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Vegetation Monitoring Assessment in Lakes Using Sentinel 2 Data; Case Study (El-Burullus Lake, Egypt)

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A B S T R A C T
Vegetation monitoring and surface water area changes for lakes and wetlands are necessary for biodiversity conservation and restoration. Based on Sentinel-2 remote sensing imageries with 10 m resolution using SNAP program and ArcGIS software were used in this study to assess the change of El-Burullus Lake from January 2019 to January 2022. The NDVI and NDWI were spatially mapped to assess the moisture content of vegetation and monitor the changes of surface water area and vegetation along the Lake. The results of variance test's homogeneity for NDVI and NDWI, obviously revealed that the ratio of variances or standard deviations is statistically significant ($p < 0.05$). For spatial autocorrelation, Moran's I results were positive values, which indicated a positive correlation for both indices NDVI and NDWI and almost the similar behaviour. Moreover, the regression analysis, between NDVI and NDWI was observed to be very strong along El-Burullus Lake. Consequently, based on the findings of the analysis, both indices NDVI and NDWI can reasonably represent a better understanding of the surface water content change in El-Burullus Lake. However, the NDVI proved its capability of vegetation monitoring and its sensitivity to the amount of liquid water content in vegetation canopies.

1. Introduction

Lakes and wetlands are of ecological importance, however, multiple human activities, have adversely influence as untreated wastewater discharges, and land reclamation, on their conservation potential globally [1], [2], and [3]. As result, numerous studies have highlighted on investigating the changes of water bodies ecosystem and monitoring the vegetation characteristics [4], [5] and [2].

In 1970, first launch of the satellites and to date, remote sensing (RS) has fascinated people with capturing images, which allows us to better understand the world across a wide frame [6]. RS technology is an efficient tool for environmental monitoring changes of large-scale areas, water pollution, and vegetation activity over longer time periods [7]. RS images are considered a comprehensive technique with an accuracy, rapid data collection, less costly and time-consuming, providing spatial and temporal aspects of data easily than in situ observations [8], [9], [10], [11], [6], and [12]. Although, multispectral imagery has proved its success to be the most commonly technology for mapping studies, researchers faced difficulties due to some of the satellite sensors with low spatial resolution for supervising small scale areas [13]. In 2015, the launch of Multispectral Imager's (MSI) Sentinel-2 sensor can significantly enhance the spatial resolution with (10 m, 20 m and 60 m) in 13 spectral bands, distributed along the visible/near-infrared (VNIR) and short-wave infrared (SWIR) spectral bands for more accuracy [14]. Therefore, Sentinel-2 is considered the best solution with better spectral resolution in the near infrared region, which is very useful in vegetation studies [15], and [16].

Over the last decades, numerous studies have been applied the satellite-based remote sensing to reveal changes in land cover change and open water area, as well as water characteristics and vegetation [17]. Whereas vegetation is considered one of the main components of terrestrial ecosystems and is a good indicator in changes monitoring [4]. Thus, spectral indices have been utilized to enable more efficient monitoring of vegetation progress and coverage change, as the Normalized Difference Vegetation Index (NDVI) and the Normalized Difference Water Index (NDWI) [18], and [3].

The NDVI is very sensitive and has been applied widely as the most common tool in vegetation assessment studies [19], [20], and [21]. NDVI represents the vegetation greenness on surface by measuring the difference between near-infrared radiation (NIR) (which terrestrial vegetation) and red spectral (RED) reflectance (which vegetation absorbs) [22], and [23]. The other index, NDWI has been utilized to monitor water content in the vegetation canopy, derived by calculating the GREEN band (visible green) and the NIR [24]. NDWI which was firstly proposed by Gao in 1996 [24], proved its sensitivity in water content variations over large areas [25], and [26]. Therefore, NDVI and NDWI are the best choice to better represent the spatial and temporal variation for vegetation of lakes.

