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EVALUATING THE EFFECT OF CLIMATE CHANGE ON DOKAN LAKE AND THE VEGETATION SURROUNDING AREA USING ADVANCED ANALYTICAL TECHNIQUES

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Abstract

The regions surrounding Dokan Lake are highly vulnerable to recent climate change, which disrupts ecosystems, hydrological cycles, and vegetation, particularly in water-scarce areas. Thus, this study uses remote sensing techniques, such as Normalized Difference Vegetation Index (NDVI) and Vegetation Condition Index (VCI), to monitor vegetation and drought conditions. In order to calculate hydrological parameters that identify changes in the lake's water level from 2014 to 2023 and to assess vegetation changes in the Khdran, Khalakan, Ranya, and Chwarqurna areas that are close to Dokan Lake. The Standardized Precipitation Index (SPI) is another tool used to analyze precipitation patterns and identify the wettest and driest years during this time frame.
Advanced analytical techniques are used in this study, including statistical tools, GIS, and remote sensing. To determine seasonal water levels, hydrological data, including precipitation and water levels, were gathered from the Dokan Dam and processed using ArcGIS (10.7.1) and GraphPad Prism (8.0.2). Vegetation and drought conditions were analyzed using the NDVI and VCI indices. A correlation analysis between water levels and SPI revealed a moderate and statistically significant relationship (P-value < 0.05; P-value = 0.034).

According to the findings, the lake's area fluctuated significantly, with the largest expansion occurring in 2019. Vegetation conditions, as assessed by the VCI index, indicate that extreme drought occurred in 2014 but significantly increased by 2022. Areas with moderate drought remained stable, while regions with mild drought experienced a gradual decrease after 2019. According to SPI analysis, 2019 was a wet year (SPI = 2.22), while 2022 saw a moderate drought (SPI = -1.18). In conclusion, the study highlights the need to consider multiple climate parameters for effective water management and climate change adaptation. The results emphasize the significance of understanding the interaction between hydrology, vegetation, and climate, which is essential for sustainable development in regions vulnerable to climate change.

Keywords: Climate Change; Dokan Lake; GIS; Remote Sensing; Vegetation; Water Level.

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1. Introduction

Water is a vital resource, covering about 70% of the Earth's surface, supporting ecosystems, agricultural development, and industrial activities (Toma, 2013; Farkha & Fatah, 2016; Yaseen *et al*., 2018). However, climate change has significantly altered rainfall patterns, causing more persistent and severe droughts (Saysel *et al*., 2002; Jesslyn *et al*., 2002; Eklund *et al*., 2016). Climate change is the greatest challenge confronting the world, especially in water-scarce regions like Iraq, and it is basically due to the increase in the concentration of greenhouse gases in the air resulting from human activities (Akanwa *et al*., 2019; Jabal *et al*., 2022; Sultan *et al*., 2023). In Iraq, especially within the Kurdistan Region, the agricultural sector heavily relies on surface water and groundwater, making it crucial for the economy. These resources are scarce, and the majority are shared with Iraq's neighbors. Furthermore, one of the most essential elements of life is water (Yaseen *et al*., 2018). Despite substantial research on the effects of environmental change on water resources, a common occurrence in Iraq's climate, drought remains a significant natural hazard that significantly affects many different aspects, including the agricultural, social, environmental, and economic. Geographic Information Systems (GIS) and Remote Sensing (RS) have been widely used recently to assess various drought types (Gaznayee *et al*., 2022).

Numerous studies demonstrate the inverse relationship between lake environmental conditions and climate change (Kebede *et al*., 2006; Azeez *et al*., 2020). Also, these researchers discuss how climate change, such as precipitation variations, has affected water resources and agriculture, especially in the Kurdistan region (Abdullah *et al*., 2016; Yaseen *et al*., 2018; Gaznayee *et al*., 2022; Abdullah *et al*., 2023). Moreover, this study focused on satellite images of Dokan and Darbandikhan lakes whose areas have undergone numerous seasonal and cyclical changes in recent years. Significant alterations happened as a result of the lake's water level being above or below its typical level (Yaseen *et al*., 2018). Gaznayee *et al*. (2022) used satellite images and remote sensing technology to investigate the changes in the water area extent for the lakes in question. Many researchers studied the physicochemical, and soil properties of the Dokan Lake (Alobaidy *et al*., 2010). However, limited research has been conducted on the impact of water on the vegetation surrounding the lake, and tools, such as the Normalized Difference Vegetation Index (NDVI) and Vegetation Condition Index (VCI) have been underutilized in this context. The social, environmental, and economic standing of the impacted area is severely harmed by drought, a complex natural disaster that is challenging to diagnose (including its onset, duration, intensity, and scope), forecast, and manage in a larger context (Gaznayee *et al*., 2022). SPI is concerned with drought situations and the drop in SPI interpretations over particular years, and it explains how SPI 12 values represent these long-term dry periods in Darbandikhan Lake (Azeez *et al*., 2020). The Standardized Precipitation Index (SPI) was determined utilizing a 30-year reference period, in accordance with WMO guidelines (Cammalleri *et al*., 2022). This study concentrates on evaluating drought over the most recent 10-year period, from 2014 to 2023, based on the 30-year baseline.

The current study aims to detect the vegetation in areas surrounding Dokan Lake by using remote sensing such as VCI and NDVI from 2014 to 2023. In addition, it explores the rate of precipitation in that period under study to establish the correlation between the water level and SPI. It also examines the status of drought in that period by using SPI and detecting the Dokan Lake's water level for the period studied through remote sensing. Thus, this research seeks to answer these questions, such as to what extent climate change affected the area of Dokan Lake, how the water of Dokan Lake has fluctuated, how the vegetation surrounding the lake of Dokan can be detected, and finally how the dry versus wet years can be detected in the target areas surrounding Dokan Lake.

2. Materials and Methods

2.1. Description of study area

Iraq is a country located in southwestern Asia between scopes 29°2 and 38°2 North and longitudes 39°2 and 48°2 East (Falih *et al.*, 2023). It shares borders with Iran to the east, Turkey to the north, Syria and Jordan to the west, Saudi Arabia and Kuwait to the south, and the Gulf to the south-east (Ahmad, F. 2012; Al-Ansari, 2013; Ahmad & Barzinji, 2020). Dokan Lake, located in the Kurdistan Region within the Sulaymaniyah Governorate in northern Iraq, is located at 35°57'N latitude and 44°57'E longitude (Toma, 2013). The lake was created by the construction of the Dokan Dam on the Lesser Zab, a major tributary of the Tigris. The dam makes Dokan Lake crucial for the regional water supply, water system, hydroelectric power generation, and surge management (Alobaidy et al., 2010). Khdran, Khalakan, Chwarqurna, and Ranya, as shown in Figure 1, are selected to examine the effect of water level on the vegetation surrounding the lake.

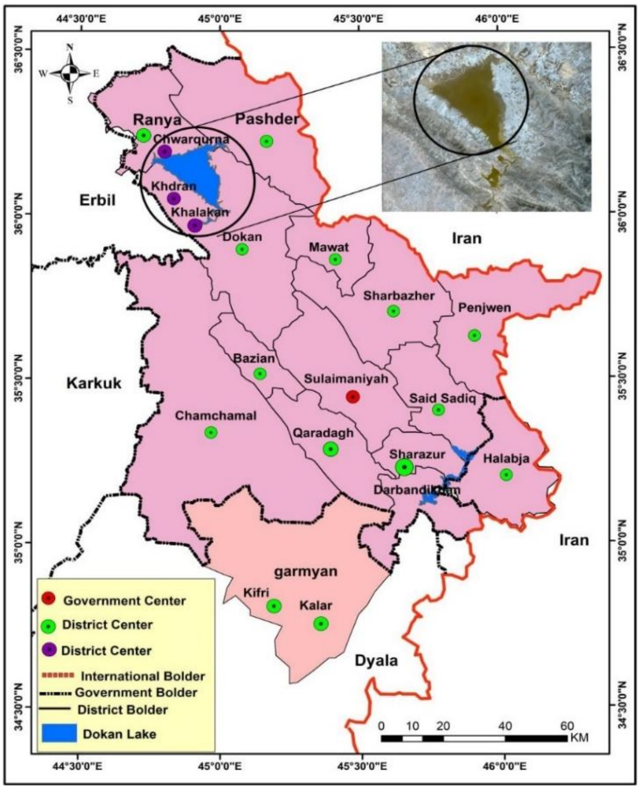

Figure 1. Shows the study areas of the Dokan Lake (Khdran, Khalakan, Ranya, and Chwarqurna).

