure 3. Estimation monthly rainfall and effective rainfall.

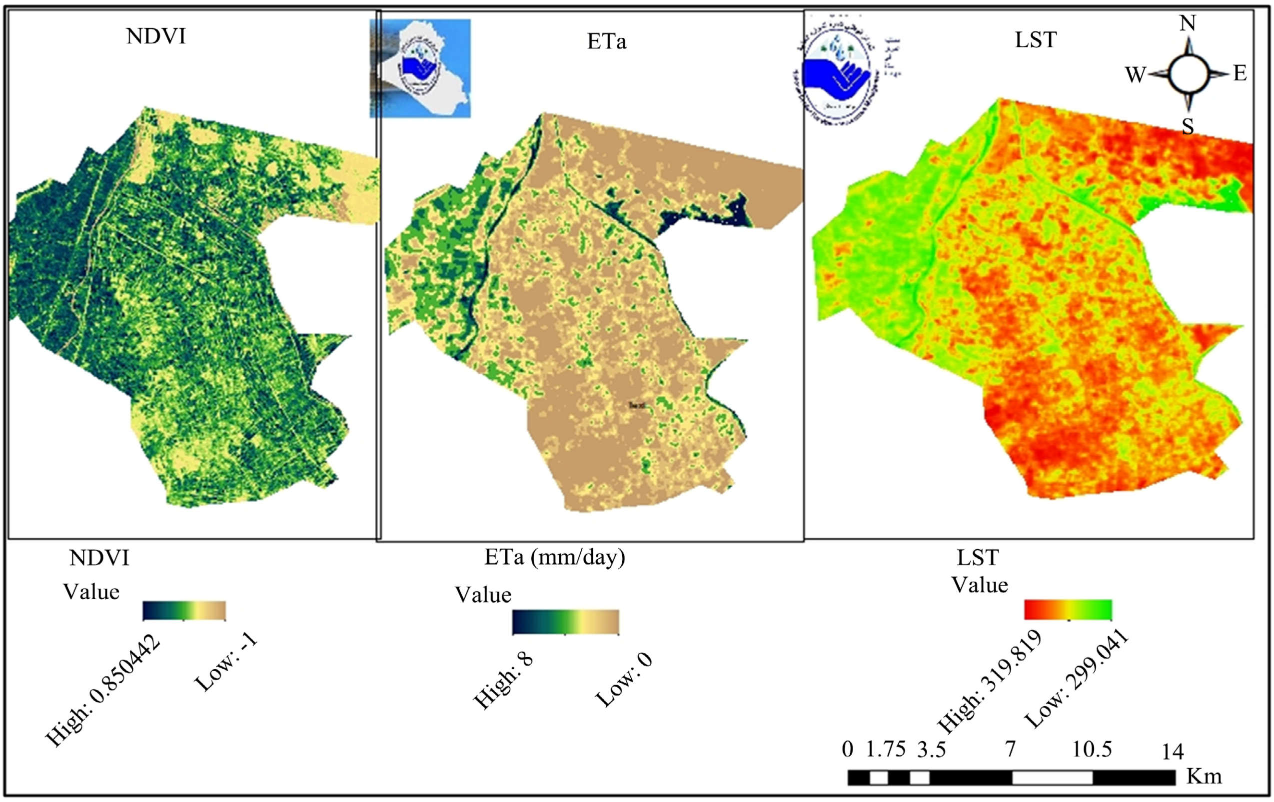

Figure 4. Sample shows Quantifying the LST, NDVI and ETa.