In 1988, RAMSAR Convention, an intergovernmental conservation association on worldwide wetlands, was declared El-Burullus Lake as a natural protectorate along the Mediterranean coast in Egypt [27]. Due to its economic importance as natural resources and is considered the second-largest lake in Egypt. Unfortunately, El-Burullus Lake is highly threatened of deterioration and surface water area reduction by anthropogenic activities, eutrophication, and untreated wastewater and agriculture drainage effluents [28]. Therefore, there are a crucial need to detect the spatiotemporal changes over El-Burullus Lake.

As a result, the objective of this study was to conduct an evaluation one of the most socio-economic coastal lagoons (El-

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Burullus Lake) using spectral indices; NDVI and NDWI, based on Sentinel-2 imageries for vegetation monitoring and open water area changes. The spatiotemporal changes were detected for all free cloud cover and available imageries between the period from January 2019 and January 2022.

2. Materials and Methods

2.1. Case Study

El-Burullus Lake is the second-largest natural lagoon in Egypt as a shallow brackish lake, which extended along the Mediterranean Nile delta of Egypt, separated from the northern border by narrow coastal sand barriers and connected to the sea at its north-eastern boundary through a small outlet (Boughaz El-Burullus). The importance of this outlet is to provide the chance for water exchange and the enhancement of lake ecosystem. El-Burullus Lake covers an area of about 455 km^2, extends between the two main branches of Nile River (Rosetta and Damietta), among longitudes 30° 30' E and 31° 10' E and latitudes 31° 21' N and 31° 35' N (Figure 1). It extends about 54 m long parallel to the Mediterranean coast, width varies between 3 and 12 km, and water depths ranges from 0.4 to 2.5 m [2].

About 75 low islands characterize El-Burullus Lake, which are scattered naturally from south to north with a variety of surface areas [29]. Many of these islands are formed of mud from lake sedimentation, while some are from sand. Such these islands are considered as significant paleogeographic indicators of relict deltaic features such as beach ridges and dunes. El-Burullus Lake borders are irregular and mostly bounded by marshes, agriculture lands, fish farms, and urban areas [30]. El-Burullus' water body is discharged through eight agricultural drains, besides connected with Nile fresh water from Brimbal canal in the western side of the lake [31]. About 3904 million m^3/year of industrial, domestic, agriculture and fish farms wastewater are discharged to the lake [32].

Over the last four decades, several studies indicated that the lake suffers from dramatic deterioration and reduction of surface area, due to as the increasing irregulated urbanization, intensive anthropogenic activities, and recently Climate-Change influence, which enhanced eutrophication and vegetation growth [33], [34], [

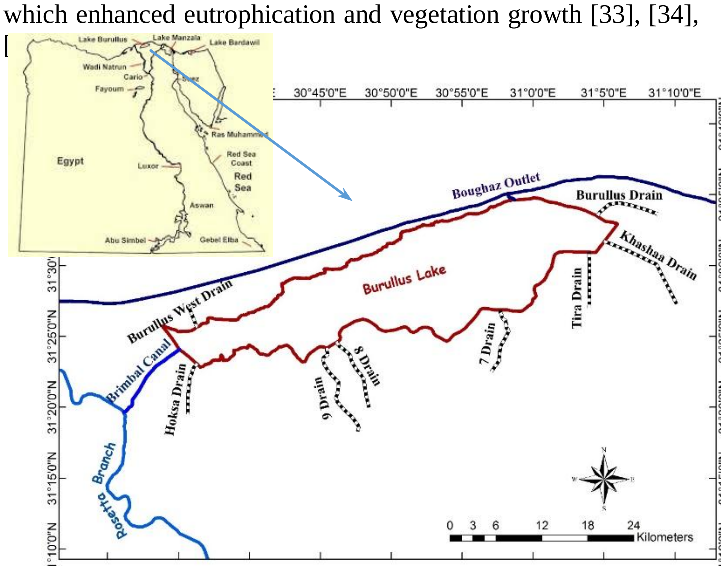


Figure 1: location map of El-Burullus Lake connected with agricultural drains and the Nile River.

