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Assessment of Cyanobacterial Cholorphyll-A as an Indicator of Water Quality in Two Wetlands Using Multi-Temporal Sentinel-2 Images †

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Abstract: Cyanobacteria rigorously affect water quality that human use for various activities ranging from drinking, to fishing and recreation, as indicated in the investigation protocol of World Health Organization (WHO). The current state of the lake necessitates constant monitoring and remote sensing is an adequate tool for the constant monitoring of the whole water body. In the present study, multi-temporal sentinel-2 images were used to assess surface water quality based on the concentration of chlorophyll a (Chl-a) of cyanobacteria and dissolved oxygen of water. Chl-a was used as an indicator for cyanobacteria bloom and dissolved oxygen was used as an indicator of water quality. Dissolved oxygen was generated using Sentinel 2 dataset. For the present study two wetlands Wadhwana and Timbi Vadodara City, Gujarat, India were assessed from 2018 to 2022. Analysis showed that, dissolved oxygen is an important environmental factor that influenced cyanobacteria abundance. It was seen that the increased concentration of chlorophyll a, was associated with reduction in dissolved oxygen and hence deteriorated the water quality

Keywords: water quality; Ramsar; wetland; Sentinel-2; chlorophyll a; temp; dissolved oxygen 3

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1. Introduction

Reservoirs are important freshwater reserves that have undergone highly negative impacts resulting in qualitative and quantitative changes in their physicochemical composition and impacts on fauna and flora [10]. With the development of industry and agriculture, large amounts of nutrients have been discharged into rivers and lakes, resulting in increased eutrophication of water bodies [11]. Algal blooms are increasing in frequency, intensity and spatial extent worldwide in recent years due to accessive nutrients in lakes. A shift in algal population can have serious environmental consequences particularly with an increase in harmful species and therefore, information about algal composition and dominance in a water body can provide dynamics of toxin-producing species such as cyanobacteria. Cyanobacteria produce cyanotoxins and taste-and-odor compounds, threatening aquatic ecosystems and public health. Therefore, monitoring and modeling of algal blooms and composition is important to assess and mitigate potential harmful species. Cyanobacteria are a key group responsible for environmental problems associated with eutrophication processes [2]. The proliferation of cyanobacteria depends mainly on the availability of nutrients, though they are also affected by several other factors such as water temperature, pH, and light, dissolved oxygen. Among water quality variables (pH, conductivity, nitrate nitrogen, phosphorus, etc.), it is one of the most important general health criteria when assessing aquatic ecosystems [8] Inland waters need to maintain high DO levels for good aquatic life. When DO concentrations drop to low thresholds (below 5 mg/L), aquatic organisms are adversely affected in terms of metabolic performance, predation risk, and behavior [4].

In the past few decades, monitoring and quality control of water bodies as required by the Water Framework Directive have led to the emergence of new techniques and methods that can facilitate the monitoring of water quality. Satellite-borne spectrometric sensors are capable of detecting phytoplankton growth and composition, and especially the presence of cyanobacteria [9]. Sentinel-2 data is very useful in monitoring the cyanobacterial bloom in water body as it operates at spatial resolution of 10 m, 20 m, and 60 m, and it captures data in 13 different bands. These measurement bands have interesting applications in the estimation of phytoplankton and cyanobacteria based on the measuring of their major pigments: Chl-a and phycocyanin [5,6,10,12,13]. Along with this dissolved oxygen and Temperature measurement also an imperative parameter of water quality which can be measured using satellite images.

Earlier study showed that Wadhwana water quality was getting degraded due to anthropogenic activities [14]. Therefore, this study is designed to assess the Chlorophyll-a along with Dissolved oxygen and Temperature to understand the present water quality of two wetlands of Vadodara district using multi-temporal Sentinel-2 data.

2. Study Area

Vadodara is a city in the western Indian state of Gujarat. It is 39 metres above mean sea level and is situated at 22°17′59″ North Latitude and 73°15′18″ East Longitude. The now-named Vadodara, formerly known as the Baroda State, built the Wadhwana reservoir in 1910. One of the Ramsar sites is the Wadhwana wetland (Figure 1), which is well-known among bird watchers in the state and is situated in the Dabhoi taluka of the district. Because it serves as a wintering habitat for migrating waterbirds, including more than 80 species that migrate via the Central Asian Flyway, the wetland is significant for its birdlife on a global scale. A mid-winter waterbird census was carried out in 2020, and around 46,000 distinct birds were counted. The wetland site serves as an international illustration of how a wetland that was initially developed for irrigation has evolved into an essential waterbird habitat and a centre for ecotourism and nature education.

