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Original research

GEE-Powered Remote Sensing Water Quality Monitoring with Field Measurements Integration at Lake Burullus for Supporting Egypt's Water Sustainability Goals

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Abstract:
The use of the Google Earth Engine (GEE) platform represents a novel, rapid, and practical remote sensing approach for supporting decision-makers in water resources management. This study employs GEE to assess water quality challenges in Egypt's Burullus Lake using generated Summer-specific composites of Landsat 8 imagery to capture peak ecological stress periods from 2013-2023. The Normalized Difference Water Index (NDWI), the Normalized Difference Turbidity Index (NDTI), and the Normalized Difference Chlorophyll Index (NDCI) were applied for detecting changes in the surface water extent, sediment load, and phytoplankton activity, respectively. The obtained results showed declining water area surfaces, increased turbidity near discharge points at the lake, and altered chlorophyll levels, indicating eutrophication—all of which directly threaten SDG 6 (clean water and sanitation). This study also compared these satellite-based findings versus measured field data by national water quality reports and introduced a proposed enhanced in-situ monitoring network. The adopted approach emphasizes the importance of integrating advanced remote sensing techniques with national field data to overcome the key limitations of traditional sampling frequency and spatial distribution, thereby supporting Egypt's commitments to the 2030 Agenda for sustainable water resource management.

Keywords: Lake Burullus, Google Earth Engine, NDWI, NDTI, NDCI.

1- Introduction

The second-largest natural lake in Egypt is Burullus Lake, which is located between the Nile's two main branches, particularly in the middle part of Egypt's Deltaic Mediterranean coastline. It is one of the three Deltaic shallow lakes, including Edku and Manzala Lakes, that are considered a highly important natural resource producing over than 40% of Egypt's total fish production.(El Kafrawy, 2018; Elbehiry, 2019).

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Human activities in their watersheds, unplanned rapid urbanization and industrialization, as well as unsuitable agricultural practices, increasingly threaten the water quality of these ecosystems, resulting in a decline in fish production to less than 12.22% and hindering the achievement of sustainable development goals (SDGs) (Abdel-Hamid, 2023; El-Sheekh, 2017; Sachs, 2015; Zahoor I., 2023).

Satellite-based remote sensing is a technology that has been widely employed to monitor and detect the dynamic changes in water quality components due to its benefits with regard to both temporal and spatial coverage using several available spaceborne sensors with visible, infrared, and microwave wavelengths. (Amani, 2020; Ritchie, 2003). Compared to conventional image processing techniques, Google Earth Engine (GEE) is a cloud-based computing platform that uses an online satellite imagery repository for geospatial research.(Amani, 2020; Tamiminia H., 2020). It makes use of Google's computer power to track environmental issues such as water management, coastal changes, climate change, and deforestation. (Ghosh S., 2022; Mutanga O., 2019). The time and effort required to download and pre-process satellite photos are reduced by this platform. However, the capabilities of GEE-Powered Remote Sensing for water quality monitoring research are mostly constrained by atmospheric inference that accounts for 80–90% of all water bodies' signals received (Sherjah, 2023) , therefore, its application in that field is still under intensive research. Although Atmospheric Correction (ACP)in (GEE) for Water Quality Monitoring removes atmospheric interference (e.g., aerosols, water vapor) that distorts surface reflectance signals, its Performance is still not validated for water pixels, leading to uncertainties in aquatic applications.(Condeça J., 2022; Sherjah, 2023). This research aims to: (i) Evaluate the effectiveness of the GEE platform for remote sensing applications in monitoring water quality at Lake Burullusin Egypt after recent rehabilitation projects (ii) Assessing the current water quality monitoring system at Lake Burullus versus the technical guidelines requirements of SDG Indicator 6.3.2 and proposing actionable recommendations for supporting policy interventions to accelerate and tracking progress toward SDG 6.