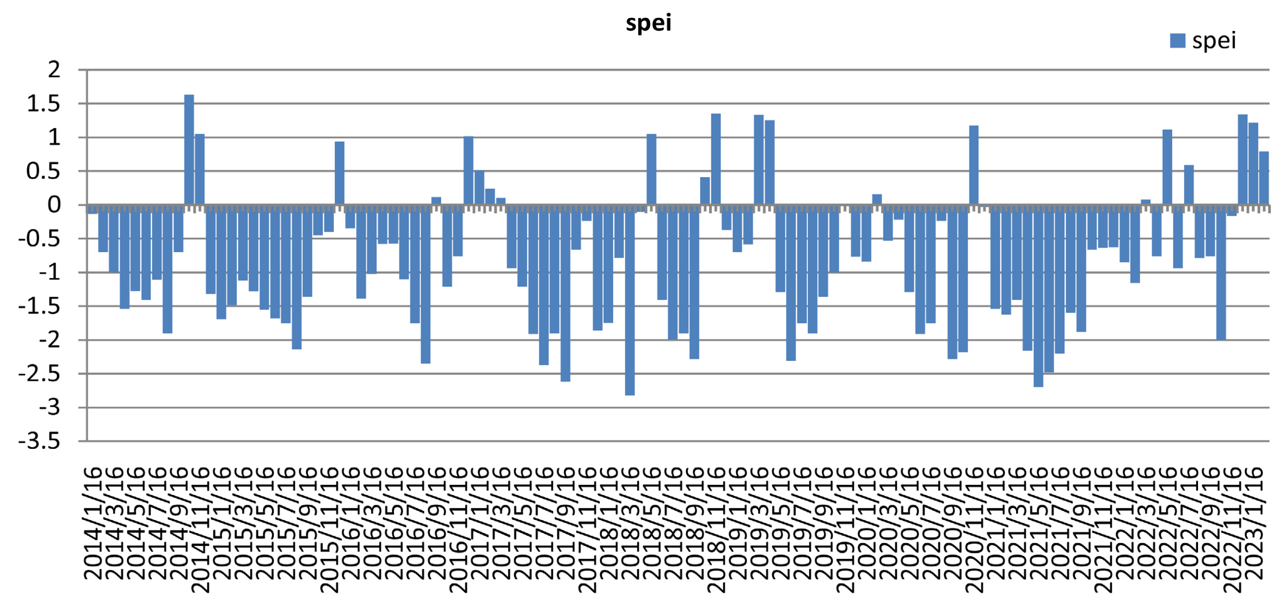

Figure 5. Value SPEI with year from 2014 to 2023 ([19]).

3.1. Evaporation, Transpiration, and Interception/Description

The actual Evapotranspiration and Interception (ETIa) is the sum of the soil evaporation (E), canopy transpiration (T), and evaporation from rainfall intercepted by leaves (I). The value of each pixel represents the ETIa in a given month. The method to calculate E and T is based on the ETLook model which was described by [20] Bastiaanssen *et al.* (2012). It uses the Penman-Monteith (P-M) equation, adapted to remote sensing input data. The Penman-Monteith equation predicts the rate of total evaporation and transpiration using commonly measured meteorological data (solar radiation, air temperature, vapor pressure and wind speed). It has become the FAO standard for calculating the actual and reference evapotranspiration. FAO irrigation and drainage paper 56 [17] describes the method in detail. The reader is advised to consult this document for detailed information on the use of the P-M equation and guidelines regarding the calculation of evapotranspiration. ETa calculation to evaluate evaporation and transpiration in region area same as carrot crop in reference [21].

3.2. Reference ET/Description

Reference evapotranspiration (ETo) is defined as the evapotranspiration from a hypothetical reference crop. It simulates the behaviour of a well-watered grass surface and can be used to estimate potential ET for different crops by applying predefined crop coefficients. This information can be used in the design of irrigation schemes. Together with estimates of the evaporation transpiration and interception, crop coefficients may be derived as the ratio between ETIa and RET. This information may be combined with land cover maps, to infer crop coefficients during the growing season for different types of crops. RET is not influenced by land cover and can be calculated using standard weather measurements and solar radiation. ETo is calculated in a similar way as evaporation and transpiration, applying the Penman-Monteith equation. The main differences are that for calculating RET some of the variables are predefined (*i.e.*, crop height, bulk surface resistance and albedo) and E and T are not calculated. The estimation ETo is calculating by WAPOR site [22].