Timbi lake is the second most frequent lake after Wadhwana. Many migratory birds drawn to it. However, both these wetlands are under threat as high amount discharge of irrigation water discharge and other industrial effluents. Aquatic life of these wetlands is at risk.

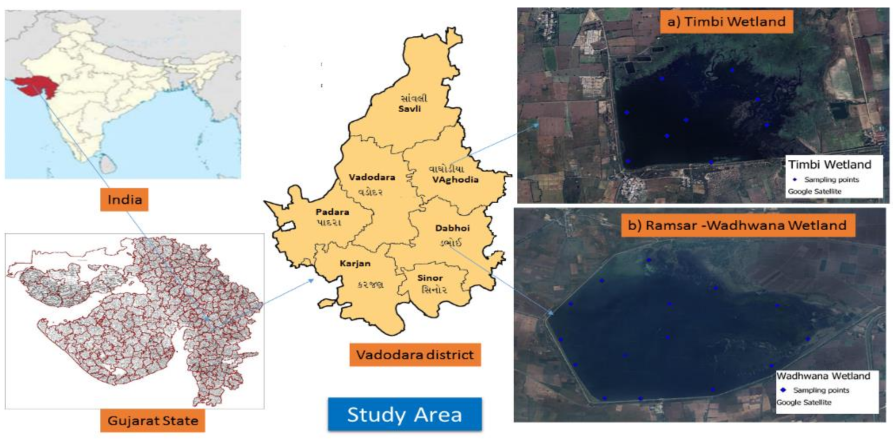


Figure 1. Study area (**a**) Timbi wetland in Waghodia Taluka and (**b**) Ramsar site- Wadhwana Wetland.

3. Materials and Methodology

In this study, water sampling and measurements were conducted in April 2018. Samples from various points were collected based on random sampling from both the wetlands Wadhwana and Timbi. Dissolved Oxygen were extracted followed the standard procedure by the American Public Health Association [15].

Data

Sentinel-2

In the present study, freely available Sentinel-2 images (Level-2A product reflectance) downloaded from January 2018 to December, 2022, from the Copernicus Open Access Hub (https://scihub.copernicus.eu/ accessed on), accessed on 22, November 2022.The data was resampled at 10 m resolution. The image was stacked and further used for processing.

Landsat-8/9

The Landsat 8/9 OLI images were downloaded from January 2018 to December, 2022 (http://earthexplorer.usgs.gov accessed on). Landsat 8 TIRS sensor has two bands in the TIR region (Band 10 and Band 11). These thermal bands have a 100-m native spatial resolution but resampled and published at 30 m by USGS. Digital Numbers (DC) were converted to Top of Atmosphere (TOA) reflectance's using radiometric coefficients included in the metadata. TOA bands were converted to brightness temperatures, and water surface temperature was retrieved using the single-channel algorithm developed by Jiménez-Muñoz et al. [1].

4. Results

4.1. Retrieval Method of Chlorophyll-A Concentration

Pre-processed sentinel 2 image was used to generate the normalized differential chlorophyll index (NDCI) was derived using an empirically derived chl-a model (Mishra and Mishra, 2012). The NDCI model uses sentinel-2 MSI spectral bands located at 665 nm and 705 nm. These are most sensitive to reflectance due to Chl-a absorption and backscattering, respectively. NDCI is calculated as followed by taking the spectral difference of these two bands and normalizing by their sum

$$\mathbf{NDCI = [(705) - (665)]/[(705) + (665)]}$$

Further, Chl-a was quantified using following equation as modelled by Kravitz, et.sl 2020

$$\text{Chl-a (mg/m}^3\text{)} = 17.441e(4.7038 * \text{NDCI})$$

The values from the image bands of the corresponding location were derived for Chlorophyll-a and LST based on the measured data coordinates (Figure 2). The values were used for further analysis and dervivation of dissolved oxygen.