2.2. Data Collection

In June 2024, Hydrological data, including precipitation and water levels, were collected from Dokan Dam and processed using ArcGIS (10.7.1) and GraphPad Prism (8.0.2). This study analyzes seasonal water levels and examines their effects on vegetation surrounding the lake, and areas such as Khalakan, Ranya, Chwaqurna, and Khdran. The analysis aims to understand the impacts of recent climate change on vegetation and hydrology around Dokan Lake and continues until January 2025. For each year in the study, Landsat 8 – 9 OLI/TIRS images from July 1st for each year were collected for this study. Due to its high resolution, Landsat 8 is especially well-suited for this work. Landsat images offer a consistent record of environmental changes going back to the 1970s. It is frequently used for long-term monitoring of environmental, vegetation, and land-use changes (Kogan, 1986). For vegetation detection, the VCI technique was applied using Landsat 8 bands 4 and 5. Additionally, the area of Dokan Lake was determined by using bands 1, 2, 3, 4, 5, 6, and 7 from Landsat 8, focusing on April and July, as these months were critical during the study period (2014 – 2023). July, in particular, was selected as the optimal month to identify crops and vegetation since rainfall typically halts during this time. Datasets were downloaded from the United States Geological Survey USGS. During the preprocessing phase, all Landsat images underwent geometric, radiometric, and atmospheric corrections, resulting in images with a 30-meter resolution, ideal for analyzing spatial changes in vegetation and water bodies. The satellite images used in this study showed minimal cloud cover (approximately 10%). Pearson's Correlation was also used to examine the relationship between Water levels and SPI, in order to assess the degree of correlation between the two variables.

2.3. Ground Truthing

Selected areas (Khalakan, Khdran, Ranya, and Chwarqurna) around Dokan Lake were visited to confirm and monitor the accuracy of the remote sensing classifications. Vegetation was identified, as shown in Figure 2 Dokan (A1, A2, A3), Ranya (B1, B2, B3), Chwarqurna (C1, C2, C3), Khalakan (D1, D2, D3) and Khdran (E1, E2, E3) visited the area of Dokan in (1/7/2024 and 10/11/2024) the area of Ranya visited in (1/7/2024 and 10/11/ 2024), area of Chwarqurna visited in (15/8/2024 and 20/11/2024), area of Khlakan visited in (15/8/2024 and 20/11/2024), and area of Khdran visited in (20/12/2024 and 5/1/2025).

2.4. Water level and VCI

Water level fluctuations of Dokan Lake over the past 10 years and their effects on the surrounding vegetation were analyzed. Water level data were collected from the Dokan Dam and measured by a steel ruler. A steel ruler, as shown in Figure 3 (A and B), is used to measure the water level in Dokan Lake, and they started their measurements in stable weather conditions, typically in the early morning or sometimes in the afternoon in the dry season. Additionally, to measure the water level, a low tide was needed to get better readings. The water level of Dokan Lake should be measured at necessary intervals. During the irrigation season, the water level is checked every day to ensure optimal conditions for irrigation.

Figure 2. A1, A2, and A3 show Dokan, B1, B2, and B3 show Ranya, C1, C2, and C3 show Chwarqurna, D1, D2, and D3 show Khalakan, E1, E2, and E3 show Khdran areas.

Figure 3. (A) and (B) show a steel ruler.

Regular monitoring is essential for supporting agricultural operations and efficiently managing water resources. The area of Dokan Lake was calculated using satellite images from USGS Landsat 8 (bands 1, 2, 3, 4, 5, 6, and 7) taken between 2014 to 2023. The VCI was used to evaluate the changes in the vegetation by contrasting present conditions with past data processed by ArcGIS (10.7.1). VCI is a remote sensing-based index that assesses the health of vegetation. It supports farmers and directs restoration efforts by assisting in the detection of drought, crop stress, and land degradation. In addition, the VCI is important in evaluating the risk of disasters and managing water as it indicates a region is prone to droughts or water deficits due to climate change (Quiring & Ganesh, 2010). To identify VCI, Landsat 8 bands 4 and 5 are used, as they are specially designed for calculating the NDVI and its time series as shown in Equation 1 (Farrar *et al*., 1994; Huang *et al*., 2021). The VCI formula is shown in Equation 2 (Kogan, 1986; Bhandari *et al*., 2012):

$$\text{NDVI}=\frac{(\text{NIR-RED})}{(\text{NIR+RED})} \tag{1}$$

$$\text{VCI}=\frac{\text{NDVIi-NDVI min}}{\text{NDVI max-NDVImin}}\times 10 \tag{2}$$

The NDVI value for the current month is shown as NDVI in Equation (1). Also, in terms of the perception reference period of ten years (2014 – 2023), the terms NDVI (min) and NDVI (max) refer to the minimum and maximum NDVI values, respectively. The VCI refers to the yearly vegetation condition index, and NDVI refers to the normalized difference vegetation index of the current year. This is referred to as the historical NDVI data. It ranges from zero to one hundred, indicating the degree to which the current state of the vegetation health is in relation to the best and worst historical values. Higher VCI indicates a better condition of the vegetation. The formula measures the state of the vegetation by the current NDVI values in comparison to the historical range of NDVI values, which reflects the rate of change of water level on the vegetation health in the region.

2.5. SPI Standardized Precipitation Index

By comparing current rainfall to historical averages, the SPI calculates the severity of drought. In this study, SPI was computed for Dokan Lake to monitor water levels, which are crucial for local communities and agriculture (Yaseen *et al.*, 2018). The SPI helps farmers in the surrounding areas adjust crop planning and irrigation, and assists authorities in guiding water resource management and assessing drought risk. The SPI for each year was calculated by using the Z-score's transformation of ten years' worth of rainfall data, identifying whether the weather was dry, normal, or wet. The SPI was computed during this study, as shown in Equation 3 (Gaznayee *et al.*, 2022):

$$SPI=\frac{P-\mu}{\sigma} \tag{3}$$

In this context: P = observed precipitation for a specific period, μ = average precipitation for the same period over a long period, and σ = standard deviation of precipitation for the same period over a long period.

3. Results

3.1. Statistical Analysis

For analysis in GraphPad Prism (version 8.0.2), Pearson's Correlation Analysis (two-tailed) was applied to measure the correlation relationship between water levels and SPI. Key indicators such as Correlation coefficient, R-squared, and P-value were examined to evaluate the performance and significance of the model and to calculate SPI for each year. The precipitation data from all years under study were combined, and a total was calculated. Finally, the z-score was used to take out the result of SPI by using Microsoft Excel and GraphPad Prism.