3.3. Precipitation Data/CHIRPS

Precipitation data delivered daily. The source of this dataset is CHIRPS (Climate Hazards Group InfraRed Precipitation with Station) quasi-global rainfall dataset and CHIRPS uses the Tropical Rainfall Measuring Mission Multi-Satellite Precipitation Analysis version 7 (3) starting from 1981 up to near present. The value of each pixel represents the total of daily precipitation in the month expressed in mm (1 mm = 1 l/m^2 or 1 mm = 10 m^3/ha) [23].

SPEI calculated by SPEI Global Drought Monitor site [19], which depends on ETo and precipitation, also location of point from latitude and longitude as well as time (month and year) and downloaded excel sheet, see **Figures 5-8** and depending on **Equation (2)**.

The Reconnaissance drought index is explained in **Table 1** and **Figure 9** which depending on **Equations (3) - (5)** we result on RDi from ETo and rainfall also we obtain on Rdist depending on logarithmic data as well as adj RDi depending on ETa and effective rainfall (Pe) also adj. Rdist depending on logarithmic data of ETa and PE.

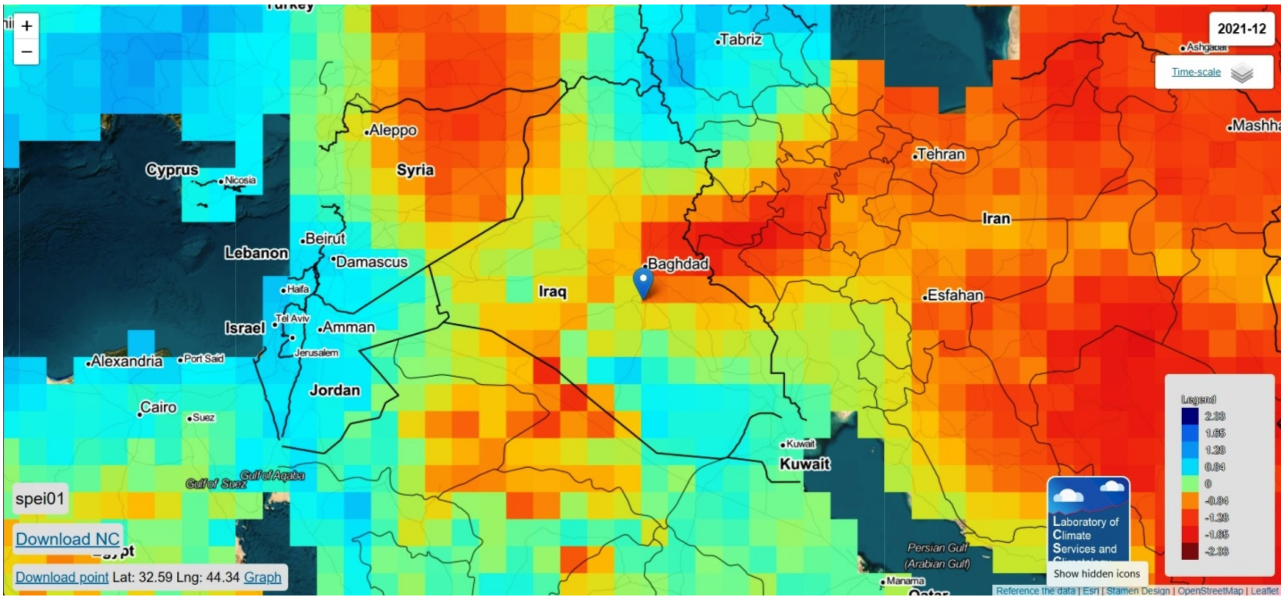

Figure 6. Map of SPEI for Iraq and neighbor countries [19].

