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Article

Assessment of aquatic ecosystem quality in Dharoi Reservoir using Sentinel-2 satellite imagery

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Abstract: Background: Dharoi Reservoir, located in Gujarat, India, is a vital freshwater resource supporting agriculture, industry, and local communities. Chl-a, a key indicator of water quality, reflects the trophic state and ecological balance of aquatic systems. **Objective(s):** This study aims to provide comprehensive insights into the water quality dynamics of Dharoi Reservoir, offering valuable information for environmental management and sustainable water resource planning. **Methods:** This study employs high-resolution Sentinel-2 satellite imagery to analyze Chl-a concentrations in the reservoir during October 2020. The Chl-a index, calculated by dividing Sentinel-2 bands B5 and B4, reveals a spatial distribution of Chl-a concentrations. **Results:** The Chl-a index ranges from 73.78 to 100. The mean Chl-a index is 91.6 with a standard deviation of 3.27, indicating elevated and variable Chl-a concentrations. **Conclusions:** The findings contribute to the understanding of the reservoir's ecological health and assist in making informed decisions for water quality management. This research exemplifies the integration of remote sensing technology and environmental stewardship, promoting sustainable water management practices in the region. **Policy recommendations:** One possible policy recommendation is to monitor and regulate the sources of nutrient inputs into the reservoir, such as agricultural runoff, sewage, and industrial effluents, to reduce the risk of eutrophication and algal blooms. Another possible policy recommendation is to implement adaptive management strategies that consider the seasonal and spatial variability of Chl-a concentrations and their impacts on water quality and availability.

Keywords: Dharoi Reservoir; Chlorophyll-a (Chl-a); Sentinel-2 satellite imagery; water quality; ecological health; sustainable water management

1. Introduction

The Dharoi Reservoir, nestled in the vibrant state of Gujarat, India, serves as a lifeline for the surrounding communities [1]. It plays a pivotal role in various sectors, including agriculture, industry, and domestic water supply [2]. However, the reservoir's water quality is not constant and experiences variations due to a combination of natural processes and human activities [3].

Natural factors such as seasonal changes, weather patterns, and biological activities can influence the reservoir's water quality [4]. For instance, during the monsoon season, the reservoir may receive a large influx of water, carrying with it sediments and nutrients that can alter the water's physical and chemical properties. Similarly, biological activities such as algal blooms can affect the water's oxygen levels and pH, impacting its overall quality [5].

On the other hand, anthropogenic factors such as industrial effluents, agricultural runoff, and domestic sewage can introduce pollutants into the reservoir [4,5]. These pollutants can include heavy metals, pesticides, and nutrients, which can pose risks to the reservoir's ecological health and the well-being of the communities that rely on it [6].

Given these challenges, regular monitoring and assessment of the water quality in Dharoi Reservoir are crucial. Such efforts can help identify potential issues early, allowing for timely interventions to mitigate any adverse impacts. Moreover, they can provide valuable data to inform decision-making processes, contributing to the sustainable management of this vital resource [7].

Furthermore, these assessments can guide the development and implementation of effective water management strategies. These strategies can include pollution control measures, watershed management practices, and community awareness programs. By ensuring the reservoir's water quality, we can safeguard its ecological health and continue to support the societal well-being of the communities that depend on it.

One of the key indicators of water quality is Chlorophyll-a (Chl-a), a pigment found in algae and plants that reflects the trophic state and nutrient status of aquatic economic, political, and cultural phenomena from a global standpoint [8–12]. High concentrations of Chl-a may indicate eutrophication, a process of excessive algal growth that can impair water quality and cause ecological imbalance [13,14].

In recent years, there have been advancements in predicting chlorophyll-a concentrations using various remote sensing and ground observation data (**Table 1**). These methods have been shown to improve the spatial resolution and reduce discrepancies between predicted and observed values.

Table 1. The recent studies related to Chl-a concentration estimation using remote sensing and GIS.

Study	Description	Reference
Remote Sensing Estimation of Chlorophyll-a Concentration in Taihu Lake	This study used remote sensing to estimate Chl-a concentrations in Taihu Lake, China. The study considered the spatial and temporal variations of the lake's optical properties.	[15]
Applying Deep Learning in the Prediction of Chlorophyll-a in the East China Sea	This study applied deep learning to predict Chl-a concentrations in the East China Sea. The study used a long short-term memory (LSTM) neural network for training and prediction.	[16]
Prediction of Chlorophyll-a and Suspended Solids Through Remote Sensing	This study used Sentinel-2 spectral images and laboratory analysis data to train an artificial neural network for predicting the concentration of Chl-a.	[17]
Machine and Deep Learning Regression Models for Predicting Chlorophyll-a	This study used machine and deep learning models applied to hyperspectral satellite imagery for predicting Chl-a.	[18]

For Dharoi Reservoir, the current reservoir level data was reported at 187.59 m on 11 January 2024. This records a decrease from the previous number of 187.84 m for 4 January 2024 [19]. The data reached an all-time high of 189.65 m on 26 October 2023 and a record low of 177.99 m on 1 August 2019 [19].