3.2. SPI (Standardized Precipitation Index)

The SPI is crucial for assessing drought severity (Edossa *et al.*, 2010). Recent climate change significantly influences precipitation patterns and vegetation health (Bradley, 2008). This study uses the SPI-12 scale on data from 2014 to 2023, in the face of WMO's recommendation that SPI calculations be conducted using a 30-year baseline period to establish climate normal. Due to data availability and the need to track short-term drought conditions, the most recent decade was chosen. In compliance with accepted climatological practices (Cammalleri *et al.*, 2022). As shown in Table 1, the data reveal fluctuations in annual precipitation, with the lowest level of precipitation recorded in 2014 and 2022 at 472.0 mm and 333.4 mm, respectively, and a peak in 2016 at 799.0 mm. However, post-2016, precipitation levels began to decline, reaching 564.8 mm in 2020 and 515.4 mm in 2023. This downward trend raises concerns about water availability and its impact on local ecosystems and agriculture. In 2014, the SPI was (-0.522), indicating dry conditions, while 2019's SPI of (2.220) reflected a wetter year. As the years progressed, the SPI showed increasingly negative values, with 2020 reaching (-0.078), highlighting persistent drought conditions that threaten vegetation and hydrology. The range of

SPI in Figure 4 demonstrates fluctuations over the years. The relationship between precipitation and SPI underscores the risks of declining water availability for vegetation. Drought conditions can lead to reduced plant health, lower productivity, and increased vulnerability to pests, further disrupting ecosystems. To analyze seasonal fluctuations, the average water level as shown in Table 1, was calculated by dividing the data into seasons. Seasonal averages were computed to show fluctuations. The average is calculated by dividing the total number of values by their sum, Xi= is each distinct value, and n= is the number of values, The formula is shown in Equation 4:

$$\text{Average} = \frac{\sum x_i}{n} \tag{4}$$

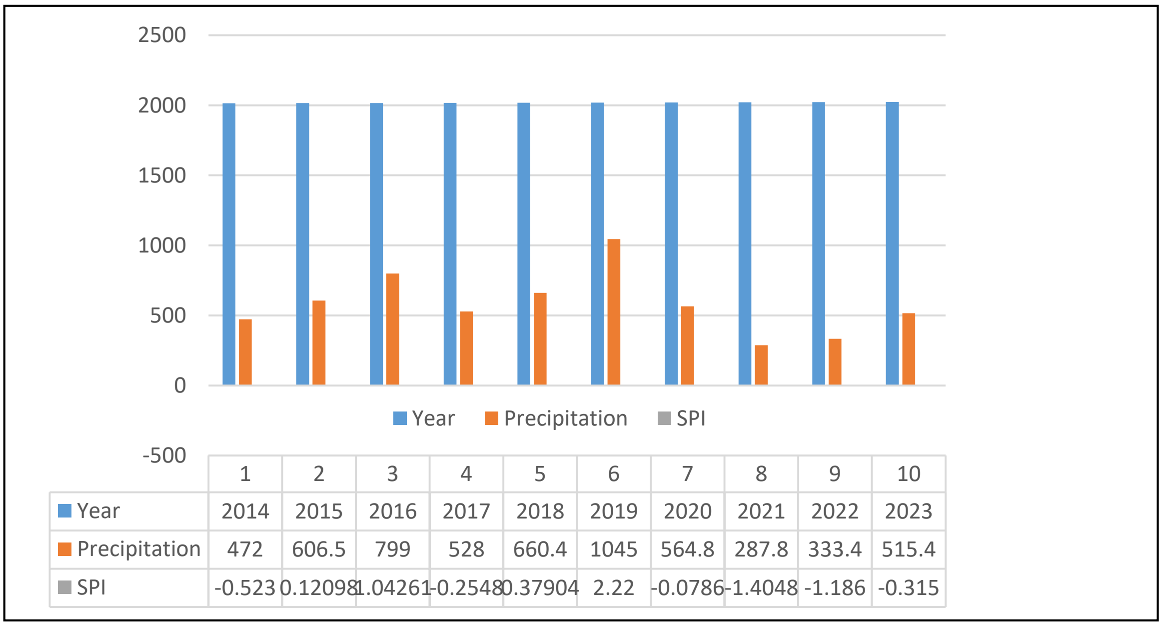

Figure 4. Shows the range of SPI from 2014 to 2023.

Table 1. The Standardized Precipitation Index (SPI) in Dokan Lake for 10 years (Kurdistan Regional Government, Ministry of Agriculture and Water Resources, 2024).

Year	Precipitation (mm)	SPI
2014	472.0	-0.522
2015	606.5	0.120
2016	799.0	1.042
2017	528.0	-0.254
2018	660.4	0.379
2019	1045.0	2.220
2020	564.8	-0.078
2021	287.8	-1.404
2022	333.4	-1.186
2023	515.4	-0.315

3.3. Water Level and Area of Dokan Lake

The water levels at Dokan Lake, as shown in Table 2, reveal distinct seasonal patterns from 2014 to 2023. Winter consistently exhibits the lowest average water levels over the years. For example, in 2014, the winter level was 479.78 meters, slightly increasing to 487.09 meters by 2023. In spring, the water level was 492.49 meters in 2014, peaking at 501.81 meters in 2020 before slightly decreasing to 493.31 meters in 2023. During summer, the highest water levels were observed, ranging from 490.9 meters in 2014 to 502.48 meters in 2020. In 2014, the autumn level was 490.3 meters, rising slightly to 486.04 meters by 2023.

Table 2. Water level of Dokan Lake (Kurdistan Regional Government, Ministry of Agriculture and Water Resources, 2024).

Water level (m) Years	**Winter**	**Spring**	**Summer**	**Autumn**	**Annual Average**
	Seasonal Average				
2014	479.8	492.5	490.9	490.3	488.3
2015	485.7	489.8	490.3	485	487.7
2016	493.2	502.3	505.2	499.6	500.1
2017	496.9	500.8	502.0	498.5	499.6
2018	494.8	500.9	500.2	493.9	497.5
2019	500.7	510.2	508.8	501.8	505.4
2020	495.9	501.8	502.5	496.7	499.2
2021	492.9	496.6	495.0	490.9	493.9
2022	489.5	493.9	493.8	489.7	491.7
2023	487.1	493.3	493.5	486.0	489.9

As shown in Figure 5, in 2014, the map of the lake displayed a substantial expanse of water cover showing that climatic parameters have a significant impact on the water level of Dokan Lake. As noted, the lake's area in 2014 was 116.8005 Km^2, which increased to 133.0142 km^2 in 2015, marking a noticeable expansion. The rates of inflow and outflow significantly influence the fluctuations in Dokan Lake's water level. In 2016, the area increased to 229.1078 Km^2, before decreasing to 208.2525 Km^2 in 2017.

In 2018, as shown in Figure 6, the map of the lake showed a slight decrease in water cover to 193.6055 km^2. However, in 2019, the lake reached its highest surface ever, at 250.6235 km^2. This was followed by a reduction in 2020 to 209.5325 Km^2. In 2021, the area was further reduced to 143.623 Km^2.

As shown in Figure 7, the maps for 2022 and 2023 show changes in water coverage. In 2022, the area increased slightly to 157.4221 Km^2. In 2023, the area decreased to 152.8236 Km^2. As shown in Figure 8, the area of Dokan Lake fluctuates over the years.