2.2. Sentinel-2 data imagery

The Sentinel-2 mission is providing a global coverage around the Earth's surface every 5 days, and this short repetition cycle improves high-resolution optical imagery for mapping the surface water changes. For the present study, freely available sentinel-2 images were downloaded from the U.S. Geological Survey (USGS) website Earth Explorer (https://earthexplorer.usgs.gov/). A time series of 23 Sentinel-2 monthly images distributed irregularly between January 2019 and January 2022 with free cloud cover, were utilized for the analysis. The Sentinel Application Platform (SNAP) software was used in this study, which is freely available and have been developed to facilitate the utilisation, displaying and processing the remotely sensed data [37]. By the SNAP, the images were resampled to 10 m (B2 band) and subset to the interested area. Moreover, mosaics were then performed for the corrected images of El-Burullus Lake.

2.3. Normalized Difference Vegetation Index (NDVI)

Along the last decades, NDVI has been widely used and commonly as remote sensing indicator for vegetation monitoring [23], and [25]. This index is derived from the normalized difference between near-infrared spectral (NIR) and visible red (RED) wavelengths, as shown in Equation (1):

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

The value of NDVI ranges from - 1 to 1, where higher positive values refer to dense green vegetated areas. While the values of NDVI close to zero and negative values, imply to bare soil, built-up areas and water coverage [22].

2.4. Normalized Difference water Index (NDWI)

The NDWI is effectively applied for measuring the moisture content, detecting changes of water content in water bodies, and enhancing their presence in satellite image [24]. This parameter is calculated using the NIR and GREEN spectral bands to highlight open water content, as shown in Equation (2):

$$NDWI = \frac{GREEN - NIR}{GREEN + NIR} \quad (2)$$

The range of NDWI values are from - 1 to 1, where positive values correspond to water bodies and negative ones imply to soil and low terrestrial vegetation [38].

2.5. Statistical analysis

The derived NDVI and NDWI from SNAP program using sentinel-2 data were analysed for basic raster statistics. Using Minitab software with a significance level of $p < 0.05$, the seasonal differences of variability for NDVI and NDWI along El-Burullus Lake was applied by performing the Bonett's and Leven's variance test. Moreover, using Geographic Information System (GIS) (ArcGIS software), Moran's I Index was quantified to assess the spatial autocorrelation in the lake, as one of the main indicators for evaluating spatial autocorrelation pattern [39]. The spatial statistic Moran's I measures the spatial correlation between feature geographical locations and associated values without differentiating between low or high values [40]. This index assesses the spatial randomness' pattern which may be clustered, random, or dispersed. Moran's I is statistically derived as the following Equation (3) [25]:

$$I = \frac{\sum_{i=1}^{n}\sum_{j=1}^{n} W_{ij}\,(x_i - \bar{x})\,(x_j - \bar{x})}{s^2 \times \sum_{i=1}^{n}\sum_{j=1}^{n} W_{ij}} \qquad (3)$$

Where the number of observations is (n), the value at point i is (xi), the value at the neighbour of point i is j, the mean of all observations is $\bar{x}$, the variance of x value is s^2, and the spatial weight of points location i and j using a binary weight matrix. The values of Moran's I ranges from -1 to +1. The positive values indicate that the data have a cluster pattern and consequently spatial autocorrelation. While the negative ones imply that the features are discrete and have spatial dispersion.

Additionally for our study area, a regression analysis was performed to illustrate the correlation between NDVI and NDWI for 2019, 2020, and 2021 years.

3. Results and Discussion

3.1. Image processing

The SNAP program was applied for processing the 23 Sentinel-2 images of El-Burullus Lake along the period between January 2019 and January 2022. The mosaic of processed images was extracted to the lake using GIS software. The area of El-Burullus Lake has not been noticed a significant change during the last three years, as shown in Figure 2. This comes as a result of the Egyptian Government's efforts for the rehabilitation and restoration of El-Burullus Lake, as part of El-Burullus Lake Rehabilitation's Project to preserve and enhance the lake's ecosystem which started in 2018 [36]. The surface water area has estimated about 245 km^2 in 2021, while in 2019 is about 233 km^2.