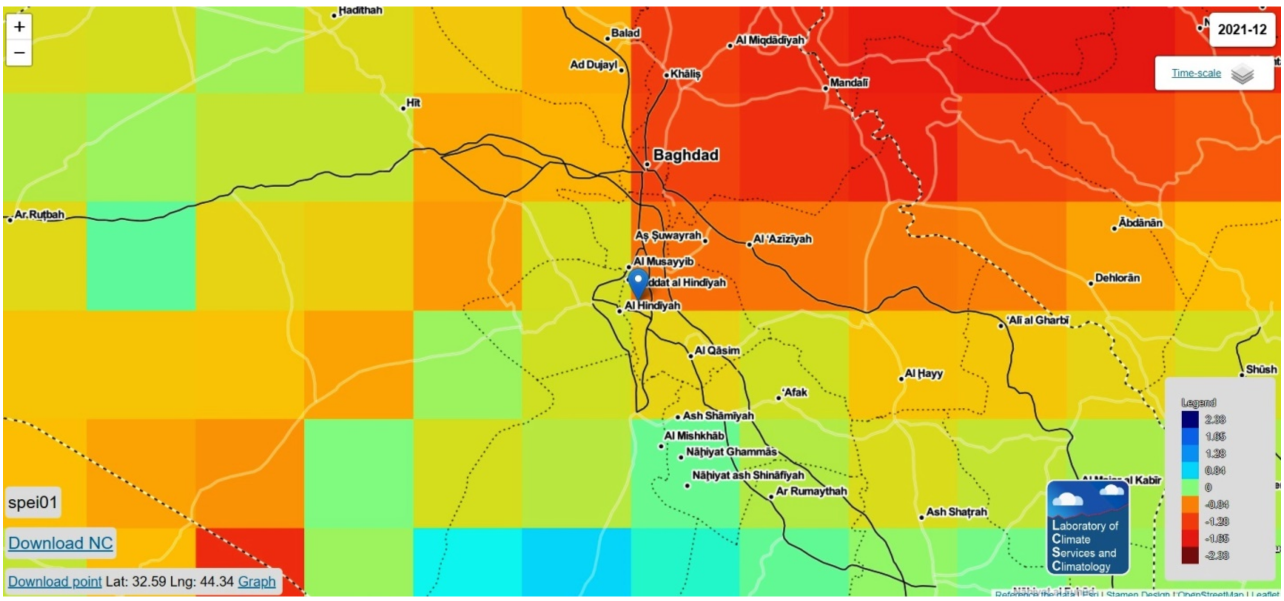

Figure 7. Map of SPEI for Sadat Alhindiya site with neighbor cities as raster [19].

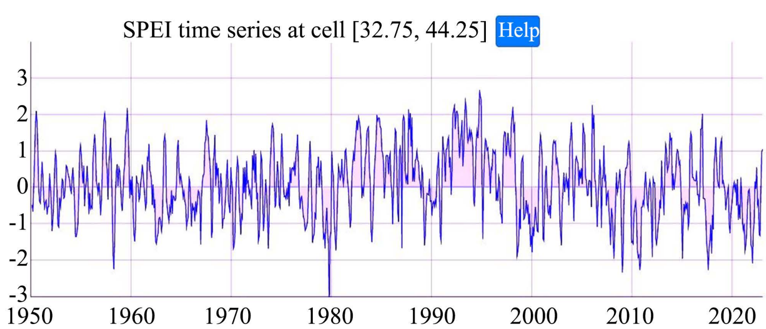

Figure 8. Value of SPEI for Sadat Al-Hindya site from location of SPEI Global Drought Monitor [19].

