LINKING TROPHIC STATE INDEX TO HIGH RESOLUTION SATELLITE IMAGERY DATA OF MRICA RESERVOIR, BANJARNEGARA – CENTRAL JAVA

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ABSTRACT

The increasing eutrophication of inland water bodies necessitates efficient, spatially extensive, and timely monitoring methods. This study investigates the utility of high-resolution PlanetScope satellite imagery for assessing the trophic state of the Mrica Reservoir in Banjarnegara, Central Java, Indonesia. Field measurements of Secchi Disk Depth (SDD), Total Phosphate (TP), and Chlorophyll-a (Chl-a) were collected at six observation stations and used to calculate Carlson's Trophic State Index (CTSI). These values were then correlated with satellite-derived vegetation indices−Normalized Difference Vegetation Index (NDVI) and Red Edge NDVI (RdEdNDVI). Polynomial regression analysis showed strong correlations between NDVI and TP ($R^2 = 0.975$) as well as between RdEdNDVI and Chl-a ($R^2 = 0.959$), confirming the potential of these indices to estimate key trophic indicators. Spatial mapping of CTSI indicated that the reservoir ranged from eutrophic to hypereutrophic, with the most degraded conditions observed near the outlet area. The findings underscore the effectiveness of remote sensing for detecting spatial variability in water quality, particularly when field sampling is limited. While challenges such as cloud cover, spectral limitations, and sampling resolution persist, this integrated approach offers a scalable and cost-efficient framework for reservoir monitoring. The study highlights the potential for replicating this method across similar freshwater systems in Indonesia to support sustainable water resource management.

Key-words: *Trophic State Index (TSI), PlanetScope, Remote Sensing, Water Quality Monitoring, Mrica Reservoir*

1. INTRODUCTION

Mrica Reservoir, formed by the Panglima Besar Soedirman (PB Soedirman) Dam on the Serayu River in Banjarnegara, Central Java, is a vital multipurpose water infrastructure in southern Java. Commissioned in 1988, the reservoir supports a wide range of services, including hydroelectric power generation, irrigation for agricultural lands, flood control, and raw water supply for surrounding communities. Over the decades, however, increased anthropogenic pressures such as agricultural runoff, sedimentation, and domestic waste have raised concerns about water quality deterioration in the reservoir (Anggraini et al., 2019). One of the most pressing environmental issues faced by reservoirs in tropical regions is eutrophication, a process driven by nutrient enrichment that leads to excessive algal growth and potential ecological imbalance (Barbosa et al., 2022).

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In reservoirs like Mrica, eutrophication not only degrades water quality but also threatens aquatic biodiversity, reduces reservoir capacity through sedimentation, and impairs the operation of hydroelectric systems. Similar challenges have been documented in other Indonesian reservoirs, such as Gajah Mungkur, where Carlson’s Trophic State Index has been effectively used to evaluate eutrophication levels (Shaleh et al., 2014).

The Trophic State Index (TSI), particularly Carlson’s TSI, has been widely used to classify the trophic status of inland waters based on parameters such as chlorophyll-a concentration, Secchi disk depth, and total phosphorus content (Carlson, 1977; Carlson & Simpson, 1996). However, in-situ monitoring of these parameters can be time-consuming, expensive, and spatially limited.

In recent years, satellite remote sensing has emerged as a cost-effective and scalable tool to monitor water quality, including eutrophication levels, in lakes and reservoirs. High-resolution satellite imagery, such as that from PlanetScope, allows the extraction of biophysical indicators like chlorophyll-a and turbidity through spectral reflectance values and band ratios. Numerous studies have demonstrated significant correlations between satellite-derived indices and water quality parameters, enabling the development of predictive models for TSI assessment (Alikas & Kratzer, 2017; Kutser, 2009; Tyler et al., 2006). Despite these advancements, there is limited research applying this approach to medium-sized reservoirs in Indonesia, including Mrica. This study aims to bridge that gap by linking in-situ Trophic State Index measurements with spectral data from high-resolution satellite imagery, providing a spatially comprehensive method for assessing and monitoring the trophic status of the Mrica Reservoir. This study presents a novel approach by integrating high-resolution PlanetScope satellite imagery with in-situ Trophic State Index (TSI) measurements to assess eutrophication in the medium-sized Mrica Reservoir—an application rarely explored in Indonesian inland waters. By developing a spatially comprehensive and cost-effective remote sensing-based model for trophic state monitoring, this research addresses existing gaps in local water quality assessment and offers a scalable tool for sustainable reservoir management in tropical regions.