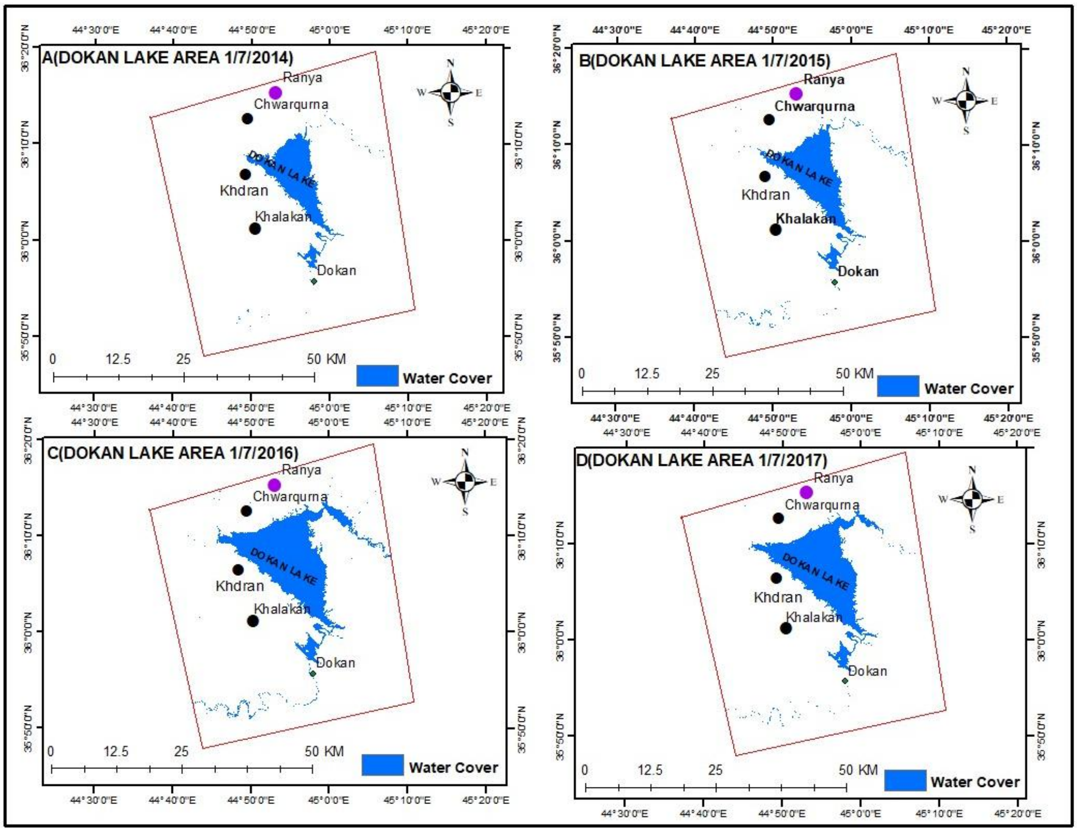

Figure 5. Shows the Dokan Lake water area during the study years from 2014 to 2017.

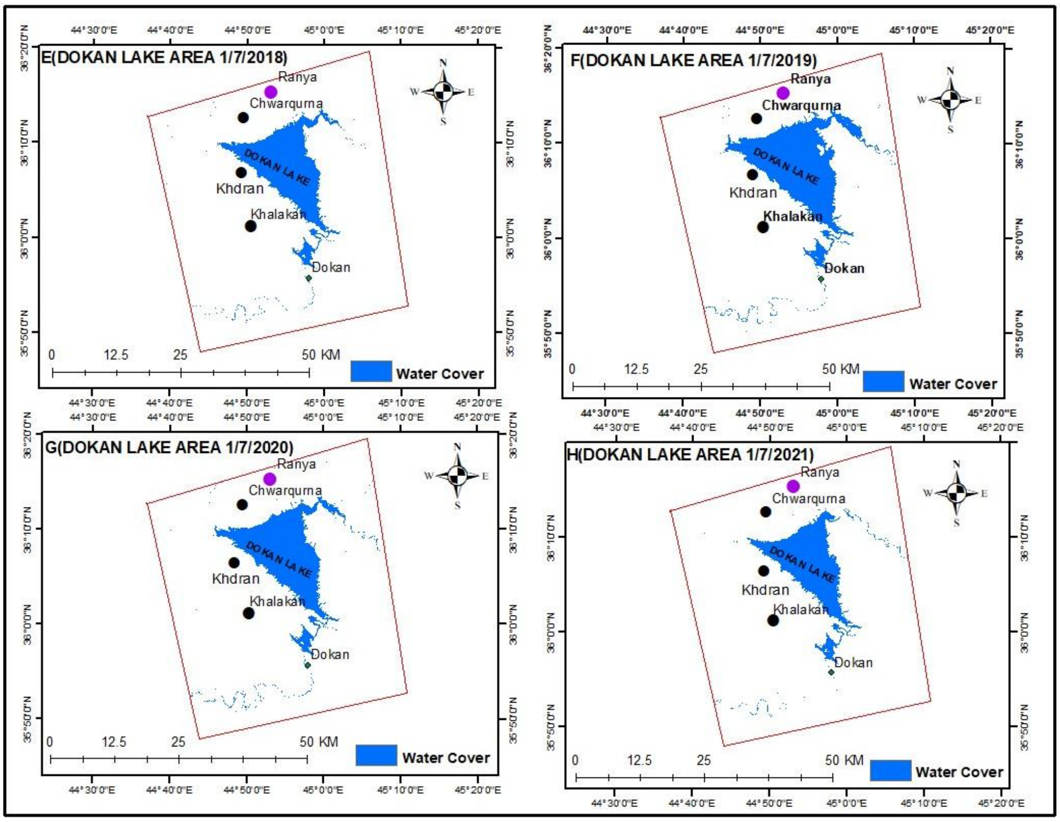

Figure 6. Shows the Dokan Lake water area during the study years from 2018 to 2021.

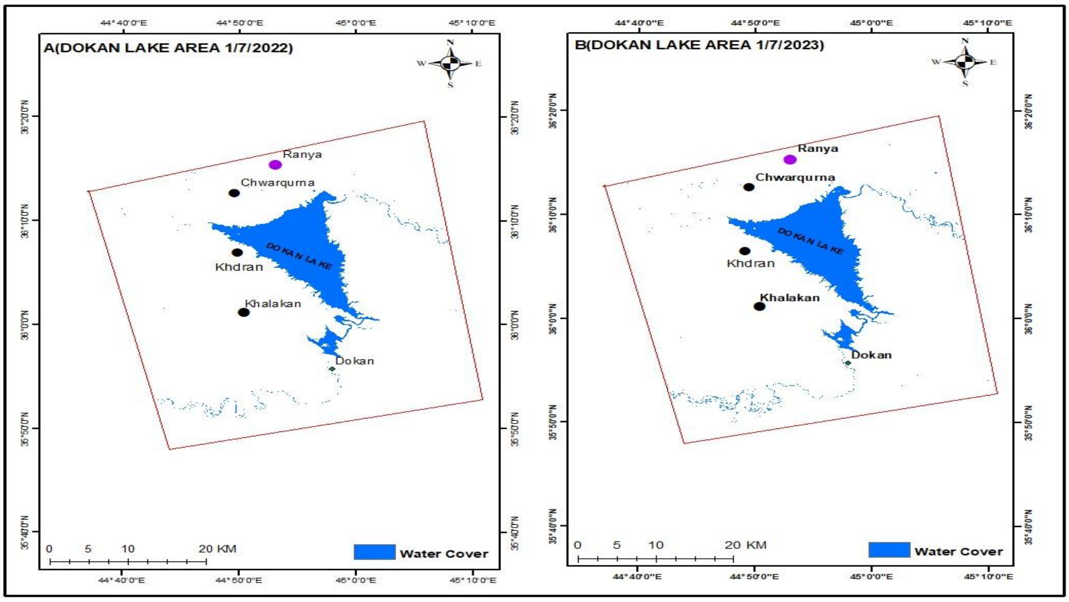

Figure 7. Shows fluctuation in the Dokan Lake water area during the study years from 2022 to 2023.