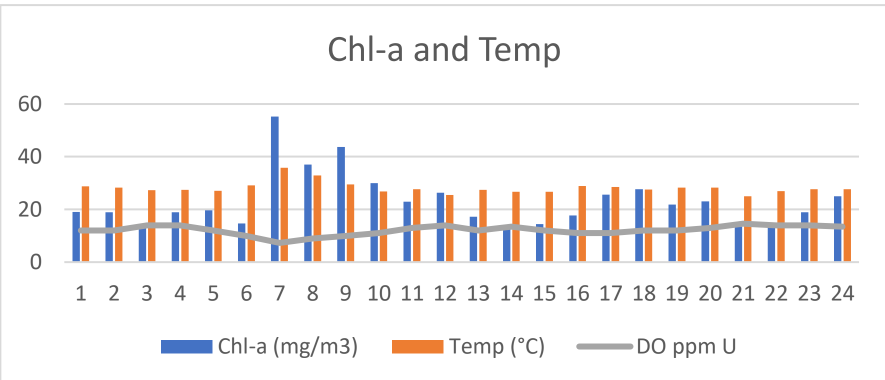


Figure 2. Satellite derived Chlorophyll-a and Temperature along with in-situ DO in the Study area**.**

4.2. Dissolved Oxygen (DO)

Sampling data from Waaldhwana and Timbi Wetland in April 2018 matched Sentinel-2 image This resulted in 24 in situ water sample matches on 18th April 2018. The in situ DO values ranged from 7.0 to 13.5 ppm in Wadhwana wetland, while it ranged from 11 to 14.6 ppm in Timbi Wetland.Field derived DO was further investigated for its relationship with Chl-a and Temperature

4.3. Analysis for Water Quality of Wadhwana and Timbi Wetland

The Chl-a and Temperature data for June, 2018 were utilized with field generated Dissolved oxygen were used.

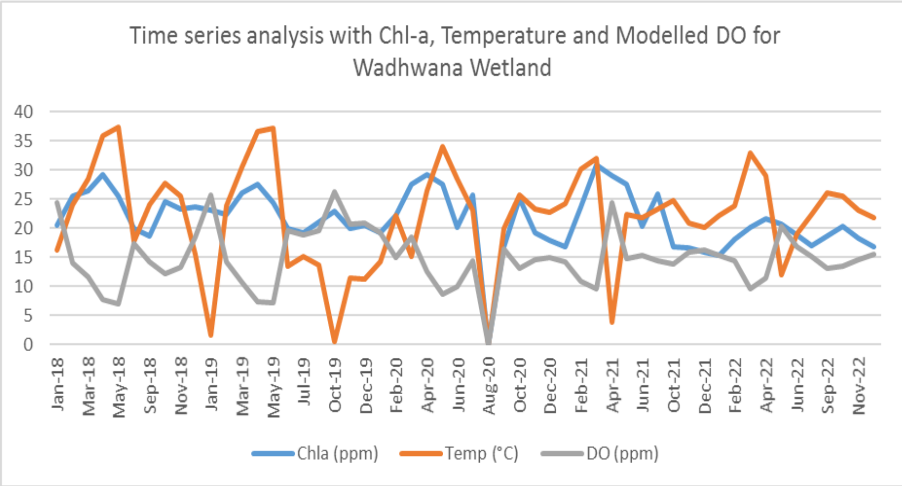
From the Table 1 Correlation between DO and Chlorophyll-a (Chl-a) shows −0.7204. This means that there is a strong inverse relationship between Chl-a and DO. R-Squared (R^2) equals 0.519. Dissolved oxygen and chlorophyll A are correlated and closely related cause a decrease in dissolved oxygen leads to increased levels of algae (chlorophyll A) wetlands [3] Correlation between DO and Temperature shows −0.8478. This means that there is a very strong in-verse relationship between Temperature and DO R-Squared (R^2) equals 0.72. Dissolved oxygen and chlorophyll A are correlated and closely related. Results from the multiple linear regression indicated that there was a very strong collective significant effect between the Chl-a, Temperature, and DO, ($F (2, 21) = 28.98$, $p < 0.001$, $R^2 = 0.73$, $R^2adj = 0.71$). R square (R^2) equals 0.734071. The coefficient of multiple correlation (R) equals 0.85. It means that there is a very strong correlation between the predicted data and the observed data. Adjusted R square equals 0.71.

Table 1. Relationship between Chla, Dissolved Oxygen and Temperature in Wadhwana and Timbi Wetland.