In this study, we aim to explore and assess the spatial distribution and variability of Chl-a concentrations in Dharoi Reservoir using Sentinel-2 satellite imagery, which offers high spatial and temporal resolution for remote sensing applications. We focus on the month of October 2024, which represents a transitional period between the monsoon and post-monsoon seasons, to capture the seasonal variations in water quality.

Our study contributes to the scientific understanding of water quality dynamics in Dharoi Reservoir and provides valuable insights for environmental conservation and water resource management in the region. By utilizing satellite-based remote sensing technology, we offer a holistic and cost-effective approach to water quality assessment that can complement and enhance the existing ground-based methods. We hope that our findings will help foster resilient and sustainable water management practices that can balance the multiple and competing demands on Dharoi Reservoir.

2. Methodology

2.1. Data collection

The study utilized Sentinel-2 satellite imagery from the Copernicus Open Access Hub, specifically the Sentinel-2 Surface Reflectance product, to assess water quality in Dharoi Reservoir. The imagery was acquired during the month of October 2020 to capture seasonal variations in water quality. Additionally, the study incorporated publicly available geographical datasets from Google Earth Engine (GEE) to enhance the analysis [20].

2.2. Calculation of Chlorophyll-a (Chl-a)

The calculation of Chlorophyll-a concentration (Chl-a) involved the use of Sentinel-2 bands B5 (705.4 nm–740.1 nm) and B4 (640.0 nm–672.5 nm), following the algorithm widely used in remote sensing applications [21]. The Chl-a concentration was computed using the formula.

$$\text{Chl-a} = (B5 \times B4) \times 100\text{Chl-a} = (B4 \times B5) \times 100 \quad (1)$$

This computation aims to leverage the spectral properties of Sentinel-2 bands related to chlorophyll absorption and reflectance in water bodies [22]. The resulting Chl-a values were then normalized to the range of 0 to 100 using the clamp function to enhance the interpretability of the data [23]. Water Classification Method: The classification of water bodies was based on Chl-a values, providing insights into different trophic states. The following classification scheme was applied.

- Class 1: Oligotrophic (Chl-a $\leq$ 10)
- Class 2: Mesotrophic (10 $<$ Chl-a $\leq$ 25)
- Class 3: Eutrophic (25 $<$ Chl-a $\leq$ 50)
- Class 4: Hypertrophic (Chl-a $>$ 50)

Non-water pixels were masked out by setting a threshold at Chl-a $>$ 0. The resulting classified image, referred to as 'Classes', provides a spatial representation of different water quality states within Dharoi Reservoir [24]. Considerations and Adjustments: In the original code, a few adjustments were made to enhance the functionality and ensure the relevance of the analysis to the study area. Notably, the study focused on Sentinel-2 data from October 2020, a period chosen to capture seasonal variations in water quality. Additionally, the code was modified to export all relevant parameters, including the Sentinel-2 bands, Chl-a concentrations, and water classes, to Google Drive for further analysis and documentation. The implementation of the methodology in Google Earth Engine provides an efficient and scalable platform for remote sensing analysis, allowing for the processing of large-scale spatial data with minimal computational resources (**Figure 1**).

