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Drought Spatiotemporal Characteristics Based on a Vegetation Condition Index in Erbil, Kurdistan Region, Iraq

Heman Abdulkhaleq A. Gaznayee[1]*, Ayad M. Fadhil Al-Quraishi[2], Ahmed Hashim A. Al-Sulttani[3]

[1] *Department of Forestry, College of Sciences of Agricultural Engineering, Salahaddin University, Erbil 44002, Iraq. ORCID ID (0000-0002-1549-407X)*

[2] *Department of Petroleum and Mining Engineering, Faculty of Engineering, Tishk International University, Erbil 44001, Iraq. ORCID ID (0000-0001-7732-129X)*

[3] *Department of Environmental Planning, Faculty of Physical Planning, University of Kufa, Najaf, Iraq, ORCID ID (0000-0001-5251-7755)*

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Abstract

Drought is a complex phenomenon that has severe impacts on the environment. Vegetation and its conditions are very sensitive to drought effects. This study aimed to monitor and assess the drought severity and its relationships to some ecological variables in ten districts of Erbil Governorate (Kurdistan Region), Iraq, throughout 20 years (1998-2017). The results revealed that droughts frequently hit Erbil throughout the study period. The Landsat time-series- based on Vegetation Condition Index (VCI) significantly correlated with precipitation, Digital Elevation Model (DEM), and latitude. Extreme VCI-based drought area percentages were recorded in 1999, 2000, 2008, and 2011 by 43.4%, 67.9%, 43.3%, and 40.0%, respectively. The highest crop yield reduction in the study area occurred mainly in 2000, 2008, and 2012 due to low precipitation rates. These results reveal the capability of the VCI for drought characteristics and highlighting relationships with some ecological variables, which provide vital information to the decision-makers, environmental, and economic sectors.

Keywords: Drought, Landsat time series, VCI, Crops yield, Erbil.

الخصائص الزمانية المكانية للجفاف بناءً على مؤشر حالة الغطاء النباتي في أربيل ، إقليم كردستان العراق

هيمن عبدالخالق احمد گه زنه يى[1]*, أياد محمد فاضل القريشي[2], أحمد هاشم عبد الحسين السلطاني[3]

[1] قسم الغابات، كلية علوم الهندسة الزراعية، جامعة صلاح الدين، اربيل، العراق

[2] قسم هندسة النفط و التعدين، كلية الهندسة، جامعة تيشك الدولية، أربيل، العراق

[3] قسم التخطيط البيئي، كلية التخطيط العمراني، جامعة الكوفة، النجف الأشرف، العراق

* Email: heman.ahmed@su.edu.krd

الخلاصة

الجفاف ظاهرة معقدة لها تأثيرات شديدة على البيئة. يعد الغطاء النباتي وظروف نموه من العناصر البيئية الحساسة للغاية لتأثيرات الجفاف. هدفت هذه الدراسة إلى رصد وتقييم شدة الجفاف وعلاقاته ببعض المتغيرات البيئية في عشرة مناطق من محافظة أربيل، إقليم كردستان في العراق، على مدى عشرون عامًا (1998-2017). أظهرت النتائج تعرض أربيل لموجات جفاف متكررة خلال فترة الدراسة. كما بينت النتائج إرتباطا معنويا احصائيا بين مؤشر حالة النبات VCI وبين معلات التساقط، ونموذج الارتفاع الرقمي (DEM) و دوائر العرض. تم تسجيل النسب المئوية لمناطق الجفاف الشديد القائمة على أساس مؤشر حالة الغطاء النباتي VCI في الأعوام 1999 و 2000 و 2008 و 2011 بنسبة 43.4٪ و 67.9٪ و 43.3٪ و 40.0٪ على التوالي. حدث أعلى انخفاض في غلة المحاصيل في منطقة الدراسة بشكل رئيسي في أعوام 2000 و 2008 و 2012 بسبب إنخفاض معدلات هطول الأمطار. تكشف نتائج هذه الدراسة عن قدرة مؤشر حالة الغطاء النباتي VCI على تحديد خصائص الجفاف وتسليط الضوء على العلاقات مع بعض المتغيرات البيئية ، والتي توفر معلومات حيوية لصانعي القرار وكلا القطاعات البيئية والاقتصادية.