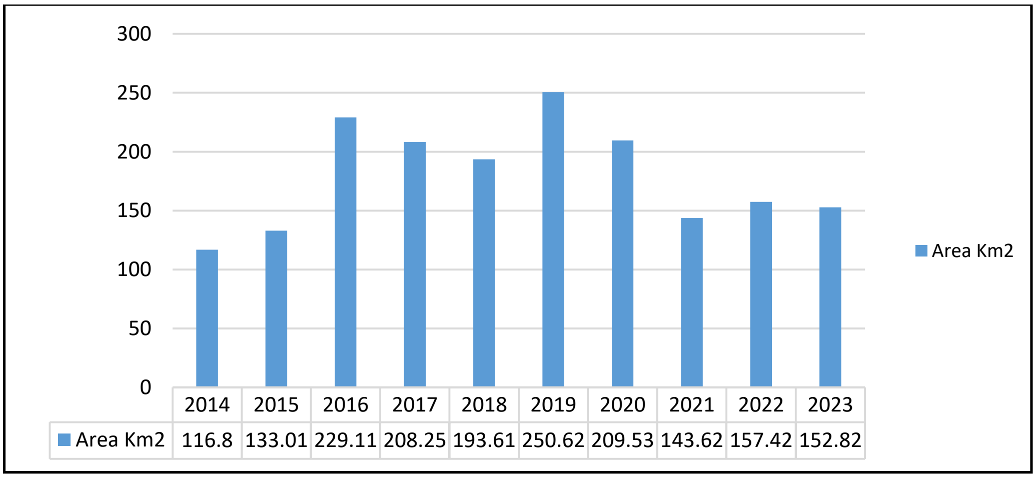

Figure 8. Shows area of the Dokan Lake from 2014 to 2023.

3.4. VCI (Vegetation Condition Index)

In this study effect of water level on vegetation in the surrounding areas of Dokan Lake was detected. Table 3 Summarizes the area of drought severity categories in the Dokan region from 2014 to 2023 using the VCI. In particular, extreme drought peaked in 2014 at 485.6 Km^2 (23.2%) but increased significantly to 1045.3 Km^2 (50%) in 2022. Severe drought also decreased from 105.5 Km^2 (5%) in 2014 to 521.74 Km^2 (24%) in 2023. Areas with moderate drought remained relatively stable, while areas with mild drought showed a gradual decrease after 2019. Areas with very mild drought were minimal, with a slight increase in recent years. Overall, the data indicate an improvement in drought conditions in the Dokan. Figure 9 shows variability over time in the area of the VCI-based drought classifications according to annual total vegetation cover.

Table 3. Area (Km^2) and Percentage (%) of the VCI-based drought severity categories in the Dokan area from 2014 to 2023.

Drought Severity Categories Based on VCI (2014-2023)					
Drought Severity Year	Extreme VCI<=10	Severe 10<VCI<=20	Moderate 20<VCI<=30	Light 30<VCI<=40	Very-Light VCI> 40
2014	485.6Km² %23.2	105.5Km² %5	121.2Km² %5.8	122 Km² %5.8	125.4Km² %60
2015	704.4 Km² %33.7	530.4 Km² %25.3	360.4 Km² %17.2	304.6 Km² %14.5	188.8 Km² %9.04
2016	601.7 Km² %28.8	601.2 Km² %28.7	407.5 Km² %19.5	283.2 Km² %13.5	195.1 Km² %9.3
2017	539.3Km² %25.8	577.6 Km² %27.6	391.7 Km² %18.7	305.4 Km² %24.6	274.7 Km² %13.1
2018	607.6 Km² %29	570.6 Km² %27.3	385.2 Km² %18.4	293.1 Km² %14	232.3 Km² %11.1
2019	297.8 Km² %14.2	485.6 Km² %23.2	391.3 Km² %18.7	301.7 Km² %14.4	612.4 Km² %29.3
2020	311.14 Km² %14.8	484.1 Km² %23.2	369.7 Km² %17.7	360.5 Km² %17.2	563.4 Km² %26.9
2021	661 Km² %31.6	505.5 Km² %24.2	325.6 Km² %15.5	271.2 Km² %12.9	325.5 Km² %15.5
2022	1045.3 Km² %50	353.4 Km² %16.9	254.3 Km² %12.1	222.7 Km² %10.6	212.8 Km² %10.1
2023	398.3 Km² %19	521.74Km² %24	406.1 Km² %19.4	356.1 Km² %17	406.4 Km² %19.4

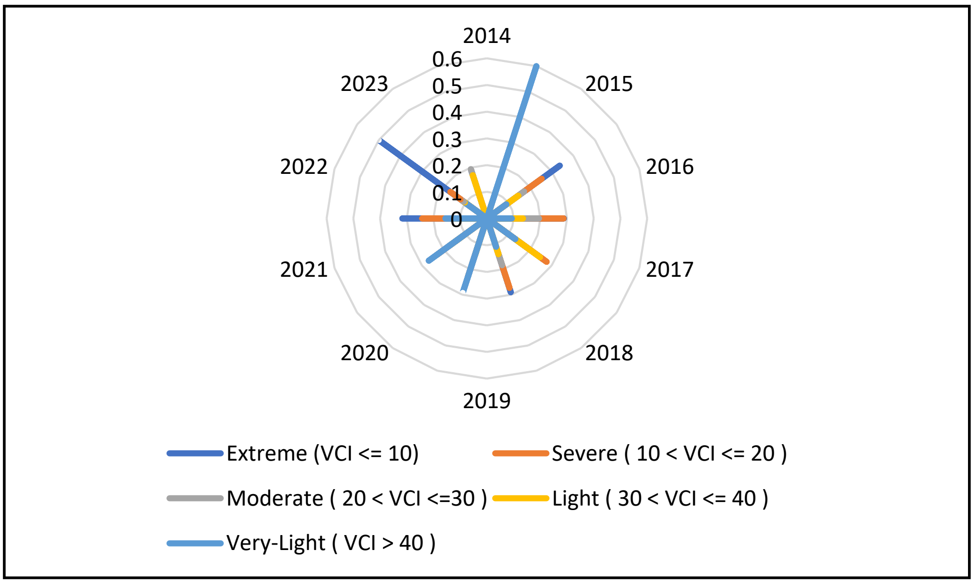

Figure 9. Variability over time in the area of the VCI-based drought classifications according to annual total vegetation cover.

As shown in Figures 10, 11, 12, 13, and 14, the vegetation around Dokan Lake has experienced fluctuations in health over the years, influenced by climatic parameters and management practices. In 2015, the area covered by vegetation decreased, and the area affected by severe drought grew by 530.4 Km^2 (25.3%). From 2014 to 2023, the drought severity class ranges from mild to severe according to Table 3 and Figure 9. During the dry years, when most of the region experienced moderate and severe drought, the extremely severe drought spread to the entire study area. However, the largest class area was recorded in 2015, 2018, and 2021 (33.7%, 29%, and 31.6%), according to the first-highest area (VCI<=10) (Table 3 and Figure 9).

The analysis in Figure 15 shows climatic parameters, especially parameters affecting SPI. Fluctuations in the lake level are evident, with the largest expansion in 2019 and the smallest in 2014. Despite higher rainfall in 2015, the lower discharge contributed to the decrease in the lake's surface area. Drought conditions in the Dokan region have improved over time, with areas of extreme and severe drought decreasing. SPI data found significant fluctuations in precipitation, with an extreme drought that occurred in 2020. The correlation between SPI and water levels indicates a moderate positive correlation. Correlation analysis between water levels and the SPI over the past years reveals a positive correlation, as evidenced by a Pearson's Correlation Coefficient (r) is 0.44, and the P-value is 0.034 < 0.05, at the alpha level of 0.05, this value shows that the correlation is statistically significant. According to the result, P-value < 0.05, so there is enough evidence to reject the null hypothesis, indicating that there is a significant effect or relationship.