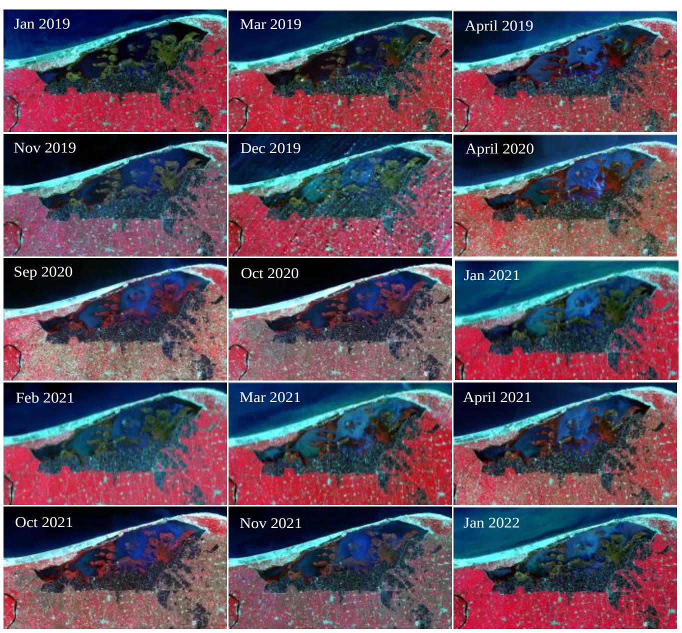


Figure 2: Sentinel-2 false-colour infrared images of El-Burullus Lake along the period between January 2019 and January 2022.

3.2. Normalized Difference Vegetation Index (NDVI)

The NDVI was applied along El-Burullus Lake from January 2019 to January 2022, using SNAP program with 10 m resolution for vegetation monitoring. Table 1 displays the monthly values of NDVI with a total of 64308 points distributed over El-Burullus Lake. In this study, El-Burullus Lake has shown mean values of (0.057 ± 0.224), (0.044 ± 0.228) and (0.060 ± 0.231) in the years 2019, 2020 and 2021 respectively. The NDVI values were divided according to the characteristics of global NDVI distribution, into five categories, namely, non-vegetation coverage and water bodies areas (-1.0 ⩽ NDVI ⩽ 0.0), bare soil, built-up areas, rocks, and sand areas (0.0 < NDVI ⩽ 0.2), low vegetation coverage (0.2 < NDVI ⩽ 0.5), medium vegetation coverage area (0.5 < NDVI ⩽ 0.8), and dense green vegetated areas (0.8 < NDVI ⩽ 1.0), Figure 3. The coverage area according to NDVI values of (0.0 < NDVI ⩽ 0.2), was decreased about 6.8% in 2020, and 11.82% in 2021, Figure 4. This decrease is considered a result of the recent rehabilitation works in El-Burullus Lake.

However, the change of vegetation coverage area along El-Burullus Lake was slightly decreased in 2020 by 3.71%, it was increased in 2021 by 6.38% with 138.68 km^2 from the total area of the lake. This vegetation coverage area was presented about 30% of the total lake area, which resulted due to the contamination from the domestic, industrial, untreated wastewater through drains [36].

These vegetation area results, which were estimated about 135.38 km^2 in 2019, were consistent with the results conducted by Masrya et al., [41] and Abd el-sadek et al., [42], which were reported as 165 km^2 in 2017 and 125 km^2 in 2019, respectively.

3.3. Normalized Difference Water Index (NDWI)

The NDWI was applied along El-Burullus Lake in this analysis to assess the moisture content of vegetation and monitor the changes of water content in water bodies from January 2019 to January 2022. The results of mean monthly NDWI were (0.129 ± 0.266), (0.098 ± 0.257) and (0.066 ± 0.247) in the years 2019, 2020 and 2021 respectively, Table 1. The average NDWI value representing the non-water content (-1.0 ⩽ NDWI ⩽ 0.0), was a non-significant change through the last three years which were 167.1, 168.1, and 167.2 km^2 for 2019, 2020 and 2021 respectively, Figure 4. Consequently, the water content of vegetation and water body according to NDWI values of (0.0 < NDWI ⩽ 1.0), was nearly the same area of 287.9, 286.9, and 287.8 km^2 of 2019, 2020 and 2021 respectively.