1. Introduction

Drought is the most severe natural risk that affects natural habitats, ecosystems, agricultural systems and reduces field crop and fodder availability [1-4]. Drought leads to the loss of plant moisture and affects the vegetation cover [5, 6]. As a result, many techniques for monitoring drought status have been developed. Remote-sensing technology has made it possible to monitor soil moisture and vegetation conditions across large areas. In sites with limited sampling gauges, remote sensing data could be the only available information source for drought monitoring [7-10]. Satellite-based drought indices such as the Normalized Difference Vegetation Index (NDVI), Vegetation Condition Index (VCI) have been widely used for detecting the onset of drought and measuring its intensity, duration, and impact globally [11-13]. To solve separate weather-related signals from the ecological ones in the NDVI, the VCI was developed. The apparent advantage of VCI is that it can be easily computed since it does not require station observation data and a satellite-based drought product. It provides near real-time data over the globe at a relatively high spatial resolution [13].

The utility of the NDVI-derived VCI for monitoring drought conditions has been studied in various regions worldwide. The VCI based on NDVI has also been compared with vegetation density, biomass, and field reflectance measurements in Kazakhstan, which has proven to be a good indicator of weather's impact on vegetation health conditions [12]. Kogan [14] found that the VCI was strongly correlated with agricultural production in South America, Africa, Asia, North America, and Europe, particularly during the critical periods of crop growth. The focus is on agricultural drought impacts upon soil moisture deficit or reductions in crop yield [11]. The evaluation of the VCI focuses on monitoring drought during the period of maximum vegetation conditions and the growing season [15, 16]. Satellite images can be used to detect, monitor, and mapping agricultural droughts, and that the VCI is suitable for the early assessment of Crop yields [17]. Vicente-Serrano [18] analyzed the drought impact on vegetation in a semi-arid region by using VCI and demonstrated that the response of the VCI varies depending on the month, land cover type, and climate of the drought-affected region [18]. According to the literature, the VCI is suitable for monitoring agricultural drought [12, 19].

During the previous years, up to 2007, the Kurdistan Region of Iraq (KRI) suffered from climate change and had received half its average precipitation [3, 20]. The decreased precipitation rate had affected the agriculture sector and water resources. Therefore, the current study aimed to monitor and assess the spatiotemporal characteristics of drought based on the VCI. Plus, the drought relationships with some ecological variables using Landsat time-series datasets for 20 years in Erbil governorate, the KRI.

2. Materials and Methods

2.1. The Study Area

The study area in this research was the entire territory of the Erbil governorate, one of the governorates of the KRI, which is located in the northern part of Iraq. The topography of Erbil is situated within two physiographic units, the mountains, and foothills. Erbil lies between latitudes of 36° 12' 11" to 36° 15' 10" N and longitudes of 44° 12' 11" to 44° 15' 10" E, while elevation ranges from 400 to 500 m above mean sea level. It covers about 15,038.93 km^2 and consists of 10 districts: Mergasur, Soran, Choman, Rawanduz, Shaqlawa, Khabat, Dashti Hawler (Qushtapa), Koysinjaq, and Makhmur. The spatial distribution of the precipitation amounts in Erbil is heterogeneous; while the mean annual precipitation reaches 430 mm, most precipitation is concentrated in Erbil's northern parts. According to its natural conditions, Erbil can be divided into three arid, middle, and northern mountainous zones (Figure 1 B). The average annual precipitation starts from 250 mm in the south of Erbil area to more than 1,200 mm in the high mountains bordering Iran in the northeast and Turkey in the north [21]. The mean daily temperature varies from 5°C in winter to 35°C in summer; however, this rises to 50 °C in the region's southern parts [22]. The climate in the study area (Figure 1) is classified as a Mediterranean climate (arid and semi-arid) [23].

2.2. Data Collection and Image Preprocessing

Landsat satellites datasets were downloaded from the United States Geological Survey website (www.gloves.usgs.gov) for April and May that they considered the months of crop growth over the study period (1997-2017). All the Landsat images have been subjected to geometric, radiometric, and atmospheric corrections in the preprocessing stage.