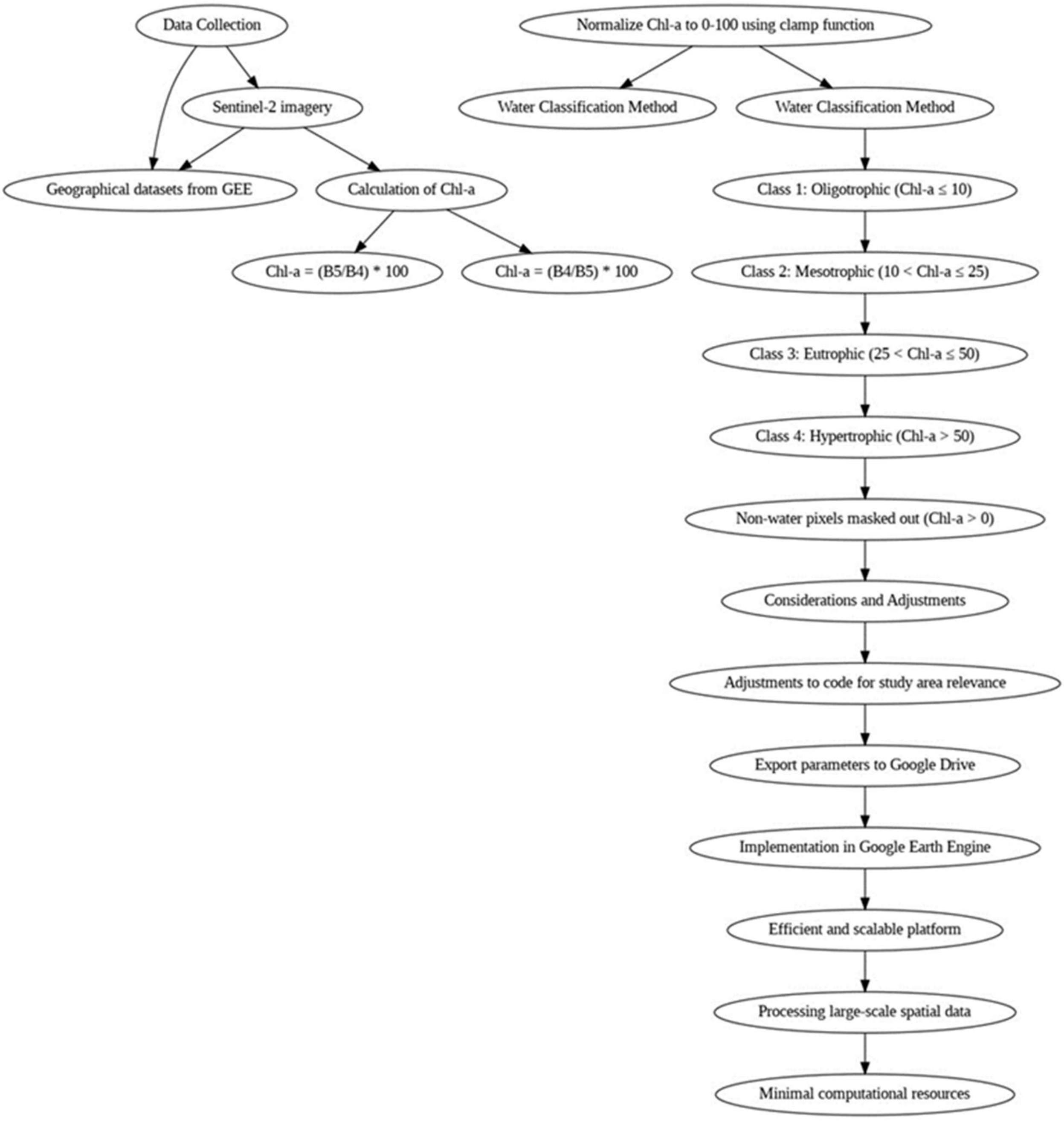

Figure 1. Methodology flow chart of the study.

3. Results

The analysis of Chlorophyll-a (Chl-a) concentrations in Dharoi Reservoir, conducted using Sentinel-2 satellite imagery, revealed a range of values from 73.78 to 100. The Chl-a index, representing the normalized concentration of chlorophyll-a in the water, provides valuable insights into the trophic status of the reservoir.

Chl-a Index Distribution: The Chl-a index varied spatially across the reservoir, with values ranging from 73.78 to 100. The distribution of Chl-concentrations was not uniform, indicating potential hotspots of algal activity or variations in nutrient levels within the water body (**Figure 2**).

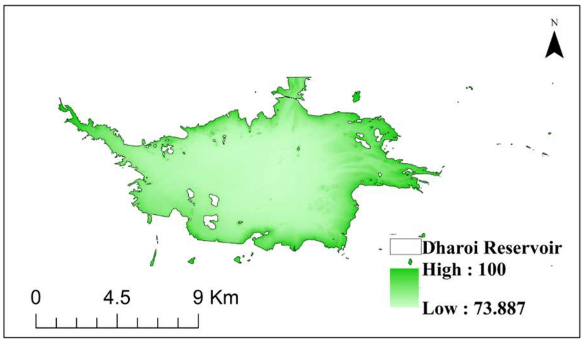

Figure 2. Spatial distribution of Chl-a index in Dharoi Reservoir.