These findings of the water lake area were almost closed with the results by Masria et al., [41], and Abd el-sadek et al., [42], where the water lake area was 238 km^2 in 2017, and 342 km^2, in 2019, respectively.

The stability of El-Burullus Lake area is considered one of the great efforts impacts by the Egyptian authorities for protection and restoration the lake ecosystem to achieve the Sustainable Development Goals (SDGs) on the lake level.

3.4. Statistical Analysis

The monthly results of NDVI and NDWI were divided into two groups (winter and summer) seasons, to estimate the Bonett's and Leven's test for assessing the seasonal differences of variability along El-Burullus Lake. Figure 5 illustrates the results of variance test's homogeneity, which obviously revealed that the ratio of variances or standard deviations is statistically significant ($p < 0.05$). These findings were coherent with the results of [43], [22], and [23], who reported that the temperature and seasonal variation had a significant role in vegetation growth.

Moran's I was performed for NDVI and NDWI to identify the spatial autocorrelation between variables and its influence in a location with other attribute values in a different location. In our study using the sentinel-2 images, ArcGIS was utilized to conduct Moran's I for the results of NDVI and NDWI along El-Burullus Lake. Table 2 displays the results of global Moran's I with its respective descriptive (p-value) level and Z-score for the period from January 2019 to January 2022. Regarding to the results in general, the Moran's I values were positive values, which indicated a positive correlation for both indices NDVI and NDWI and almost the similar behaviour. However, for NDVI the spatial pattern of El-Burullus Lake is clustered for all months from January 2019 to January 2022 except February 2021, March 2021, April 2021, and January 2022, are random pattern. While for NDWI, the spatial random pattern is resulted for seven months, which are March 2019, January 2021, February 2021, March 2021, May 2021, June 2021, and January 2022, and the left sixteen months are clustered. Moreover, to present the relation between NDVI and NDWI, regression analysis was applied for 2019, 2020, and 2021 years. The correlation of NDVI and NDWI was observed to be very strong along El-Burullus Lake of R-squared at 96.71%, 98.26%, and 97.97%, for the years 2019, 2020, and 2021, respectively.

Consequently, based on the findings of the analysis, both indices NDVI and NDWI can reasonably represent a better understanding of the surface water content change in El-Burullus Lake. However, the NDVI proved its capability of vegetation monitoring, which is in agreement with Gao [24] who mentioned that NDVI are sensitive to the amount of liquid water content in vegetation canopies.

Applying these indices, which are based on continuously updated spatiotemporal maps, provides us with a comprehensive vision of water quantity and quality management of Lake Burullus, and helps in forecasting and controlling the environmental ecosystem before deterioration.

Table 1: Descriptive statistics (mean ± standard deviation) of NDVI and NDWI, calculated for 23 months of El-Burullus Lake, distributed from January 2019 to January 2022.

	NDVI	NDWI
Jan-2019	0.088 ± 0.229	0.226 ± 0.296
Mar-2019	0.056 ± 0.201	0.160 ± 0.272
Apr-2019	0.109 ± 0.203	0.039 ± 0.224
Aug-2019	0.119 ± 0.247	0.018 ± 0.246
Oct-2019	0.058 ± 0.242	0.115 ± 0.278
Nov-2019	-0.006 ± 0.233	0.185 ± 0.293
Dec-2019	-0.025 ± 0.209	0.159 ± 0.255
Apr-2020	0.088 ± 0.229	0.049 ± 0.252
Sep-2020	0.060 ± 0.242	0.093 ± 0.260
Oct-2020	0.036 ± 0.290	0.149 ± 0.331
Dec-2020	-0.008 ± 0.152	0.100 ± 0.185
Jan-2021	-0.022 ± 0.204	0.163 ± 0.254
Feb-2021	-0.028 ± 0.220	0.183 ± 0.270
Mar-2021	0.067 ± 0.217	0.048 ± 0.241
Apr-2021	0.067 ± 0.242	0.078 ± 0.279
May-2021	0.119 ± 0.226	-0.046 ± 0.205
Jun-2021	0.120 ± 0.195	-0.055 ± 0.162
Jul-2021	0.105 ± 0.219	-0.017 ± 0.198
Aug-2021	0.090 ± 0.227	0.018 ± 0.210
Sep-2021	0.074 ± 0.214	0.050 ± 0.230
Oct-2021	0.055 ± 0.287	0.128 ± 0.330
Nov-2021	0.017 ± 0.292	0.174 ± 0.341
Jan-2022	0.011 ± 0.191	0.115 ± 0.240