2.3. Drought Spectral Indices

2.3.1. VCI

The VCI was derived to differentiate the weather-related component of NDVI from ecological factors [24]. It can be calculated using Eq. 1

$$\boldsymbol{VCI} = 100 * \frac{NDVI - NDVI_{min}}{NDVI_{max} - NDVI_{min}} \qquad (1)$$

NDVI: can be derived for Eq. 2 [25, 26].

$$\boldsymbol{NDVI} = \frac{(NIR - RED)}{(NIR + RED)} \qquad (2)$$

The NDVI in Eq.1 represents the NDVI value of the current month. At the same time, ($NDVI_{min}$) and ($NDVI_{max}$) denote the minimum and maximum of the NDVI values, respectively, throughout the observation period. Five classes of the VCI and their corresponding drought severity categories are used in the present study to address the drought severity (see Table 1).

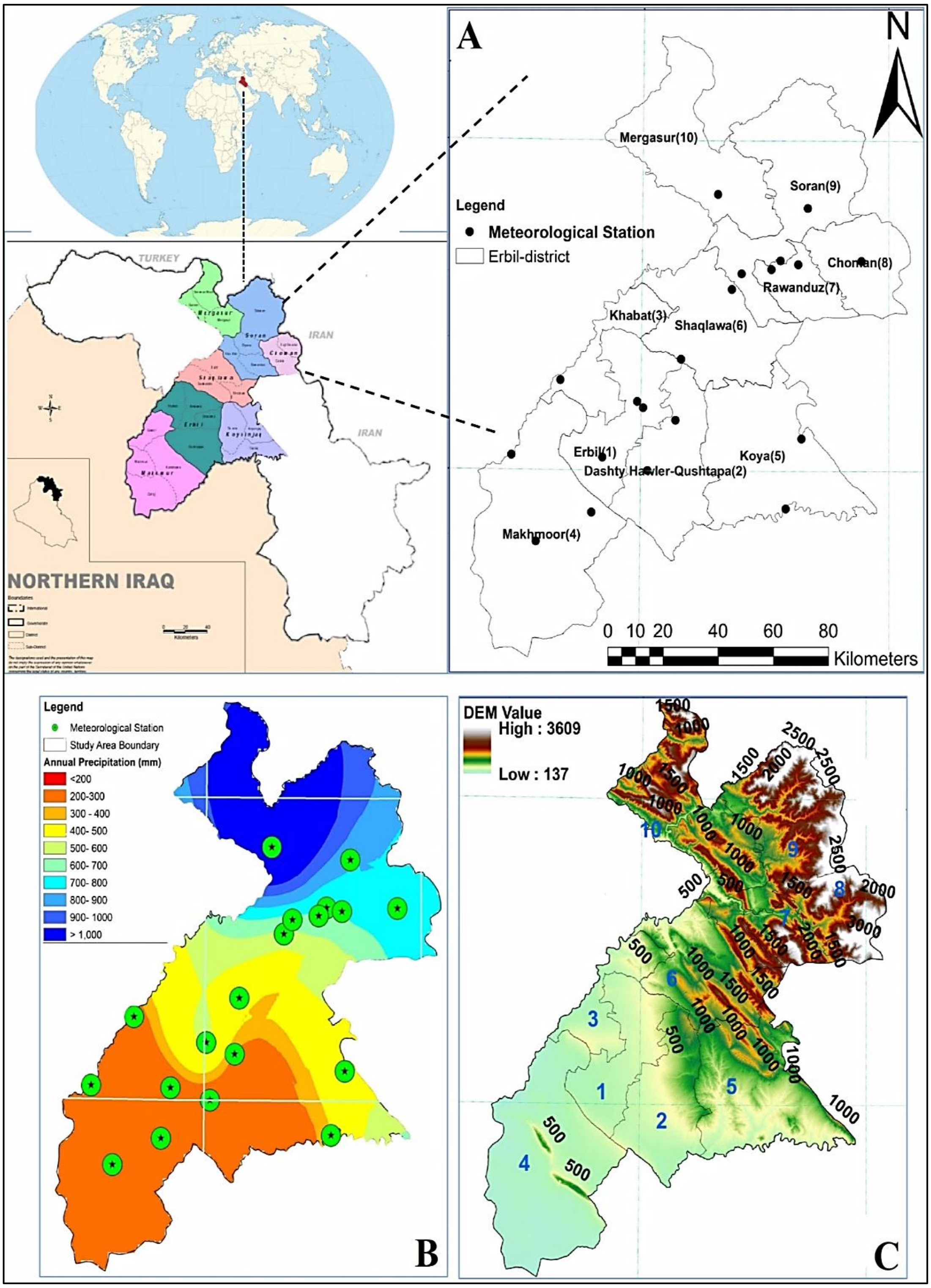

Figure 1-Location map of the study area. (A) Erbil governorate districts, their codes, and the meteorological stations locations, (B) Meteorological stations and the geographical distribution of annual precipitation (mm/year) in Erbil during 1997-2017, (C) Digital Elevation Model (DEM) of Erbil Governorate, and the district's codes.