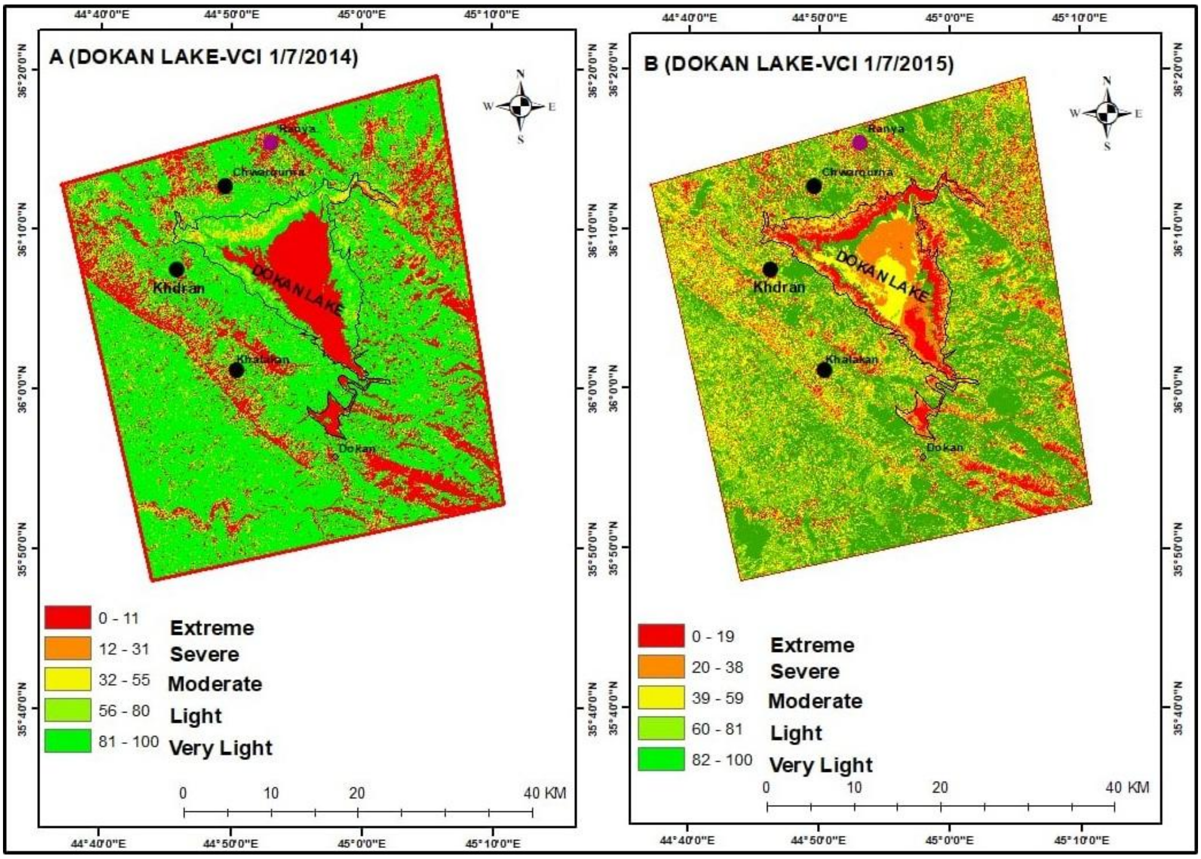

Figure 10. Shows the VCI analysis for the Dokan Lake and the study areas for the years 2014 and 2015, respectively.

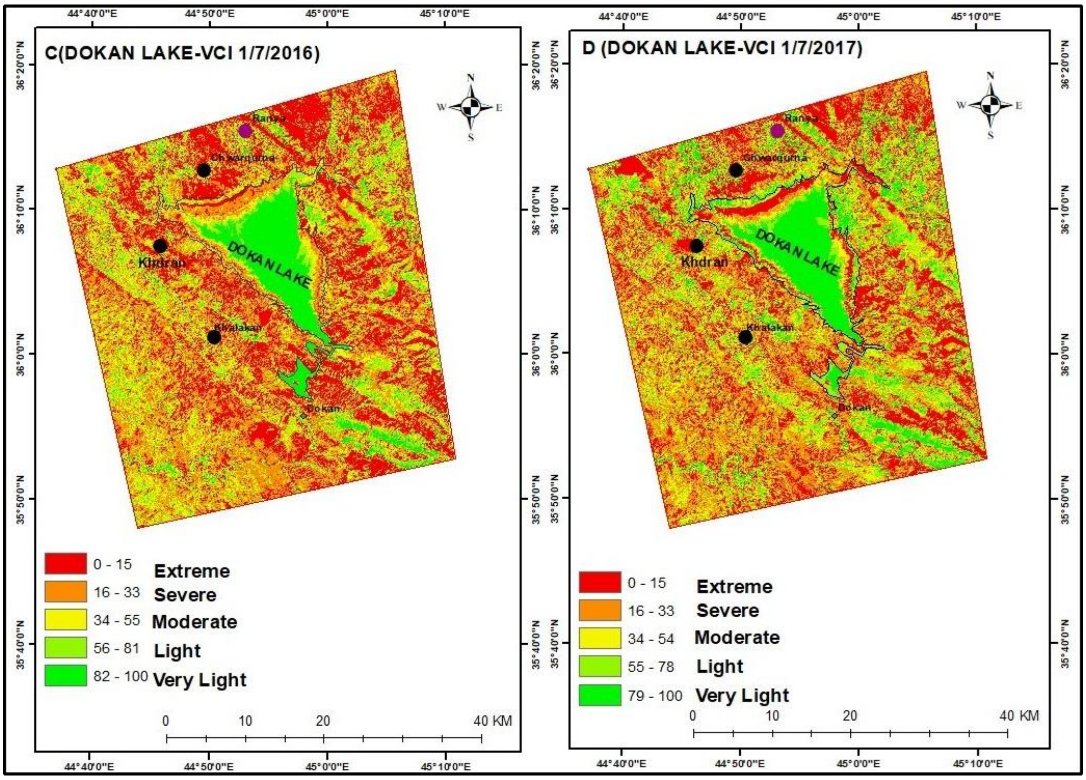

Figure 11. Shows the VCI analysis for the Dokan Lake and the study areas for the years 2016 and 2017, respectively.

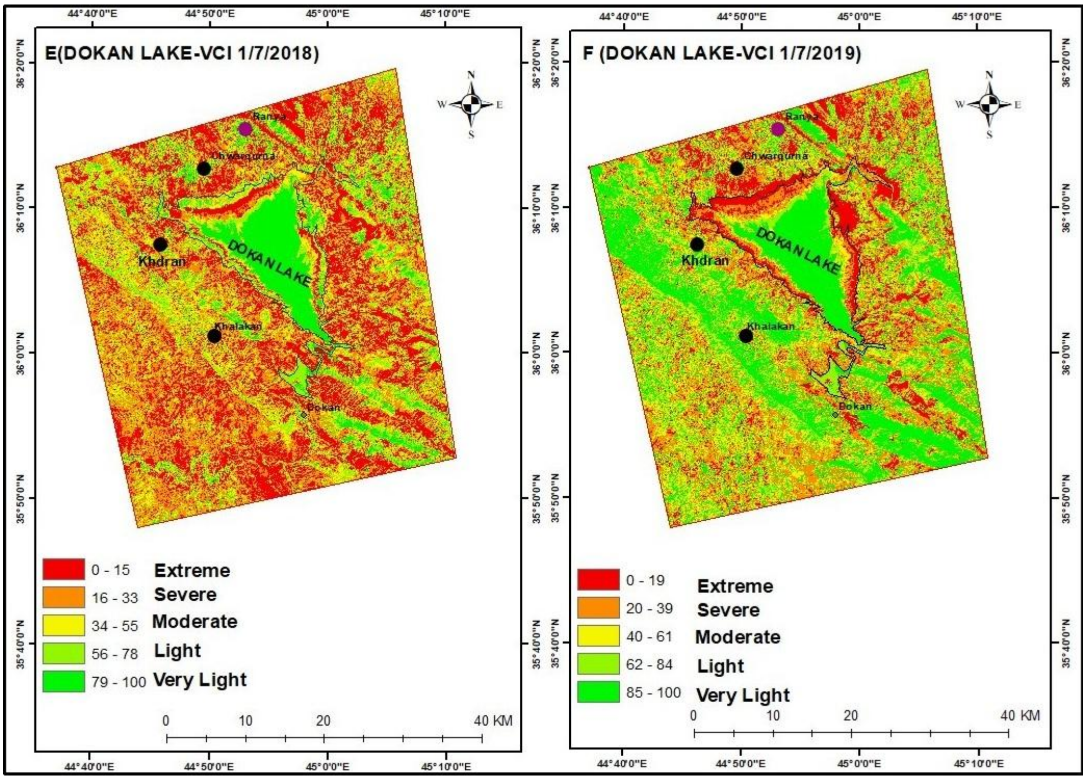

Figure 12. Shows the VCI analysis for the Dokan Lake and the study areas for the years 2018 and 2019, respectively.