2. METHODS

2.1. Study Area

The study was conducted in the Mrica Reservoir, located in Banjarnegara Regency, Central Java, Indonesia, at approximately 7° 20′ - 7° 25′ S latitude and 109° 34′ - 109° 38′ E longitude (**Fig. 1**).

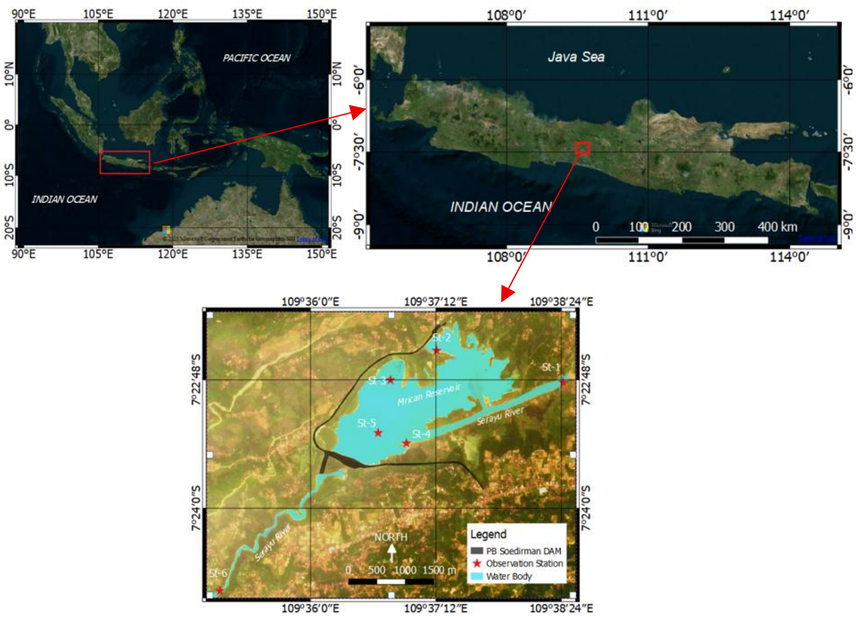

Fig. 1. Study area.

The reservoir was formed by the construction of the PB Soedirman Dam on the Serayu River, one of the major river systems in Central Java. Situated at an elevation of around 150–200 meters above sea level, the reservoir lies within a humid tropical climate zone characterized by distinct wet and dry seasons influenced by the monsoonal cycle.

Geographically, the surrounding area is dominated by a mixture of hilly terrain, agricultural lands, and forested slopes, contributing to a dynamic watershed environment. The topography features moderate to steep slopes in the upstream catchment, which significantly influence surface runoff, erosion, and sediment transport into the reservoir. These geomorphological conditions contribute to high sedimentation rates, a persistent challenge that reduces the reservoir's storage capacity and affects its operational efficiency.

2.2. Research Flowchart

As shown in **Fig. 2**., this study begins by defining the Area of Interest (AOI) of the Mrica Reservoir and acquiring high-resolution PlanetScope imagery with less than 10% cloud cover. The selected imagery is processed by masking the water body and deriving NDVI and Red Edge NDVI. Simultaneously, field data on Secchi Disk Depth (SDD), Total Phosphate (TP), and Chlorophyll-a (Chl-a) are collected from inlet, outlet, and reservoir points. These data are used for validation and statistical correlation with satellite indices. The results produce spatial distributions of SDD, TP, and Chl-a, which are then used to calculate the Trophic State Index (TSI) to assess the water quality of the Mrica Reservoir.