Table- 1 VCI values classification in terms of drought [27].

Drought Category	Values
Extreme drought	≤10
Severe drought	10< & ≤20

Moderate drought	20< & ≤30
Mild drought	30< & ≤40
No drought	≥40

2.4. Drought Risk Zone Estimation using Principal Component Analysis (PCA)

The PCA is helpful to summarize several variables into fewer important components. It is a powerful and widely used linear technique in statistics, signal processing, image processing, and elsewhere. In statistics, PCA is a method for simplifying a multidimensional dataset to lower dimensions for analysis, visualization, or data compression [28]. The PCA, sometimes referred to as the orthogonal empirical function, shows a linear combination of k variables that have strong relationships as shown as follows:

$$PC_i = E_I^T X = \sum_{j=1}^{K} e_{ij}\, X_{k,}\ K = 1,2,3,4 \qquad (3)$$

where PCi = *i*th principal component; E^T_i= *i*th eigenvector; X_k = *k*th original variable; and e*ij* = *k*th element of the *i*th eigen component.

3. Results and Discussion

The study results (Figure 2) showed that the most critical years for drought based on the VCI index were 1999, 2000, and 2008. In contrast, the vegetation cover was remarkably reduced compared with other years through the investigation period. The drought peaked in 2000, its highest severity; thus, it is considered the driest year within the study period. The VCI Extreme Drought Classes (EDC) were calculated based on each year's vegetation cover area. The less vegetation cover area occurred in 2000 with an expanded extreme drought area by 777.8 Km^2 (% 67.9). Drought severity class varies from mild to severe in 1999, 2000, 2005, 2008, and 2011 (Table 2 and Figure 2). However, the very severe drought extended to include the entire study area in the dry years, that the majority of the area experienced a moderate and severe drought. On the other side, the second-highest area of the (EDC) (VCI<=10) revealed that the largest class area was recorded in 1999, 2005, 2008, and 2011 (43.4%, 31.2%, 43.3%, and 40.0%), respectively (Table 2 and Figure 3).

Based on VCI values classification in terms of drought in Table 1, for the study period from 1998 to 2017, it was evident that the vegetation cover characterized by considerable spatial variability, mainly in the Southern parts, constantly remains the least vegetated area. Strong relationships were found between VCI and precipitation across most Erbil districts, whereas some small patches were not affected by drought, particularly in the northern part of the Erbil. According to [3, 28], Erbil's northern and eastern districts are characterized by high elevation and more annual precipitation averages. A time-series based drought indices provide a framework for evaluating the drought situation in the area under investigation. The VCI variations indicated that the vegetation cover was stressed in April of 2000 and 2008, and drought conditions had developed since the precipitation was less than the average. The southern parts of the study area were more vulnerable to severe drought due to decreasing vegetation cover [29, 30].

The causes of droughts are complicated since it is related to the atmosphere, topographic, and hydrologic factors that affect soil moisture and vegetation growth [31]. Erbil's plain is considered the essential cultivated area in the KRI. Erbil's plain has been classified under drought conditions in 1999, 2000, and 2008 based on the VCI index (Figure 2). It is evident from the maps (Figure 2) that 1999, 2000, 2005, 2008, and 2011 were dry years.

Figure 2-Drought severity classes based on the VCI in Erbil from 1998 to 2017.