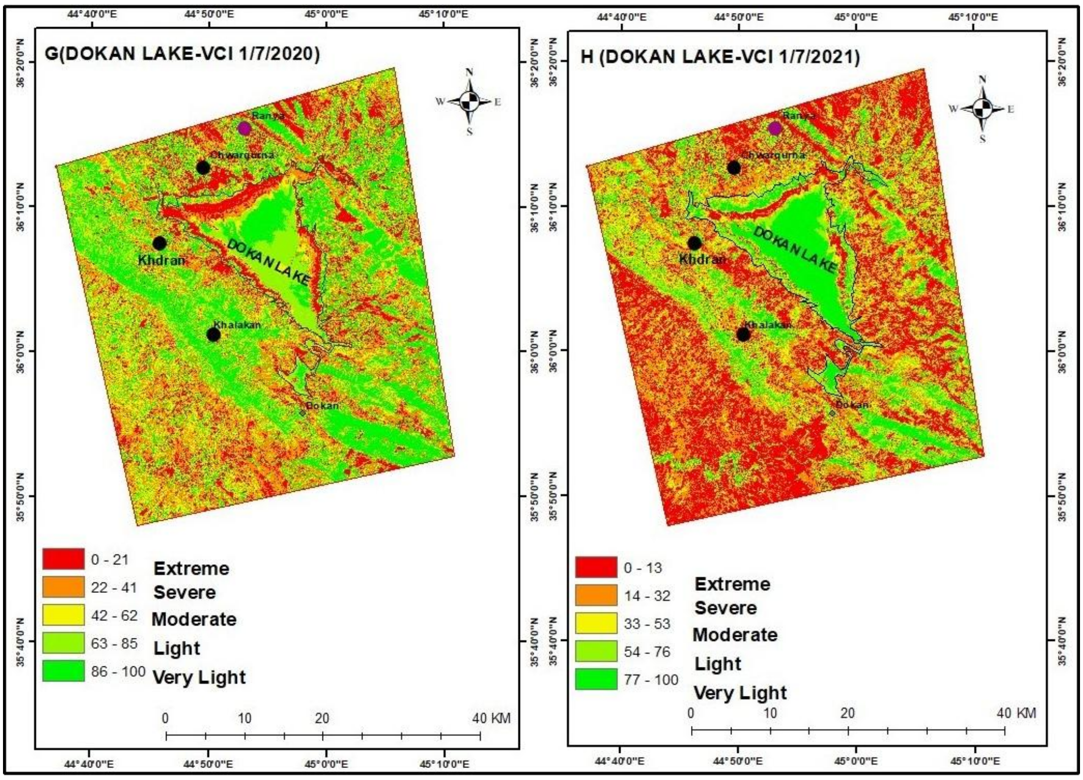

Figure 13. Shows the VCI analysis for the Dokan Lake and the study areas for the years 2020 and 2021, respectively.

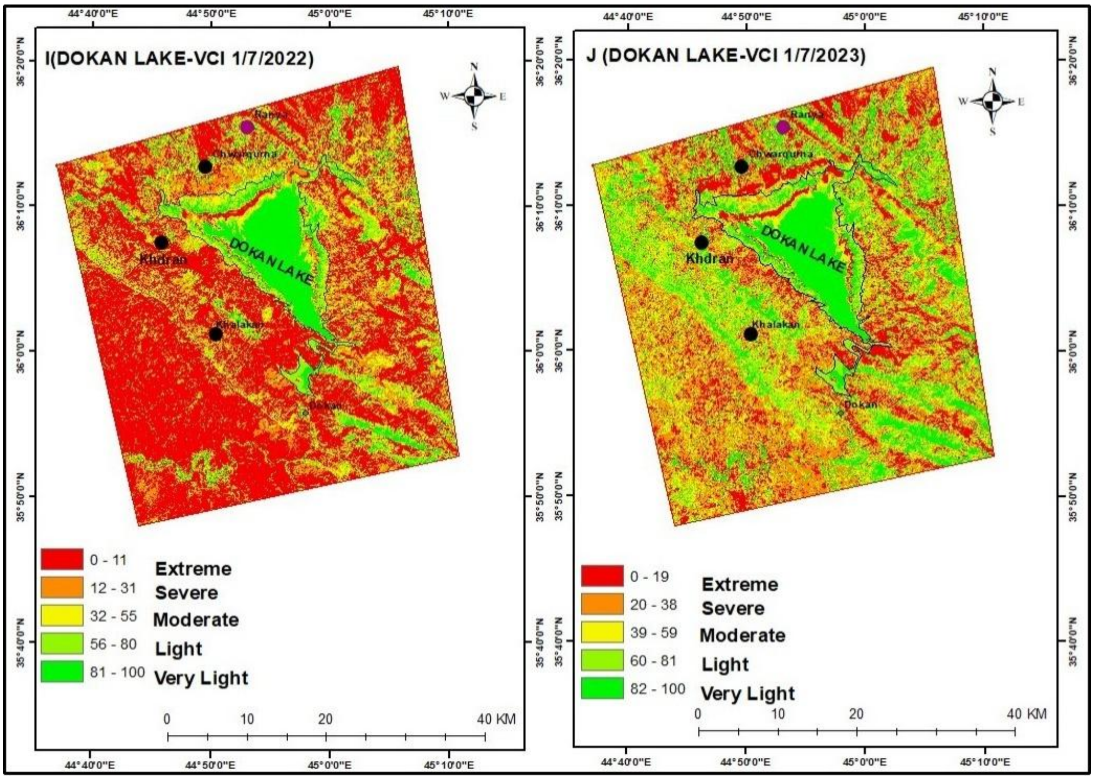

Figure 14. Shows the VCI analysis for the Dokan Lake and the study Areas for the years 2022 and 2023, respectively.

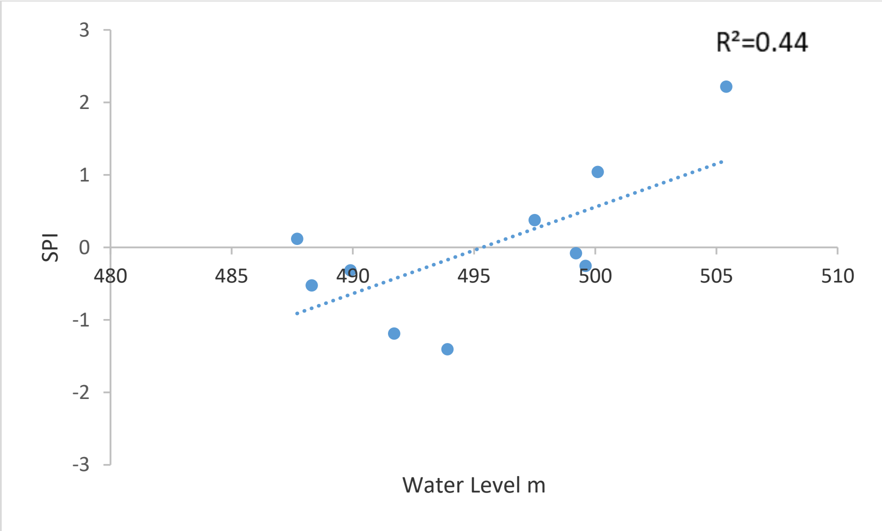

Figure 15. Scatterplot relationship between the water level of Dokan Lake and SPI.