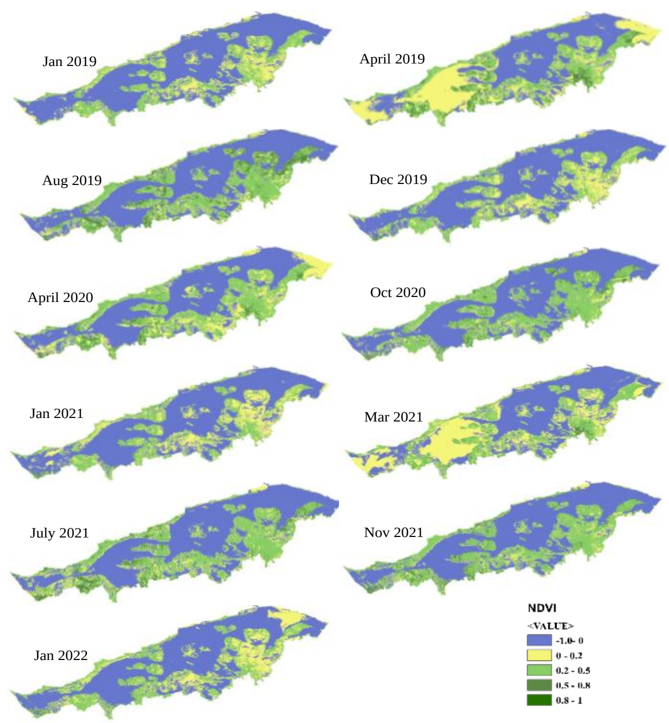


Figure 3: NDVI distribution map of El-Burullus Lake along the period between January 2019 and January 2022.

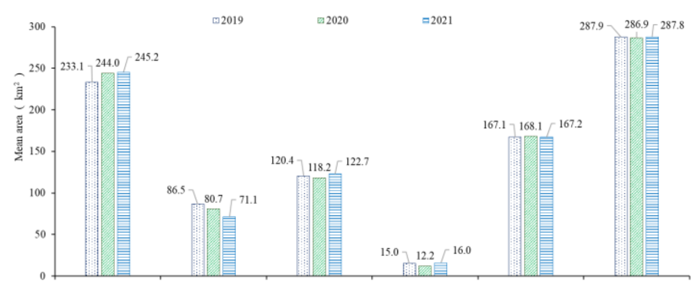


Figure 4: The mean area of El-Burullus Lake for NDVI and NDWI classifications for the years from 2019 to 2021.