2. Materials and Methods

2.1. Study Area

The Lake Burullus in Egypt, shown in Figure1, has a boundary area of around 420 km2 with water depth varying between 0.4m to 2.0 m along the Mediterranean coast. (Hany et al., 2021). Its highly location-specific economic importance relies on its various surroundings, including industrial water supplies, eutrophication, tourism, and fisheries, among others. Additionally, the health, composition, and growth of fish stocks are significantly impacted by any notable alteration in water quality.(Alprol, 2021)

2.2. Data Used

In order to monitor water quality changes at Lake Burullus, Landsat 8 OLI, launched in 2013, satellite images were selected. The Earth Engine includes a copy of the US Geological Survey (USGS) Collection 2, Level 2 archive, which contains Landsat surface reflectance (SR) data that are radiometrically and geometrically corrected to ensure the highest levels of accuracy and data quality control. The specifications of the imageries used in the study, as well as the description and wavelength ranges for the selected bands from Landsat 8, are given in Table 1.

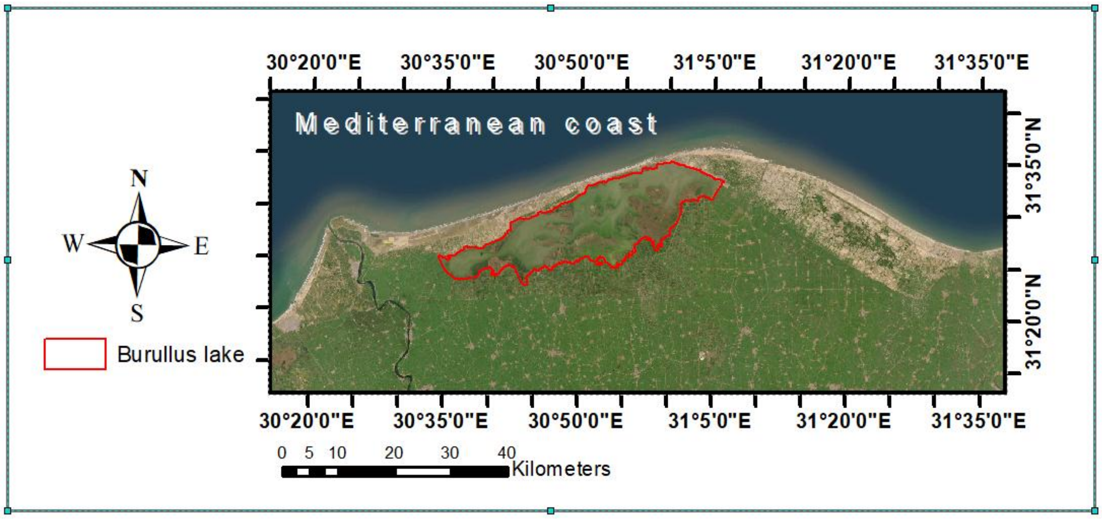


Fig. 1: Burullus Lake Study Area Location

Table 1. The details for the selected satellite images/Bands in the study area

Imagery specifications	Satellite	Date	Sensor ID	Path/row	Spatial Resolution (m)
	Landsat 8	2013 to 2023	OLI_TIRS	177/38	30

Band Number-Name	Wavelength Range (µm)
Band 3- Green	0.53-0.59
Band 4-Red	0.64-0.67
Band 5-Near-Infrared (NIR)	0.85-0.88

The data selected for this research from the years 2013 to 2023 was downloaded, taking into consideration only seasonal summer months that represent the highest temperature, as it makes eutrophication, like algal blooms, increase and has the highest consequences on water quality parameters. (Verweij W., 2010; Zwolsman, 2007)

The available annual Reports of the Lake Burullus Environmental Monitoring Program are published by the Environmental Agency Affairs (EEAA) on the Ministry of Environment in Egypt website, and will be used to check the compatibility of the obtained results by remote sensing techniques applied in this research versus on-site measurements observed in these documented reports.

2.3. Estimation of Water Quality Indices

In remote sensing, target recognition and information extraction are significantly impacted by cloud existence. As a result of cloud and cloud shadow cover problems, their potential to hide the land surface and their effects on the reflectance capabilities of the target item can reduce the accuracy of results for remote sensing applications.

In this study, by the GEE platform, a variety of cloud masking methods can be used with Landsat 8 data. The Quality Assessment (QA) band included with Landsat 8 images is one of the popular methods. Because the QA band includes information regarding cloud and shadow cover, these regions can then be identified and masked. In this study, 10% cloud coverage was selected when filtering data by GEE, and the band of quality assessment was used for the cloud removal processing to generate Landsat 8 images from 2013 to 2023 with an annual interval, focusing on summer season months using the median synthesis method.