The statistical summary of the Chl-a index in Dharoi Reservoir is presented below:

Mean Chl-a Index: 91.6

Standard Deviation: 3.2

These summary statistics provide a comprehensive overview of the central tendency and variability of Chl-a concentrations in the reservoir. The high mean Chl-a index suggests that, on average, the reservoir exhibits elevated chlorophyll-a levels, potentially indicating a eutrophic condition and hypertrophic condition. The standard deviation provides insights into the variability of Chl-a concentrations, highlighting areas of spatial heterogeneity in water quality.

The observed Chl-a concentrations in Dharoi Reservoir indicate a significant presence of chlorophyll-a, which is often associated with the proliferation of phytoplankton and algae. While elevated Chl-a levels can contribute to the richness of aquatic ecosystems, excessive concentrations may lead to eutrophication, impacting water quality and ecosystem health (**Figure 3**).

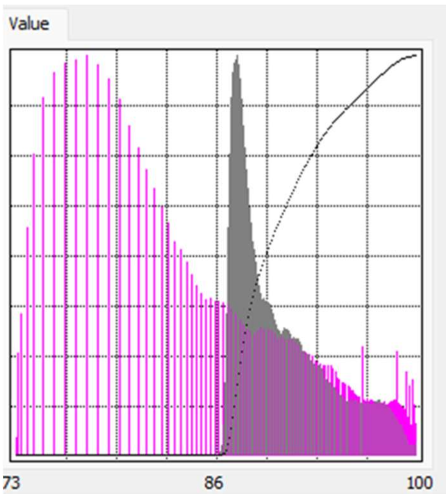

Figure 3. Histogram of Chl-a index.

4. Discussion

These results contribute to a better understanding of the current state of water quality in Dharoi Reservoir, supporting informed decision-making for environmental management and resource conservation [25]. The analysis of Chlorophyll-a (Chl-a) concentrations conducted using Sentinel-2 satellite imagery, provides valuable insights into the trophic status of the reservoir [26]. The Chl-a index, which represents the normalized concentration of chlorophyll-a in the water, varied spatially across the reservoir, indicating potential hotspots of algal activity or variations in nutrient levels [27]. The mean Chl-a index of 91.6 suggests that the reservoir, on average, exhibits elevated chlorophyll-a levels, potentially indicating a eutrophic or even hypertrophic condition. The standard deviation of 3.2 provides insights into the variability of Chl-a concentrations, highlighting areas of spatial heterogeneity in water quality [28].

The histogram of the Chl-a index further illustrates the distribution of chlorophyll-a concentrations in the reservoir. The significant presence of chlorophyll-a, often associated with the proliferation of phytoplankton and algae, suggests that while elevated Chl-a levels can contribute to the richness of aquatic ecosystems, excessive concentrations may lead to eutrophication, impacting water quality and ecosystem health [29].

5. Conclusion

This study has demonstrated the feasibility and utility of using Sentinel-2 satellite imagery to estimate Chl-a concentrations in Dharoi Reservoir, a vital freshwater resource in Gujarat, India. The results revealed high spatial heterogeneity and variability of Chl-a levels across the reservoir, indicating different trophic states and water quality conditions. The mean Chl-a index of 91.6 suggested that the reservoir was generally in a eutrophic state, with high algal biomass and potential risk of harmful algal blooms. The spatial distribution and statistical summary of Chl-a provided valuable insights into the water quality dynamics and ecological status of the reservoir, which are essential for informed decision-making and effective management practices.

This study also highlighted the limitations and challenges of using satellite remote sensing for water quality assessment, such as the influence of atmospheric correction, water depth, and bottom reflectance on the accuracy of Chl-a estimation. Future research should address these issues by incorporating more ground-truth data, improving the calibration and validation of Chl-a algorithms, and applying more advanced methods such as machine learning and neural networks. Moreover, future studies should also consider other water quality parameters, such as turbidity, suspended solids, and nutrients, to obtain a more comprehensive and holistic understanding of the reservoir’s ecosystem. Additionally, future studies should explore the temporal variations and trends of Chl-a and water quality in relation to climatic factors, hydrological regimes, and anthropogenic activities.

The findings of this study have important implications for the sustainable management and conservation of Dharoi Reservoir and other similar water bodies in the region. The integration of satellite remote sensing with on-the-ground monitoring and management strategies can enhance the efficiency and effectiveness of water resource management, environmental protection, and public health. This study also contributes to the broader discourse on the role of science and technology in advancing our knowledge and stewardship of complex aquatic ecosystems. As we face the challenges and opportunities of the 21st century, this study underscores the need for continued collaboration and innovation among researchers, policymakers, and stakeholders to safeguard our invaluable water resources.

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Conflict of interest: The authors declare no conflict of interest.

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