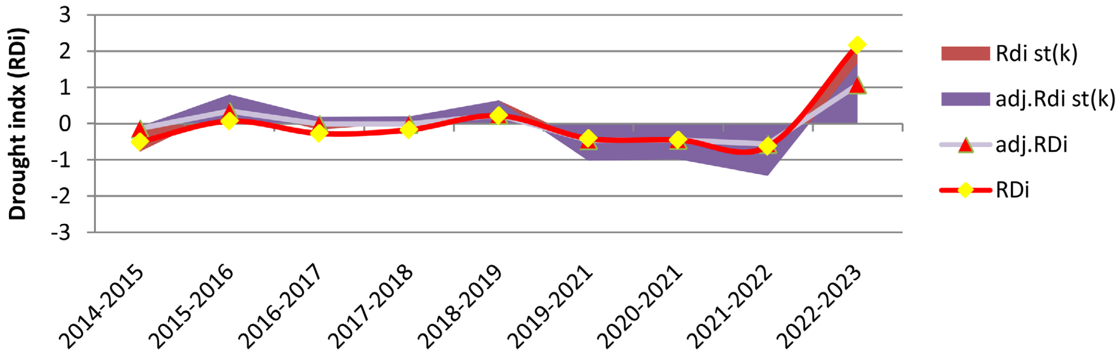

Figure 9. RDi, Rdist, adj RDi and adj. Rdist values.

Table 1. RDi, Rdist, adj RDi and adj. Rdist ([10] and [11]).

Date	RDi	Rdi st(k)	adj. RDi	adj. Rdi st(k)
2014-2015	−0.505	−0.77177	−0.13937	−0.07587
2015-2016	0.064	0.435793	0.342388	0.807289
2016-2017	−0.273	−0.16582	−0.01661	0.189026
2017-2018	−0.175	0.033217	−0.01047	0.201403
2018-2019	0.217	0.647221	0.236118	0.643438
2019-2021	−0.411	−0.49895	−0.46517	−1.02098
2020-2021	−0.452	−0.6112	−0.45386	−0.97938
2021-2022	−0.628	−1.22401	−0.56586	−1.43537
2022-2023	2.162	2.155515	1.072835	1.670439

3.4. Standardized Precipitation Index (SPI)

The drought index is the standardized precipitation index (SPI) [10]. The SPI index represents the deviation of precipitation from the long-term average as shown Equation (1) and as explain in **Figure 10** and the percent SPI dividing on SPEI represent the index to evaluate drought as shown **Figure 11**.

In **Figures 12-14** same as work in up but result to site work by collection of rain fall to two years in Al-Hindya barrage station and estimation ETa from SSEbop from python code but ETo is calculating by WAPOR site [22].

3.5. Discussion

To discuss the results of the indicators for the regions of Iraq in general and the specific region in particular in this **Figures 6-14** The most severe drought has been observed during the current four years, followed by rainy years, but they are few compared to the high temperatures and lack of rain. This is evidence that the areas of Iraq in general and the specific region in particular are extremely dry and have negatively affected the quantities of water, agriculture, and air temperature. Although there are wet years, they are small compared to the dry years, so they do not fill the shortfall caused by the dry years. This shows that Iraq is one

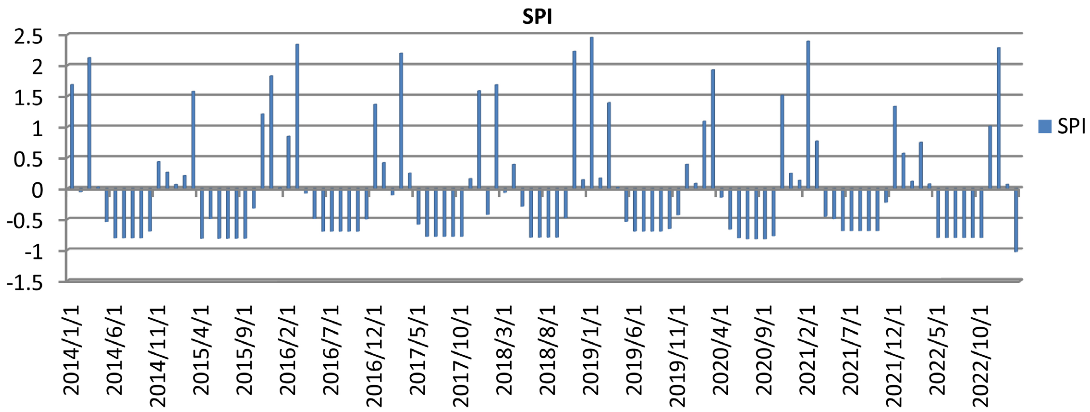

Figure 10. Standardized precipitation index (SPI) for the period between the years 2014-2022.