Based on the boundary shapefile of the Burullus lake, Landsat 8 imageries from GEE were clipped and the spatial distribution of water quality indices, e.g., Normalized difference chlorophyll index (NDCI), Normalized difference turbidity Index (NDTI), as well as Normalized difference water index (NDWI) to detect changes in water surface extent were estimated by using band rationing equations listed in Table 2 and were mapped by ArcGIS Software. The NDTI values increase with turbidity, and higher values of NDCI indicate higher Chlorophyll-a (Chl-a) concentration in the water, which means poor water quality.(Meena, 2021)

All results will be compared with on-site measurements based on the available published reports from 2012 to 2021 for Burullus Lake by EEAA. The data extracted from reports regarding Chlorophyll-a concentration and transparency values are extracted and summarized in Table 3.

Table 2. Band ratio algorithms used to derive water quality indices in Burullus Lake

Sensor Image	**Index**	**Band ratio EQ.**	**Ref.**
Landsat 8	NDWI	= (B3(Green)-B5(NIR))/(B3(Green)+ B5(NIR))	(McFeeters, 1996)
	NDTI	= (B4(Red)-B3(Green))/ (B4(Red)+B3(Green))	(Lacaux, 2007)
	NDCI	= (B5(NIR)-B4(Red)) / (B5(NIR)+B4(Red))	(Dörnhöfer K., 2016)

Table 3. Summary of Chlorophyll-a concentration and transparency values of on-site measurements at Burullus Lake in EEAA published reports

Year	Annual Average Chlorophyll-a (µg/L)	Annual Average Transparency (cm)	Ref.
2012-2013	72	23.44	(E. E. A. A., 2013)
2015-2016	47	38.23	(E. E. A. A., 2016)
2017-2018	76	38.13	(E. E. A. A., 2018)
2019-2020	68	34.48	(E. E. A. A., 2020)
2020-2021	64	Not mentioned	(E. E. A. A., 2021)

2.4. Comparative assessment of the EEAA monitoring system vs. SDG 6.3.2 monitoring technical guidelines

(SDG 6) focuses on ensuring the availability and sustainable management of water and sanitation for all. The progress towards this goal is measured through specific indicators. Egypt has been classified under the "significant challenges remain" category regarding SDG 6, with a stagnating or less than 50% improvement rate toward the required targets, as shown in Figure 2. The most relevant indicator to the water quality monitoring was "NO.6.3.2 Proportion of bodies of water with good ambient water quality," but there were no data available on the official UN SDG tracking platforms (*https://www.sdg6data.org/en/country-or-area/Egypt*), as well as the National Statistical Report on Monitoring Indicators of the 2030 Sustainable Development Goals in Egypt (CAPMAS, 2019).

According to the SDG indicator 6.3.2 technical guidance document (UNEP, 2023), Level 1 data type is constrained to five core physico-chemical parameters: oxygen, salinity, nitrogen, phosphorus, and acidification, which are in situ data measured directly at monitoring locations or through collected samples. Monitoring these data is the foundational approach for countries to report on water quality and ensure that all countries can be compared on a global scale for Sustainable Development Goal (SDG) indicators, particularly SDG 6.3.2. While Level 2 data type can encompass additional parameters, including biological indicators and ecosystem approaches, allowing for a more comprehensive assessment of water quality. This Level 2 data is optional and can include remote sensing data, such as satellite observations, in addition to in situ measurements for allowing countries the opportunity to reflect local water quality pressures and utilize relevant information beyond the constraints of Level 1. The SDG indicator 6.3.2 technical reports also include the design details of the water quality monitoring programme that provide guidance for countries that could not meet the reporting requirements (UNEP, 2020, 2023).