5. Discussion

This study evaluates the impact of recent climate change on the water levels of Dokan Lake and the surrounding vegetation health by analyzing hydrological data. The analysis reveals significant fluctuations in the lake's water levels and area, as observed from satellite images influenced by precipitation (Chopra, 2006; Baboo & Thirunavukkarasu, 2014). Hydrological data from Dokan Lake indicated notable variations in its water levels over several years. Landsat 8/9 OLI and TIRS are ideal for studying Dokan Lake due to their ability to detect precipitation changes and assess the surrounding environment using consistent, high-quality multispectral data. As shown in Table 2, in 2014, the average water level of the lake was 488.4 m, but it shrank to its lowest recorded size of 487.7 m in 2015. The area then increased to 500.1 m in 2016 before fluctuating again in subsequent years. In 2017, the water level reached 499.6 m, then decreased to 497.5 m in 2018. In 2019, it reached 505.4 m, then dropped to 499.21 m in 2020. In 2021, the water level ultimately reached 493.9 m, and in 2022, it was 491.3 m. Finally, in the last year, 2023, it reached 489.9 m. These fluctuations are largely attributed to changes in the lake's inflow and outflow, which are driven by precipitation patterns. The fluctuations highlight the influence of parameters like outflow, inflow, and rainfall that impact the lake's size (Al-Ansari, 2013). The SPI was used to assess drought and normal conditions at Dokan Lake over 10 years. SPI data from 2014 to 2023 showed the relationship between climatic conditions and lake water levels, as shown in Table 2.

The SPI data from 1990 to 2013 clearly represents a conversion from early 1990s conditions, which were generally wetter, to later 1990s increasingly dry conditions. A number of years between 1991 and 1995 were moderate to extremely wet, but beginning in 1998, droughts increased in frequency and intensity, with extreme droughts occurring in 2007 – 2008 and 2008 – 2009. All things considered, the trend points to a shift toward longer and more intense dry spells, especially during the 2006 – 2013 window, which may indicate a change in regional climate patterns according to the Kurdistan Regional Government (2024). The current study data presented in Table 1 highlight significant fluctuations in annual precipitation over the study period, with a notable decline in precipitation levels post-2016. While 2016 saw a peak of 799.0 mm, but dropped to 333.4 mm by 2022, signaling a concerning trend in water availability. This decline is compounded by the corresponding decrease in the SPI, which shifted from -0.522 in 2014 (indicating dry conditions) to -0.078 by 2020, signifying increasingly severe drought conditions. These persistent droughts threaten local ecosystems and agriculture, with reduced precipitation potentially harming vegetation, lowering agricultural productivity, and increasing susceptibility to pests. Variations in precipitation and discharge rates are related because higher precipitation usually results in higher discharge from runoff, whereas lower precipitation leads to lower discharge. Predicting flooding, droughts, and water availability all depend on this relationship. The relationship between precipitation and SPI underscores the growing risks of water scarcity, highlighting the importance of monitoring these trends to mitigate their impact on both natural and human systems. A similar SPI-based analysis conducted on Darbandikhan Lake also provided additional context for understanding the hydrological dynamics of the region (Azeez *et al*., 2020).

The vegetation around Dokan Lake has experienced fluctuating health due to a combination of climatic conditions, as shown in Figures 10, 11, 12, 13, and 14. In 2014, the recovery indicates that management initiatives and better weather conditions contributed to the restoration of vegetation health. Nonetheless, in 2015, severe stress, likely due to drought and land degradation, impacted the ecosystem. Despite setbacks in 2016 and 2018, when stress levels increased once more, there was improvement in 2017 and 2019, suggesting improved environmental conditions and better management. Another stressor occurred in 2020, but by 2021, vegetation health had recovered, demonstrating the benefits of ongoing management and advantageous climatic conditions. Vegetation had mostly recovered by 2023, indicating that even though the ecosystem is susceptible to changes in the climate, adaptive management techniques and advantageous environmental conditions can result in a substantial recovery. These results demonstrate how crucial the long-term maintenance of ecosystem health depends on climate resilience and sustainable management. This is especially noticeable in areas such as Iraq, particularly in the vicinity of Dokan Lake. In regions like South America, Africa, Asia, North America, and Europe, there was a strong correlation between agricultural production and the VCI, particularly during critical crop growth periods (Kogan, 1986; Gaznayee & Al-Quraishi, 2020). Satellite images help identify and map dry seasons in agriculture. The VCI is particularly useful for early assessments of crop yields (Unganai & Kogan, 1998). The effects of climate change on vegetation near Dokan Lake were assessed using the VCI, which helps evaluate how vegetation reacts to changing weather patterns, particularly during droughts. Gain a better understanding of how climate change impacts vegetation and water resources by examining how changes in precipitation and other climatic factors impact vegetation health and hydrological processes in the Dokan area through the analysis of the VCI (Vicente-Serrano, 2006).

6. Conclusions

The examination of Dokan Lake's water levels and dry spell conditions demonstrates the important influence of climatic factors, particularly precipitation and water level. Variations in the lake's area, like its expansion in 2019 and decline in 2015, demonstrate how precipitation and runoff influence water levels. The results show that Dokan Lake's area varies, especially in 2014 and 2015, when it was less than in prior years. The rate of vegetation increased in 2019 as a result of the higher precipitation rate. Water level and SPI have a significant correlation since Pearson's Correlation Coefficient (r) is 0.66, and the P-value is 0.034, which indicates that the result is a statistically significant P-value < 0.05. Additionally, the SPI for these three years (2016, 2018, and 2019) showed wetter conditions than the other years, as indicated by positive SPI values. The progression of dry spell conditions over the observed period and the decrease in extreme and very dry seasons reflect positive changes in the climate of the region. The SPI and water levels have a positive correlation relationship, indicating how important it is to monitor these factors for effective vegetation management and water management, especially in drought-prone areas. Strategies like rainwater collection and effective irrigation systems must be put into place, given the significance of the SPI's findings and the effect they have on water levels. Remote sensing and field surveys can be used to monitor vegetation. Furthermore, it is crucial to develop drought preparedness plans that involve community involvement through awareness campaigns. Encouraging sustainable land management, such as soil conservation and planting new trees, and developing guidelines for funding assistance and water usage restrictions will further improve vegetation health and resilience to drought. To reduce water loss, consider putting solar panels on the surface of Dokan Lake to create shade, cool the water, and produce renewable energy while reducing evaporation. Promoting water-efficient technologies, collecting rainfall for irrigation, and routinely inspecting and repairing distribution system leaks will strengthen water management initiatives in the region. By encouraging sustainable farming practices and increasing community awareness of water conservation, the overall effectiveness of water management efforts can be enhanced.

Author's contribution

In this paper, I developed a research framework to assess the impacts of climate change on vegetation and hydrology in Dokan Lake. I conducted extensive fieldwork and data collection utilizing satellite images and advanced analytical techniques to evaluate changes in vegetation cover and water levels. I performed data analysis and interpreted the findings, contextualizing discoveries through a comprehensive literature review and developing recommendations. Additionally, I collaborated with an advisor to refine methodologies and presented my findings at academic presentations, contributing to the broader understanding of climate change impacts on ecosystems.

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