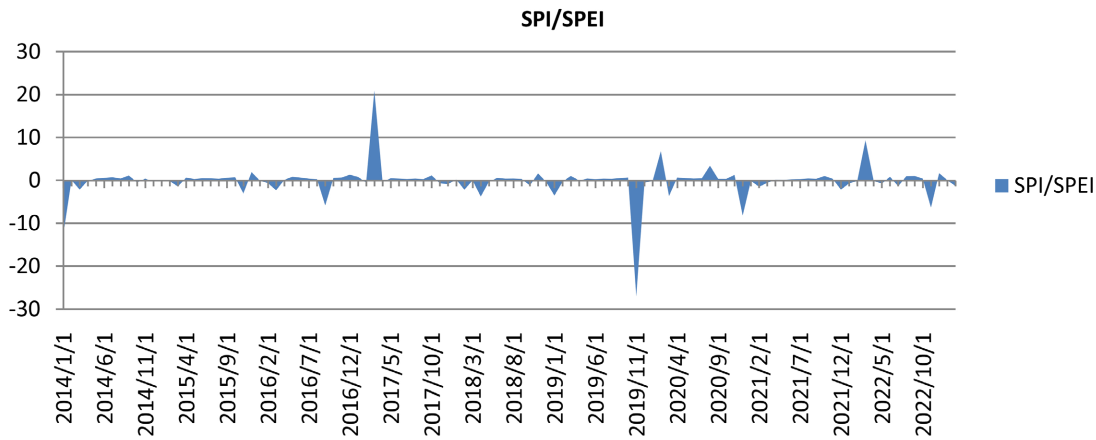

Figure 11. SPI/SPEI values for the period between the years 2014-2022.

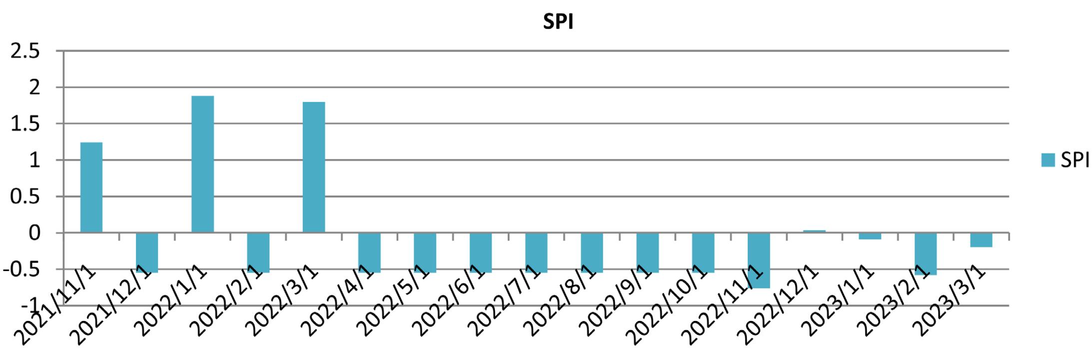

Figure 12. SPI value for the two years (2021-2022, 2022-2023).

of the areas with high drought indicators currently, which has negatively affected the amount of its water. The influence of climate changes on the water cycle was investigated via estimating the changes in water cycle elements such as rainfall interception, evaporation, runoff and stream flow. As the focus of this work was the drought events occurrence, great attention was given to describe the drought by a number of drought indices. The drought indices investigated in this study were able to identify all the historical drought events. The adjusted RDI calculated