To support SDG Indicator 6.3.2 tracking and reporting Progress in Egypt, a comparative analysis between the current monitoring system by EEAA at Lake Burullus against SDG Indicator 6.3.2 Technical Guidelines will be applied regarding the following:

- The number and distribution of monitoring stations at Lake Burullus
- The frequency of sampling recorded by EEAA of the Level 1 water quality parameters measured aligns with the SDG 6.3.2 indicator requirements

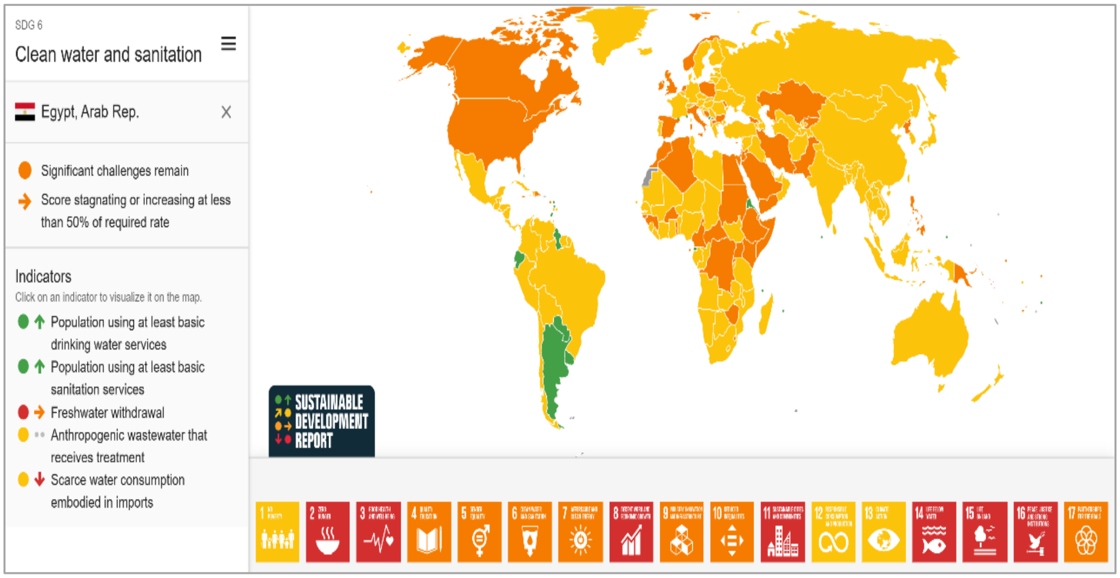


Fig 2. Estimated SDG6 progress in Egypt using the SDG dashboard interactive map
Data source: Sustainable Development Report, 2024.

3. Results and discussion

The results of the script implemented in the GEE for water quality analysis based on the described information in previous sections, NDTI, NDCI, and NDWI were exported to GeoTiff format. The turbidity spatial distribution and concentration of chl-a at Lake Burullus were mapped as shown in Figures (3&4), and NDWI Tiff files were converted to shapefiles to calculate surface water areas in (km^2) for each year. The extracted maximum values for NDTI, NDCI, and surface water areas calculated from 2013-2023 during the summer season are illustrated in Table 4 and the Figure. 5.

Lake Burullus receives annual water discharge from agricultural drainage by multiple main drains, including Drain 11, 8, 7, Nasser Drain, Garbiah, Tirah, and Burullus PS, Brimbal West, and Brimbal Channel equals 3.77×10^6 m^3 and 1.94×10^6 m^3, respectively(Hany et al., 2021). The NDCI maps in Figure 4 showed that from 2013 to 2023, high NDCI concentrations were consistently observed mainly in the western and occasionally in the central portions of Lake Burullus. This could be due to the nearby farmlands' nutrient-rich water inflows from agricultural drainage(Ali, 2011).In contrast, high NDTI values were generally more localized in the north-eastern portion of the lake, suggesting that it could be as result that the eastern sector is the lake's shallowest region in addition to the turbidity and sediment inputs that are more concentrated near drainage outlets as well as near south-western margins that receives water from four drains and from Brimbal canal (A Elsayed et al., 2019).