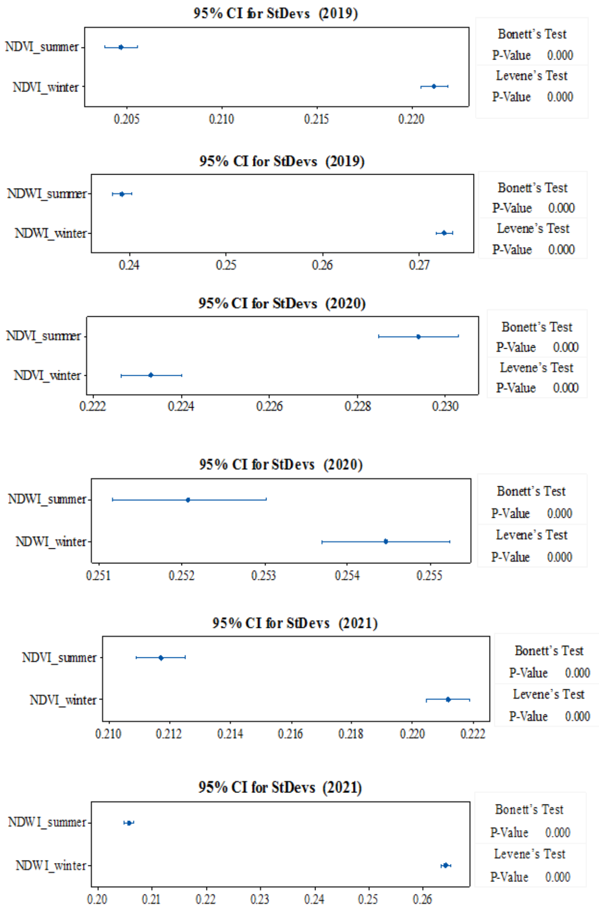
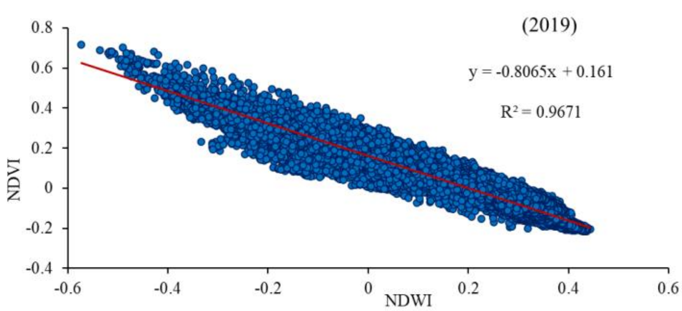


Figure 5: Seasonal variances of the NDVI and NDWI along El-Burullus Lake for the years from 2019 to 2021.



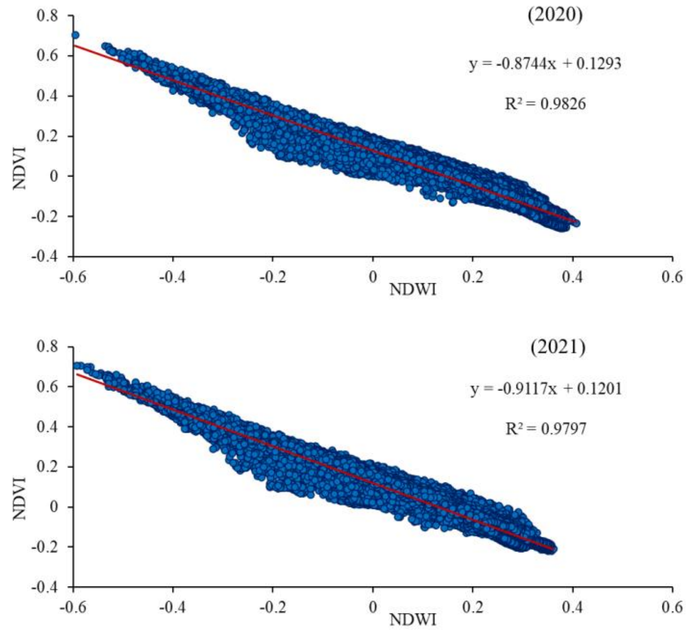


Figure 6: Linear regression model results of NDVI vs NDWI along El-Burullus Lake for 2019, 2020, and 2021 years.