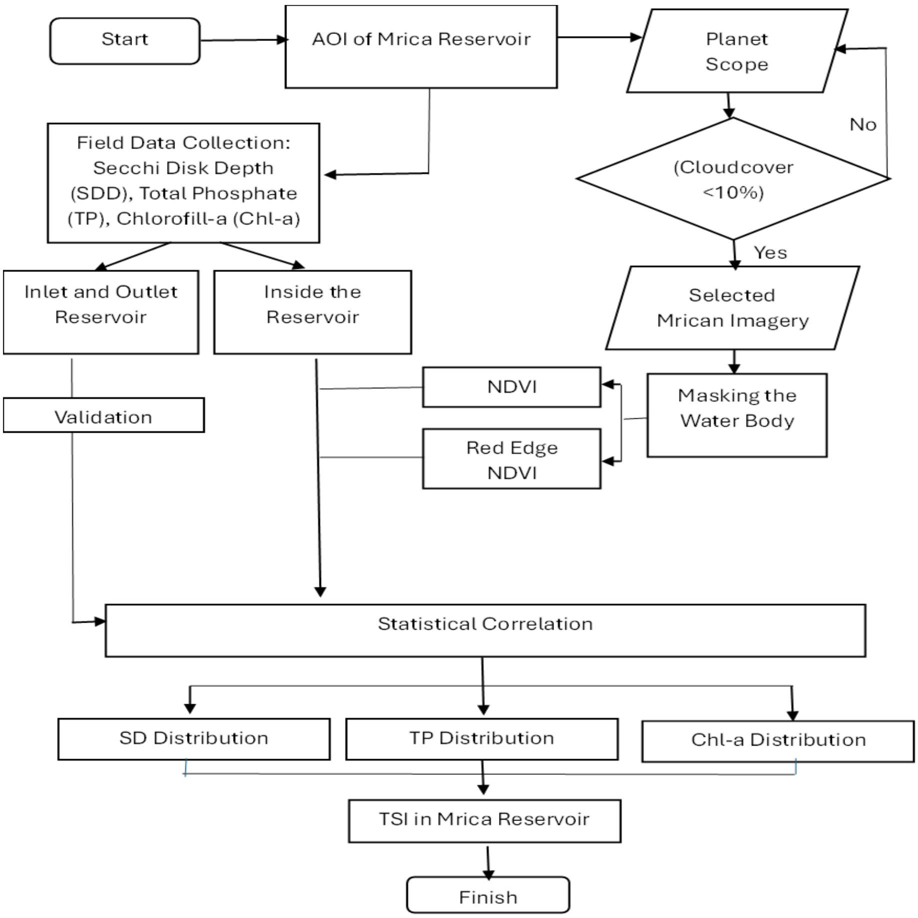

Fig. 2. Workflow of the research.

2.3. Satellite Data and Image Processing

High-resolution satellite imagery from PlanetScope was utilized for this study. The imagery was acquired during the dry season to minimize atmospheric disturbances and cloud cover. PlanetScope imagery provides daily images with a spatial resolution of approximately 3 meters and includes the following spectral bands used in this analysis:

Red band (R) with the wavelength of 665 μm

Red Edge band (RE) with the wavelength of 705 μm

Near Infrared band (NIR) with the wavelength of 865 μm

Two vegetation-related indices were computed to assess water quality proxies:

1. Normalized Difference Vegetation Index (NDVI):

$$NDVI = (NIR-R) / (NIR+R) \quad (1)$$

2. Red Edge NDVI (RdEd-NDVI):

$$RdEdNDVI = (NIR-RE)/(NIR+RE) \quad (2)$$

These indices were derived using cloud-free PlanetScope imagery clipped to the outline of Mrica Reservoir, obtained through Object Identification processing. Pre-processing steps included radiometric and geometric correction, atmospheric correction using surface reflectance products, and masking of non-water areas.