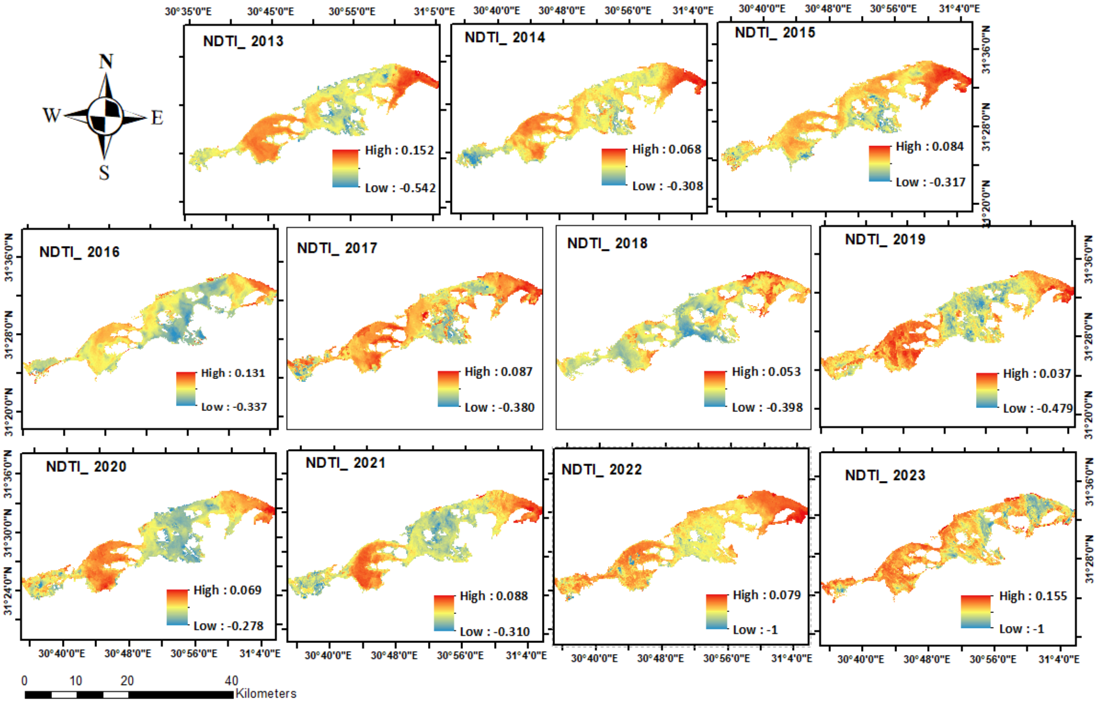


Fig.3 NDTI spatial distribution at Lake Burullus from 2013 to 2023

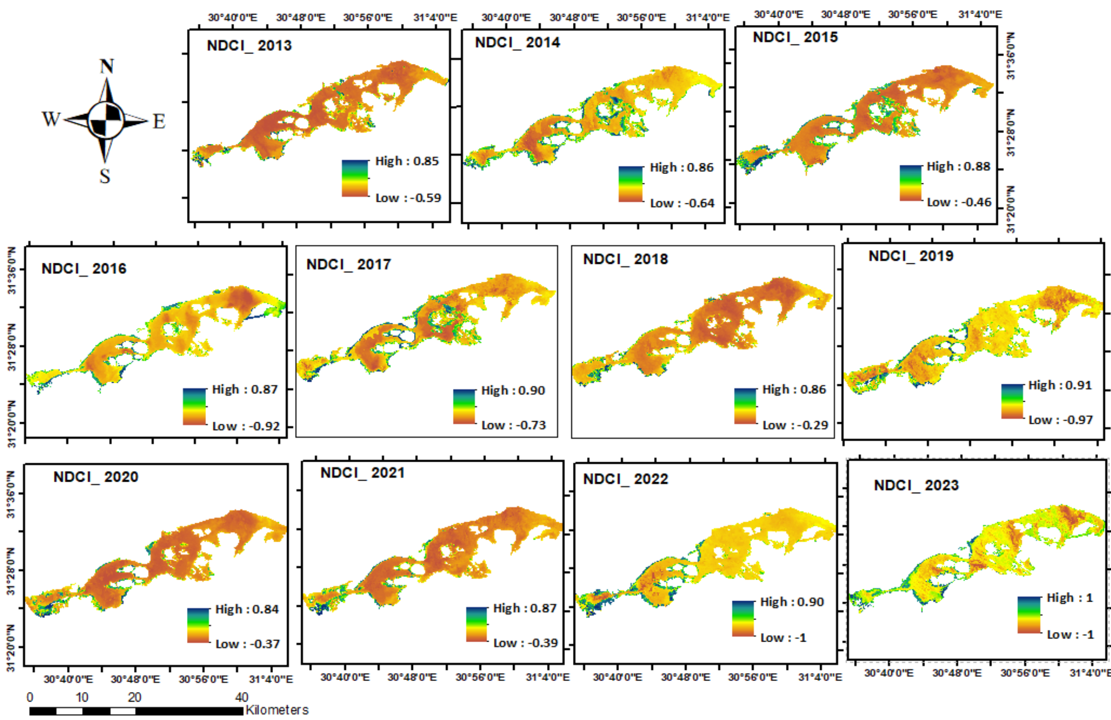
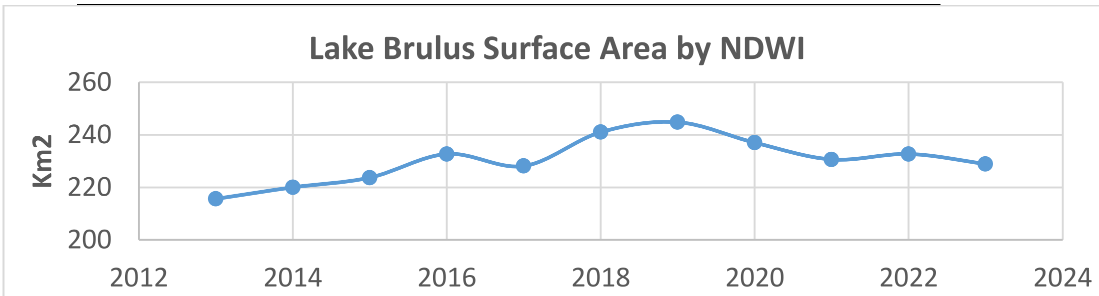