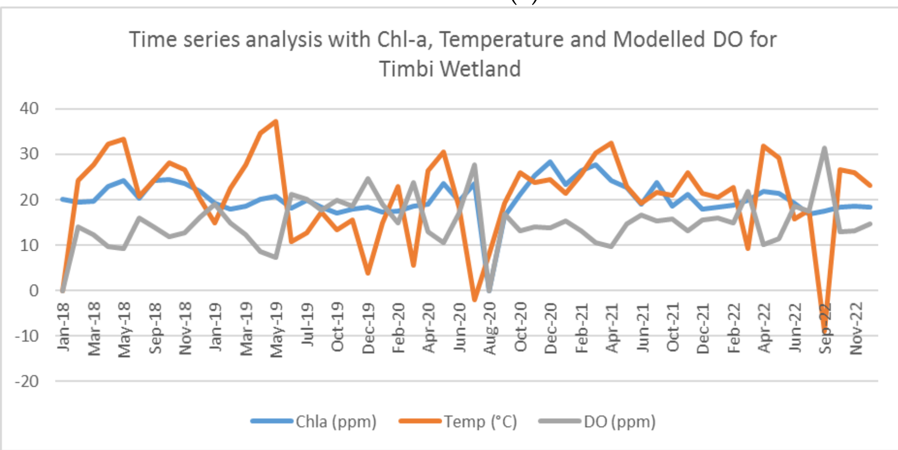
Regression Model	Empirical Equation	R^2	R
Chl-a and DO	DO=15.0403 − 0.1271 Chla	0.52	−0.72
Temperature and DO	DO=31.364 − 0.6834 Temp	0.72	−0.85
MLR with Chl-a, DO and Temperature	DO = 28.902228 − 0.0332848 Chl-a − 0.56885 Temp	0.73	0.71

4.4. Predictive Models for Water Quality of Wadhwana and Timbi Wetland

To verify the accuracy of the proposed MLR model, a comparative analysis of time series data from 2018–2022 was performed for Wadhwana (Figure 3a) and Timbi wetland (Figure 3b). The correlation values between the Sentinel-2 DO and Chl-a and between the Sentinel-2 DO and Temperature the test results exceeded 0.6 and 0.89 respectively. The results of the simulation in comparison with the measurements are shown in Figure 3a,b. Model prediction fit the data well. Taking consideration of the measurement errors and space-time variations, all simulations are good and reasonable results. The RMSE of each profile are ranged between 0.6 and 1.24.



(**a**)



(**b**)

Figure 3. Time series analysis with Chl-a, Temperature and Modelled DO for (**a**) Wadhwana wetland (**b**) Timbi Wetland**.**

The MLR model could reasonably simulate interannual dynamics. This model represents the temporal pattern of Chlorophyll-a with DO and Temperature which can be seen in fig With increase in algal bloom in wetland and with rise in temperature significantly decreased the oxygen, which had a significant negative impact on the lake ecosystem when compared to the reduction in the algal bloom. It was observed from time series data (Figure) that in summer months i.e., March to May in 2018 to 2020 with increase in Temperature the dissolved oxygen was found to be low and chlorophyll-a was high. In Ramsar Wadhwana wetland high temperature shift was seen in 2021 to 2022 temperature which was preponed from March to February and showed significant algal bloom. Timbi wetland followed similar pattern showed high temperature shift in February 2021 instead of March, 2021. Comparing these results to the concentration of chlorophyll a, it appears that this decrease in dissolved oxygen was always followed by an increase in the concentration of oxygen-consuming algae. In both the wetland dissolved oxygen was an indicator through which the chlorophyll-a can be understood. Assessment of chlorophyll-a is required as it indicates the stage of eutrophication that could pose a threat to reservoirs worldwide

5. Conclusions

Based on the results of this study, Sentinel-2 imagery can be successfully used to map dissolved oxygen with high accuracy as seen Ramsar site Wadhwana and Timbi wetland.

An accurate mapping of Dissolved oxygen which is an indicator of water quality parameter can be used to obtain a general picture of the variability of their concentrations on algal bloom (chlorophyll-a) due to their significant impact on water quality status.

Supplementary Materials: The following supporting information can be downloaded at: www.mdpi.com/xxx/s1, Figure S1: title; Table S1: title; Video S1: title.

Author Contributions: This research article has been written by two authors: A.M., Department of Botany, Faculty of Science, The Maharaja Sayajirao University of Baroda, Vadodara (Gujarat), India; and U.P., Department of Botany, Government College, Daman, Daman 396210. The first author was involved in data downloading, processing and analysis, draft preparation, review and editing. The second author was involved in draft paper and review. In this study authors have used Qgis-3.2software for image analysis, mapping and used excel fot statistical outputs. All authors have read and agreed to the published version of the manuscript.

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Data Availability Statement: This study has been used Sentinel-2 multispectral imagery that is publically available at https://scihub.copernicus.eu/ (accessed on) and Landsat-8 multispectral imagery that is publically available at http://earthexplorer.usgs.gov (accessed on).

Conflicts of Interest: The authors declare no conflict of interest.

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