4. Conclusions

Sentinel-2 remote sensing imageries with 10 m resolution using SNAP program and ArcGIS software were used in this study to assess the change of El-Burullus Lake for the period between January 2019 and January 2022. Two indices the NDVI and NDWI were applied to assess the moisture content of vegetation and monitor the changes of surface water area and vegetation along the Lake. From the processed images, the area of El-Burullus Lake has not been noticed a significant change during the last three years, which considered as a result of the Egyptian Government's efforts for the rehabilitation and restoration of El-Burullus Lake, as part of El-Burullus Lake Rehabilitation's Project to preserve and enhance the lake's ecosystem. The surface water area has estimated about 245 km^2 in 2021, while in 2019 is about 233 km^2. The vegetation coverage area according to NDVI values was presented about 30% of the total lake area, which resulted due to the contamination from the domestic, industrial, untreated wastewater through drains. While, the average NDWI values showed a non-significant change through the last three years, and this stability of El-Burullus Lake area is considered one of the great efforts impacts by the Egyptian authorities for protection and restoration the lake ecosystem. The Bonett's and Leven's variance test was applied for assessing the seasonal differences of variability along El-Burullus Lake. The results of variance test's homogeneity for NDVI and NDWI, obviously revealed that the ratio of variances or standard deviations is statistically significant ($p < 0.05$). For spatial autocorrelation, Moran's I results were positive values, which indicated a positive correlation for both indices NDVI and NDWI and almost the similar behaviour. Moreover, the regression analysis, between NDVI and NDWI was observed to be very strong along El-Burullus Lake of R-squared at 96.71%, 98.26%, and 97.97%, for 2019, 2020, and 2021, respectively.

Eventually, necessary steps are recommended by the decision-makers to protect the boundaries and area of the lake environment from encroachments and reclamations through continuously cleaning of the lake from floating plants. Besides, implementing a long-term strategy for better sustainability to preserve the lake from deterioration by continuous water quality monitoring program and adequate treatment of agriculture and urban wastes before discharging it into the lake.

Conflict of Interest

The authors declare no conflict of interest.

Table 2: Spatial autocorrelation results of Moran's I with identifying the dataset pattern.

	NDVI				NDWI			
	Moran's I	**z**	**p**	**Type**	**Moran's I**	**z**	**p**	**Type**
Jan-2019	0.266094	2.220936	0.026355	clustered	0.277246	2.306403	0.021088	Clustered
Mar-2019	0.246766	2.108833	0.034959	clustered	0.138661	1.256734	0.208850	Random
Apr-2019	0.224640	1.913728	0.055655	clustered	0.242985	2.051642	0.040204	Clustered
Aug-2019	0.356384	2.913247	0.003577	clustered	0.284593	2.364076	0.018075	Clustered
Oct-2019	0.320937	2.637559	0.008351	clustered	0.255685	2.140370	0.032325	Clustered
Nov-2019	0.236090	1.987574	0.046859	clustered	0.228220	1.928622	0.053778	Clustered
Dec-2019	0.291869	2.410844	0.015916	clustered	0.270020	2.247767	0.024591	Clustered
Apr-2020	0.216609	1.846311	0.064847	clustered	0.249097	2.090621	0.036562	Clustered
Sep-2020	0.344913	2.815788	0.004866	clustered	0.270588	2.251525	0.024352	Clustered
Oct-2020	0.361217	2.944799	0.003232	clustered	0.275470	2.292216	0.021893	Clustered
Dec-2020	0.198135	1.706287	0.087955	clustered	0.203655	1.742012	0.081506	Clustered
Jan-2021	0.188338	1.655394	0.097845	clustered	0.112427	1.057183	0.290428	Random
Feb-2021	0.188844	1.639127	0.101187	random	0.153395	1.361906	0.173227	Random
Mar-2021	0.175949	1.556212	0.119658	random	0.158499	1.417436	0.156355	Random
Apr-2021	0.181573	1.585631	0.112823	random	0.198095	1.709754	0.087311	Clustered
May-2021	0.199950	1.727724	0.084038	clustered	0.184072	1.605630	0.108355	Random
Jun-2021	0.229811	1.961121	0.049865	clustered	0.132293	1.224503	0.220763	Random
Jul-2021	0.326021	2.681068	0.007339	clustered	0.215722	1.844710	0.065080	Clustered
Aug-2021	0.287672	2.385836	0.017040	clustered	0.193151	1.669794	0.094960	Clustered
Sep-2021	0.346109	2.824060	0.004742	clustered	0.224640	1.913728	0.055655	Clustered
Oct-2021	0.354440	2.883742	0.003930	clustered	0.310287	2.553074	0.010678	Clustered
Nov-2021	0.333200	2.733254	0.006271	clustered	0.304030	2.506520	0.012193	Clustered
Jan-2022	0.144256	1.299840	0.193656	random	0.110544	1.041679	0.297560	Random

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