Fig.4 NDCI spatial distribution at Lake Burullus from 2013 to 2023

Table 4. NDTI, NDCI values, and area of water bodies by GEE in Lake Burullus

year	NDCI max	NDTI max	Water surface area (km2) by NDWI
2013	0.85	0.162	215.6
2014	0.86	0.068	220
2015	0.88	0.083	223.7
2016	0.87	0.131	232.7
2017	0.9	0.087	228.1
2018	0.86	0.053	241
2019	0.91	0.037	244.8
2020	0.84	0.069	237
2021	0.87	0.088	230.6
2022	0.9	0.079	232.7
2023	1	0.155	228.9



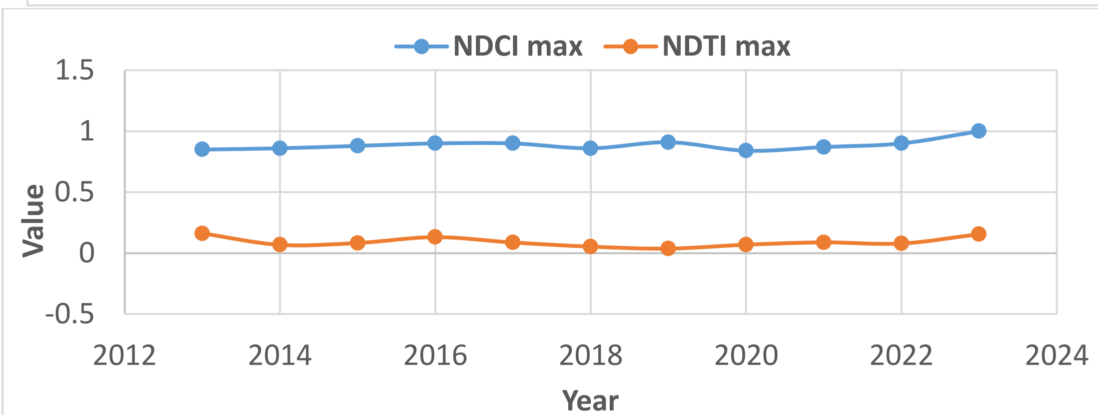


Fig. 5. Time series plot of Water surface area, NDCI, and NDTI at Lake Burullus

The results show that NDCI and NDTI extracted values showed a general consistency when compared with Chlorophyll-a concentration and transparency values extracted from reports in Table 5, as follows:

- Regarding NDCI [From 2015 to 2016, the lake had Low chlorophyll (47) versus lower NDCI values ranging from (0.88–0.87). From 2017–2018, the lake had high chlorophyll (76), also higher NDCI values ranged from (0.90- 0.86). From 2019–2020, the lake had medium chlorophyll (68) versus medium values of NDCI, ranging from (0.91–0.84).
  Regarding NDTI, which has an inverse relationship with transparency, from 2012–2013, the lake had low transparency (23.4) versus relatively high NDTI (0.162). From 2015–2016 lake had higher transparency (38.2) versus Lower NDTI values, ranging from (0.083–0.15). From 2017–2018, the lake had good transparency (38.1) versus very low NDTI values ranging from (0.087–0.053). From 2019–2020, the lake transparency decreased slightly to (34.48), while NDTI values increased slightly from (0.037–0.069).

Also, the results regarding the time series plot of water surface areas of the lake, NDCI, and NDTI values in Fig.5 show:

- Low fluctuation and mostly stable patterns could be explained due to focusing only on summer months in this research, not including water level variations by rainfall in winter seasons, and their impact on water quality parameters.
- The water surface areas of the lake by the time it was monitored show declining patterns in similar research (Mohsen ,2018.; Elshemy, 2018) , while the lake area increased from **215.**6 km² in 2013 to a peak of 244.8 km² in 2019, which may mainly be due to the recent rehabilitation projects in 2019. This involves the lake inlet's expansion and deepening(Hany A., 2022).
- Water surface areas of the lake showed no correlation or weak relationship with NDCI values, which agreed with some recent studies (Elhag M., 2019; Rawat, 2023), as well as in Lake Burullus.(A Elsayed et al, 2019) Found that the nutrient input from drains is the main driver of eutrophication, not the lake area. Also, in many lakes, NDCI and NDTI values may correlate, but in shallow, nutrient-rich lakes like Burullus, phytoplankton growth can occur without high sediment levels and may be influenced by other environmental factors.

Finally, the results regarding the Comparative Analysis of Lake Burullus Monitoring System Against vs. SDG 6.3.2 Requirements are summarized in Table 6 with actionable recommendations for an enhanced monitoring system.

Table 6. Assessment of EEAA's Lake Burullus monitoring system vs SDG 6.3.2 guidelines

Aspect	SDG 6.3.2 Guidelines	Current EEAA monitoring System (Lake Burullus)	Assessment
Sampling Frequency	**Min no of samples:** 4 times/year (once per season)- Ideal: Monthly sampling- High-variation areas: more frequent or continuous.	Mostly Seasonal sampling - that may miss critical periods.	**Partial Compliant -** does not meet the ideal frequency for High-variation areas.
Spatial Distribution of Monitoring Stations	NO. and locations of sites should capture all variability in water quality	12 stations-unevenly distributed- mostly near drains and lake edges, shown in Figure 6	**Partial Compliant -** but lacks sufficient spatial representativeness (see recommended addition location below)

Recommendations to the decision maker and interventions for technical upgrade

- Remote sensing using (GEE) cannot directly measure all of the Level 1 water quality parameters mentioned in SEC 3.3, but several can be indirectly estimated using satellite data, such as Nutrient Regime, which can be indirectly inferred through Chlorophyll-a (via NDCI) linked to eutrophication. As well as Turbidity, which can be estimated using NDTI. Therefore, it is a recommended suggestion to integrate direct field measurements with GEE in the current monitoring system that offers wide spatial coverage access to satellite imagery (e.g., Landsat 8, Sentinel-2) with revisit periods of 5–16 days to overcome key limitations in sampling frequency and spatial distribution. This can support continuous or monthly monitoring, fulfilling the guideline's recommendation and allowing the analysis of the entire water body, including inaccessible regions, trend analysis, and long-term assessment of water quality, which are critical for tracking SDG 6.3.2 progress.
- According to the spatial analysis of the current monitoring stations' distribution, it is recommended to add 3 new stations as described in detail in Table 7 and shown in Figure 6 to align with SDG 6.3.2's requirement for representative sampling across inflows, open water, and outflows.