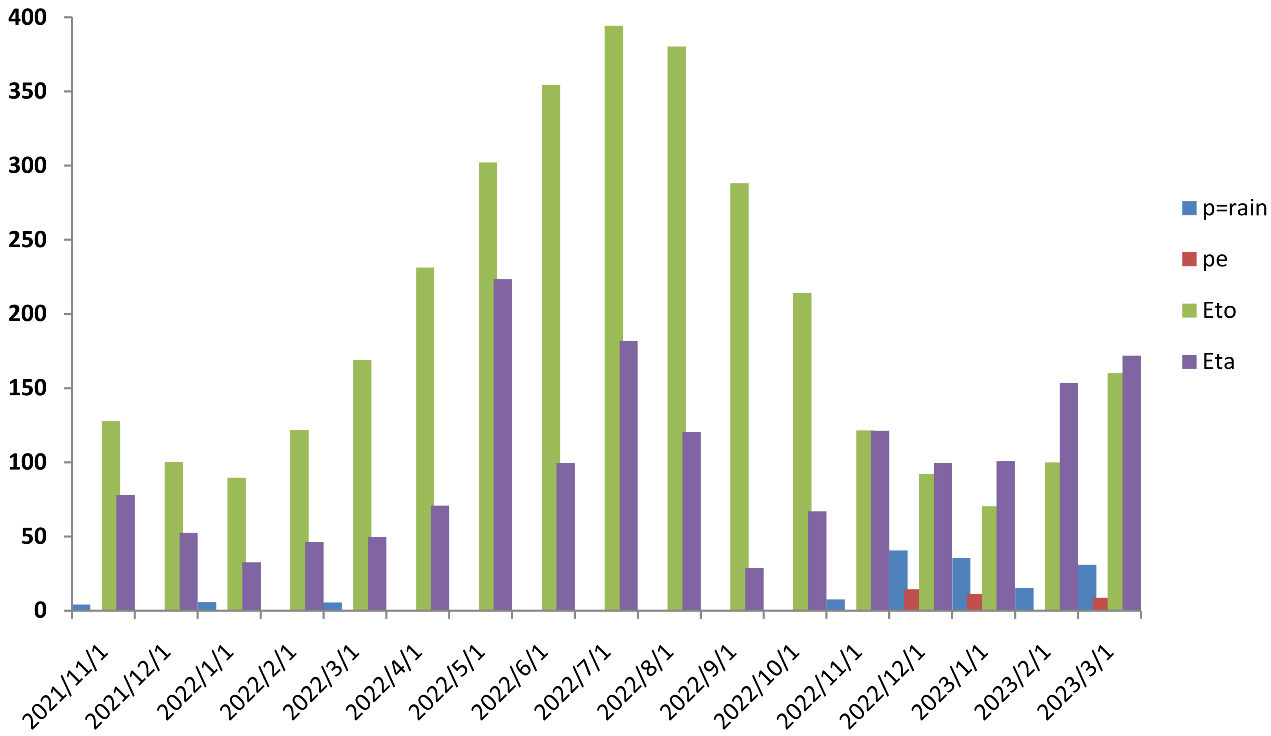

Figure 13. P, Pe, ETo and ETa Values for the the period (Nov.2021-Mar.2023).