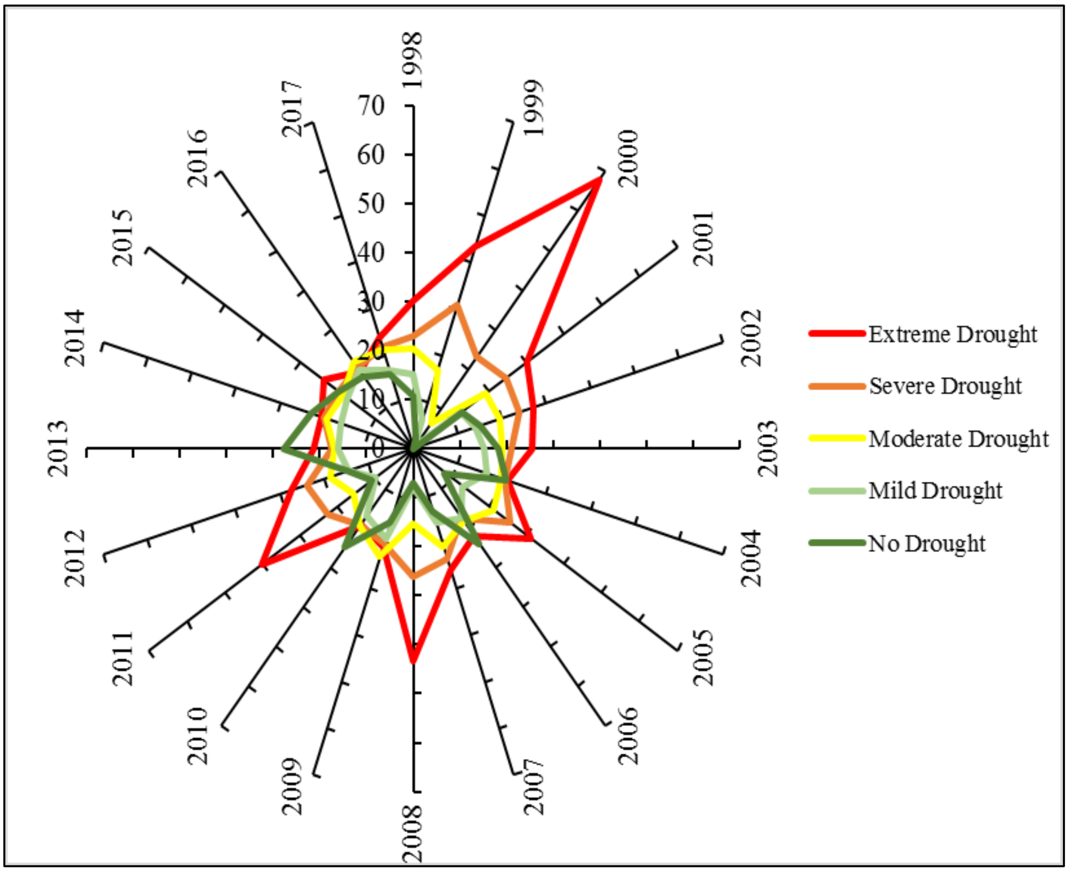

Figure -3 Temporal variation of percentage area of the VCI-based drought categories based on total vegetation cover each year.

Table 2-Area of the VCI-based Drought Severity Categories in the Erbil in 1998 through 2017.