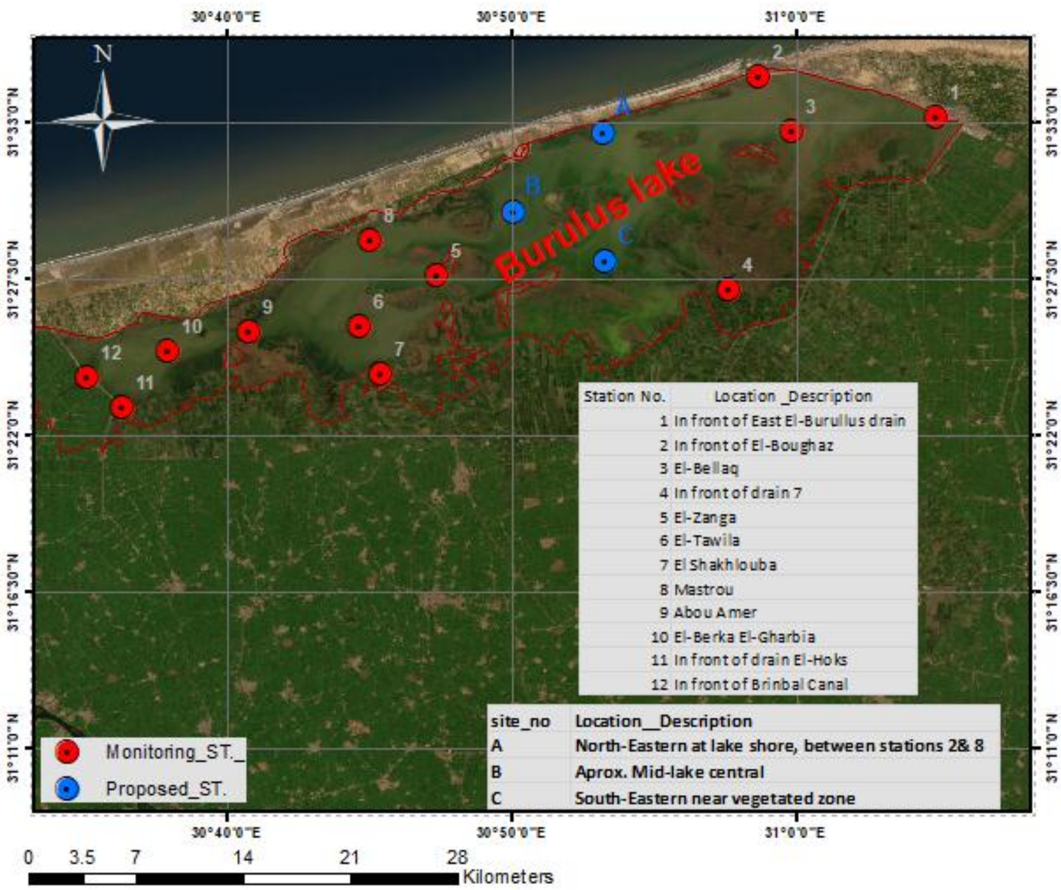


Fig. 6. Current and proposed Spatial Distribution of water quality monitoring stations with location description at Lake Brullus

Table 7. Details of the proposed addition of new monitoring stations

Site No.	Location Description	Reason
A	North-Eastern at Lake Shore	Needed to cover the spatial gap between current stations 2 & 8 along the northern lake shoreline
B	Approx. Mid-lake central- (directly east of Station 5)	Needed to enhance the current network's central open-water coverage. While accounting for the lake's shifting boundaries and shrinkage
C	South-Eastern near vegetated zone	Needed to cover the spatial gap in the southeast of the lake near vegetated shallow zones

4. Conclusion

Remote sensing via the GEE platform has proven effective in capturing water quality spatial and temporal patterns in Lake Burullus from 2013 to 2023, with a good agreement with field-based measurements published by EEAA reports.

The comparative analysis between the EEAA's monitoring framework for Lake Burullus and the SDG 6.3.2 technical guidelines by the United Nations Environment Programme (UNEP) reveals the need for expanding the current in-situ monitoring network for better representative sampling. To overcome existing limitations of sampling frequency and spatial distribution, this study recommends a hybrid approach that combines remote sensing with direct field measurements to improve the capability to track SDG6 progress and to achieve Egypt's commitments to the 2030 Agenda for Sustainable Development.

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