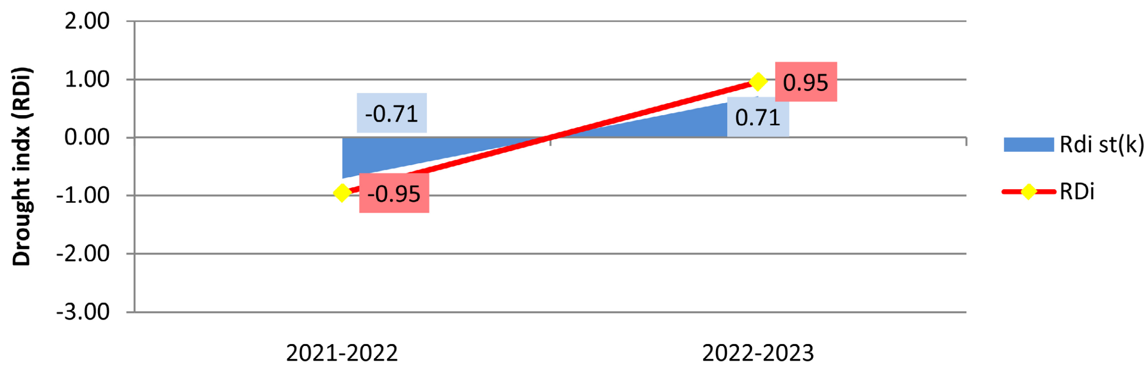

Figure 14. Drought index of two years (2021-2022 and 2022-2023).

using actual evapotranspiration and net rainfall, in addition to the conventional RDI, SPI/SPEI were used as indicators to identify future drought events. The standardized precipitation index, SPI/SPEI, indicated the significantly negative deviation from average precipitation in last fourth years, specifically in 2019-2023 and other last years are shown in figures. The indices helps in finding different types of droughts, as precipitation is the key climatic variable also increasing of temperature helped on increasing of evapotranspiration. The following Table 2 shows a comparison between our study and some studies for other countries that climate change has affected for some years. The study does not address it in Iraq and in the region specified as a case study. Other studies and research will be conducted for the rest of Iraq. Table 2 shows three indicators (SPI, SPEI and DRI).

Table 2. Three indicators (SPI, SPEI and DRI) a comparison between our study and some studies for other countries.

	SPI	SPEI	DRI
Our study 2014-2023, Iraq	0.5 to 1.5 in the rainy years, −0.5 to −1 as moderately dry	−1.5 to −2.5 which means severely dry	0 to −1 was dry and moderately dry
M. Afzal1 and R. Ragab, Yorkshire, UK, [10]	1996 when SPI indices were well Below −2, "extreme drought" level.	1996 when SPEI indices were well Below −2, "extreme drought" level.	less than −1
McKee *et al.*, 1993, Colorado, USA [8]	above 2.0 extremely wet, 1.5 - 1.99 very wet, 1.0 - 1.49 moderately wet, −0.99 to 0.99 near normal, −1.0 to −1.49 moderately dry, −1.5 to −1.99 severely dry and −2.0 and less, extremely dry		

4. Conclusions

The following conclusions are obtained:

- The calculation of the SPI of the region ranged from some results indicating that the years were between 0.5 to 1.5 in the rainy years, but most of the years were between −0.5 to −1 as moderately dry because in the middle of Iraq while in the south of Iraq may be severely dry or extremely dry.
- Estimation of the SPEI of the study area ranged from −1.5 to −2.5 which means severely dry. The SPEI measures are negative values meaning the months and years were drier (evapotranspiration losses were greater than precipitation).
- Quantifying the RDi, Rdist, adj RDi and adj. RDIst of research losses via evapotranspiration (ET) exceed the precipitation, drier conditions and eventually drought would happen. RDi is between 0 to −1 was dry and moderately dry while some months and years are positive and will be wet through rainfall for ten years (2014-2023).
- From indices showed that the region was a drying study area due to the impact of climate change because of the reduction of precipitation and increase in temperature which caused rising of evapotranspiration at surface water and land during the last few years.
- This study notes the region passes on drought wave therefore we need to be rationing available water and using modern irrigation in cultivation also rationing domestic water use to reduce the waste or loss water of during drought time.
- The conclusion reached by the research paper means that the last years were years of drought according to the three indicators.

5. Recommendations

- Iraq facing water scarcity and the researchers recommended using the three indices SPI, SPEI and RDI to evaluate the scarcity there.
- Using the models to evaluate the drought indicators for all cities of Iraq.
- Monitoring the water scarcity by remote sensing sites, models, and programs to know more about drying of the regions.
- Use Modelling to estimate the impact of future climate change on water resources availability for irrigated areas.

Conflicts of Interest

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

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