	Total Vegetation cover area		**Extreme Drought VCI<=10**		**Severe Drought 10<VCI<=20**		**Moderate Drought 20<VCI<=30**		**Mild Drought 30<VCI<=40**		**No Drought VCI> 40**	
Year	**(km²)**	**(%)**	**(km²)**	**(%)**	**(km²)**	**(%)**	**(km²)**	**(%)**	**(km²)**	**(%)**	**(km²)**	**(%)**
1998	7664.8	100	2,333.9	30.3	1,773.7	23.1	1,567.1	20.4	1,159.0	15.1	831.1	10.8
1999	7593.2	100	3,303.7	43.4	2,345.1	30.8	1,293.1	17.0	486.0	6.4	165.3	2.2
2000	1129.3	100	777.8	67.9	267.2	23.3	75.5	6.6	8.4	0.7	0.4	0.0
2001	5928.1	100	1,797.4	30.2	1,466.8	24.7	1,133.5	19.1	763.9	12.8	766.5	12.9
2002	8278.5	100	2,248.2	27.1	1,987.9	23.9	1,616.2	19.5	1,172.4	14.1	1,253.8	15.1
2003	8124.3	100	2,084.6	25.6	1,725.7	21.2	1,559.2	19.1	1,251.9	15.4	1,502.9	18.4
2004	10067.8	100	2,144.2	21.2	2,103.1	20.8	2,012.4	19.9	1,684.0	16.7	2,124.1	21.0
2005	7133.8	100	2,235.5	31.2	1,842.7	25.7	1,514.9	21.2	941.9	13.2	598.8	8.4
2006	7885.7	100	1,743.3	22.0	1,402.1	17.7	1,456.2	18.4	1,377.1	17.4	1907.0	24.1
2007	7636.4	100	1,979.8	25.9	1,804.1	23.6	1,618.5	21.1	1,209.2	15.8	1024.8	13.4
2008	5293.6	100	2,304.3	43.3	1,395.0	26.2	805.7	15.2	419.3	7.9	369.3	6.9
2009	7505.2	100	1,589.0	21.1	1,532.1	20.3	1,740.6	23.1	1,448.9	19.2	1,194.6	15.9
2010	10277.8	100	1,965.7	19.1	2,001.8	19.4	2,006.6	19.5	1,750.1	17.0	2,553.6	24.8
2011	6202.4	100	2,490.7	40.0	1,416.6	22.8	980.4	15.8	621.1	10.0	693.6	11.1
2012	6085.0	100	1,675.6	27.4	1,464.8	24.0	1,138.2	18.6	894.7	14.7	911.7	14.9
2013	9526.0	100	2,055.3	21.5	1,667.8	17.5	1,601.5	16.8	1,541.7	16.1	2,659.7	27.8
2014	9593.0	100	1,997.7	20.8	1,933.7	20.1	1,872.5	19.5	1,575.4	16.4	2,213.7	23.0
2015	9429.9	100	2,246.6	23.8	1,881.0	19.9	1,762.9	18.6	1,663.8	17.6	1,875.6	19.8
2016	10292.3	100	2,003.1	19.4	2,113.6	20.5	2,257.1	21.9	2,034.4	19.7	1,884.1	18.3
2017	8338.1	100	1,991.8	23.8	1,815.1	21.7	1,776.2	21.2	1,421.4	17.0	1,333.6	15.9

3.1. PCA

Results of the PCA showed that the negative impact of climatic factors, elevation, and latitude on the crop area is represented by decreasing precipitation rates, particularly in the low elevation areas (Figure 3). Whereas the annual precipitation does not exceed 200 mm, it decreases fluctuations of the amount of rain in April with high temperatures in that month, leading to plant stress and increased evaporation rates of crops grown in those areas.
The VCI results help to monitor the onset of agricultural drought as an early warning system. Figure 4 presented spatial pattern changes of the ecological parameters and VCI for an average of 20 years in the ten districts of Erbil Governorate. This result indicates that the growing-season VCI pattern responds to the moisture stress at least over Erbil, plus it appears to be sensitive to the long-term precipitation deficiencies.

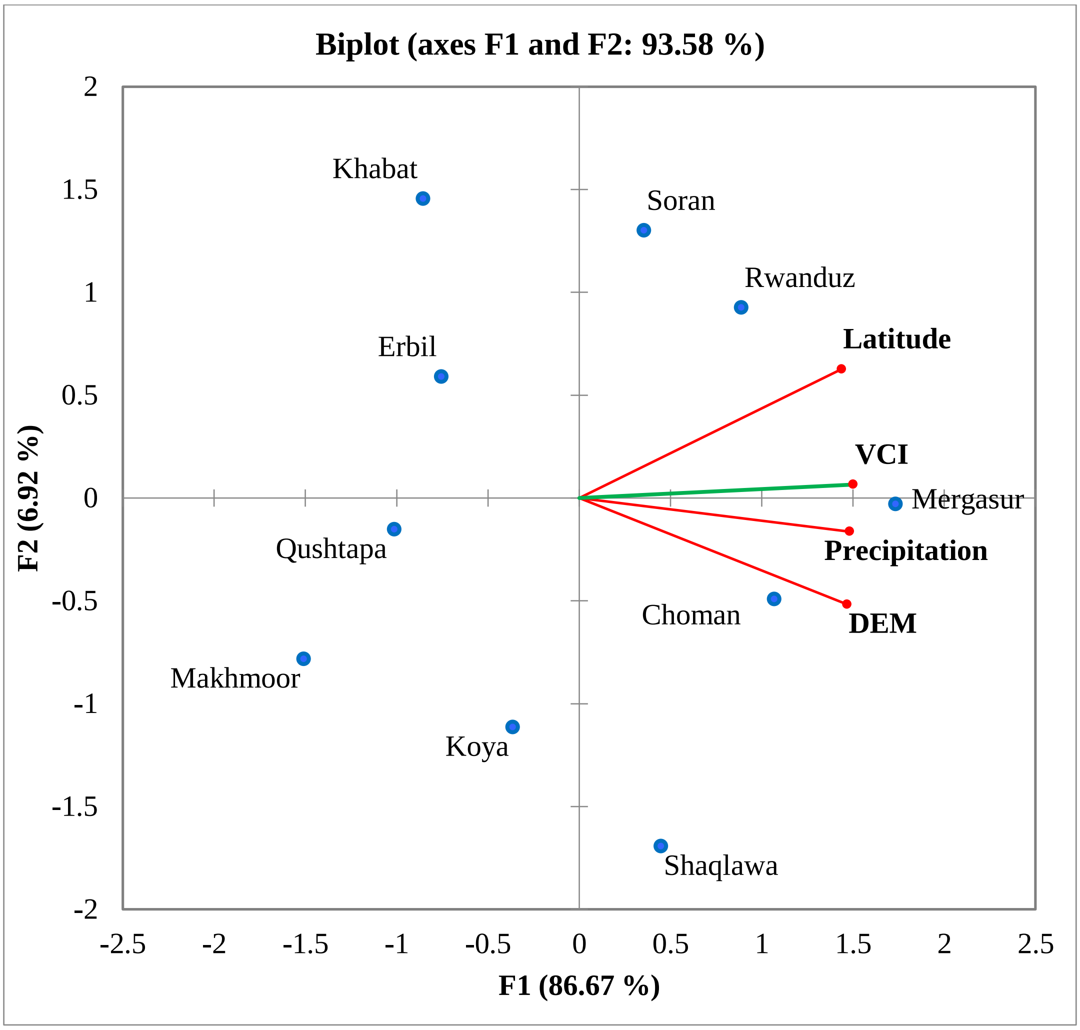

Figure 4-Principal Component Analysis of Spatial pattern changes of ecological parameters and drought index (VCI) for an average of 20 years in 10 districts in Erbil Governorate. (Relationships between Latitude, DEM, Precipitation, and VCI).

3.2. Correlation Matrix (Pearson) Analysis

Positive significant correlations were found between the VCI and precipitation (r= 0.82), VCI and latitude by (r= 0.85), and VCI and DEM (r= 0.87). The mountainous areas with high elevation (around 2,000 meters above sea level) are more widely in the northeast direction and gradually decrease toward the southwest (Figure 1 C). Statistically, significant positive correlations were calculated between precipitation and VCI.

Table -3 The Correlation matrix Pearson (n)) values among spectral index and their latitude, DEM, and precipitation.

Variables	Latitude	DEM	Precipitation	VCI
Latitude	**1**	**0.73**	**0.81**	**0.85**
DEM	**0.73**	**1**	**0.86**	**0.87**
Precipitation	**0.81**	**0.86**	**1**	**0.82**
VCI	**0.85**	**0.87**	**0.82**	**1**

Values in bold represent a statistical significance at alpha level of 0.05.

3.3. The Relation of VCI with the Crop Area and Crop Yield

The first decline in crop yield begun in 1999-2000, and the second decline in crop yield occurred in 2007-2008 and 2011-2012. This reduction was precisely in line with the decrease in precipitation and vegetation area and values based on the VCI index observed in Erbil Governorate throughout the same year (Figure 3). The highest yield reduction occurred in 2000 and 2008 due to agricultural drought events (Figure 5). The reduction was attributed to the precipitation amount's fluctuation to satisfy the minimum crop water requirement [6, 11, 32]. Crop yield is generally correlated with the VCI, which can be employed to develop a relationship between the VCI and crop yield. Furthermore, a drop in precipitation averages had occurred in those three drought years, as well as a significant reduction in the VCI values (Figure 4).

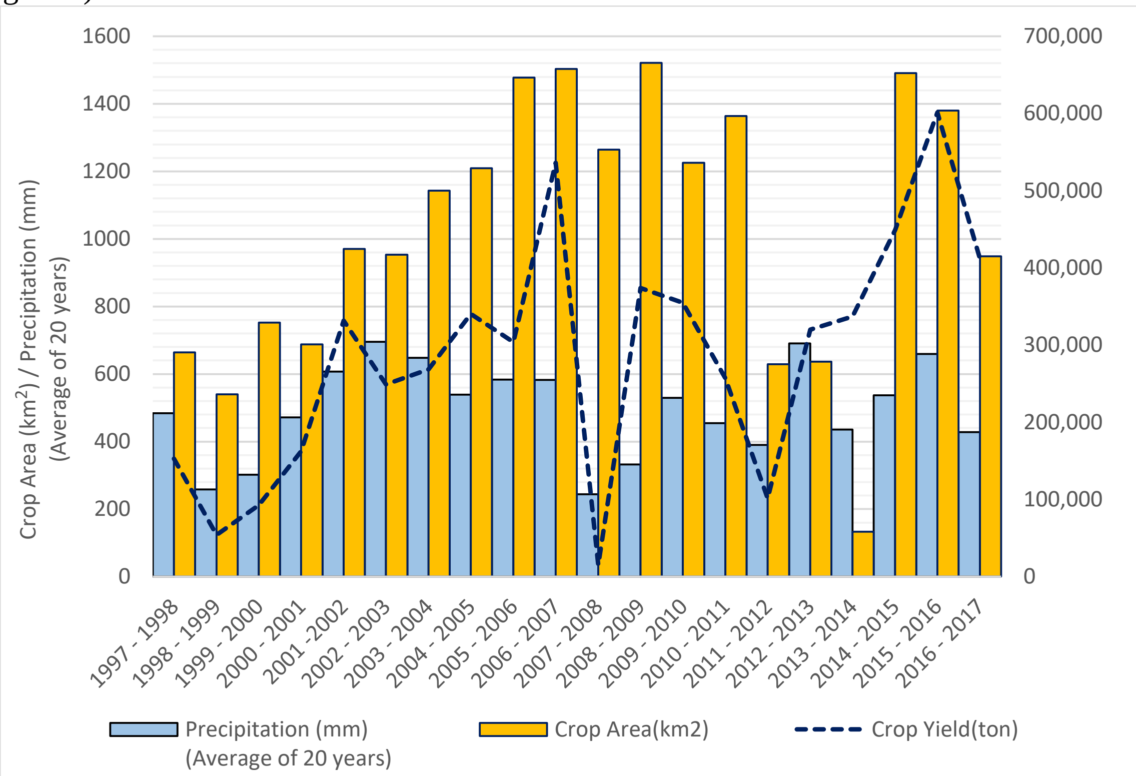

Figure 5-Average annual precipitation (mm), crop area (km^2), and crop yield (Ton) for 20 years in the study area.

4. Conclusions

The development of advanced processing and analysis techniques and improved computing capabilities of remote sensing and GIS has resulted in new approaches that can be used for drought monitoring. In this study, the Vegetation Condition Index (VCI) map for 20 years

was calculated to monitor the drought and vegetation conditions **.** The study's main conclusion can be drawn that three severe drought years during the twenty years in Erbil governorate were distinguished, especially in southern parts (plain area), which are characterized by very suitable soil characteristics for agricultural uses. Maps of the VCI showed that most areas of Erbil experienced severe to very severe drought in 2000 and 2008**.**
Consequently, the droughts can be attributed to the lack of precipitations and also to the high land surface temperature throughout the critical plant growth stage. As mentioned in the previous sections, the northern and eastern parts of the Erbil are characterized by high elevation and have more annual rainfall averages. The DEM's derived maps had the same importance for dissection of the vegetation cover distribution in the study area. The results showed a significant relationship between the VCI and crop yield. It also found that the decrease in crop yield directly correlated to the low rate of precipitation. Precipitation is thus the key factor contributing to vegetation stress in these areas. In this case, VCI had the highest correlation with precipitation more than the latitude. The southern part of the Erbil shows a net decrease of its vegetative cover during the considered time range. It seems to be affected by land-degradation processes caused by droughts, which issue in this area.
In contrast, the forest land consists of trees and shrubs in the northern parts of Erbil, which have deeper root systems than grasslands and croplands. The vegetative cover area was more statistically related to some ecological and terrain variables (precipitation and DEM), particularly in 2000 and 2008. Landsat-based VCI was significantly correlated with precipitation, latitude, and DEM. The elevation was one of the essential factors affecting precipitation rates, mainly in the plain area characterized by wheat and barley field crops. This study could contribute to investigating the fragility in Iraq, particularly in Erbil, the KRI. For future studies, satellite imageries with higher temporal and spatial resolutions are highly recommended.
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