2.4. Field Sampling and Laboratory Analysis

Field observations were conducted at 6 sampling stations distributed across the reservoir to capture spatial variability. The stations were selected based on accessibility, representativeness of water bodies, and proximity to potential nutrient inflow sources.

At each station, Secchi Disk Depth (SDD) was measured in situ to assess water clarity. Water samples were collected from the surface layer using a bottle sampler. The collected water was then preserved and transported to the laboratory for chemical analysis.

The laboratory procedures followed the APHA Standard Methods for the Examination of Water and Wastewater, 24th Edition (APHA, 2017), which included: Chlorophyll-a (Chl-a) concentration analysis using spectrophotometry after pigment extraction. Total Phosphate (TP) determination using the ascorbic acid method after persulfate digestion.

2.5. Trophic State Index (TSI) Calculation and Classification

Carlson's TSI was computed based on three parameters: SDD, Chl-a, and TP. The following formulas were used (Carlson, 1977; Carlson & Simpson, 1996):

$$TSISD = 60 - 14.4\ln(SD) \quad (3)$$

$$TSIChl - a = 9.81\ln(Chl - a) + 30.6 \quad (4)$$

$$TSITP = 14.2\ln(TP) + 4.15 \quad (5)$$

$$CTSI = [TSI(SD) + TSI(Chl\text{-}a) + TSI(TP)] / 3 \quad (6)$$

where:

CTSI: Carlson Trophic State Index.

TSISD: Trophic state index for Secchi disk depth (SDD/m);

TSIChl-1: Trophic state index for chlorophyll-a (Chl-a/mgL^{-1});

TSITP: Trophic state index for total phosphorous (TP/mgL^{-1}).

Table 1 presents the classification of the Carlson Trophic State Index (CTSI) and its interpretation for lakes and reservoirs, which has been modified from the Indonesian Ministry of State for the Environment (MOSE, 2009). The CTSI categorizes water bodies based on nutrient levels, particularly nitrogen (N) and phosphorus (P), which influence water clarity and algal growth. Oligotrophic waters (CTSI 0‑20) are characterized by low nutrient concentrations and minimal signs of pollution. As nutrient levels increase, the water transitions to mesotrophic (20‑40) and eutrophic (40‑60) conditions, indicating moderate to high enrichment. High eutrophic (60‑70) and hypereutrophic (70‑100) classifications reflect severe nutrient pollution, often resulting in algal blooms and ecological degradation. This classification provides a useful framework for assessing the trophic state and ecological health of the Mrica Reservoir.

Table 1.

Classification of CTSI.

CTSI Class	State		Information
0-20	Oligotrophic		Trophic status of lake and/or reservoir water containing low levels of nutrients. This status indicates that the water quality is still natural and has not been polluted by sources of N and P nutrients.
20-40	Mesotrophic		Trophic status of lake and reservoir water containing moderate levels of nutrients. This status indicates an increase in N and P levels, but is still within tolerance limits because it has not shown any indication of water pollution.
40-60	Eutrophics	Meso-eutrophics	Trophic status of lake and reservoir water containing high levels of nutrients. This status indicates that the water has been polluted by increased levels of N and P.
60-70		High eutrophics	
70-100	Hyper-eutrophic		Trophic status of lake and reservoir water containing very high levels of nutrients. This status indicates that the water has been heavily polluted by increased levels of N and P.

2.6. Data Analysis

To quantify the relationship between satellite-derived vegetation indices and field-measured water quality parameters, a statistical correlation analysis was performed using second-order polynomial regression. The analysis aimed to evaluate how well NDVI and Red Edge NDVI (RdEdNDVI) derived from PlanetScope imagery—can predict key trophic state indicators, including SDD, Chl-a concentration, and TP. Vegetation index values were extracted at each of the six field sampling locations within Mrica Reservoir using spatial overlay methods in a GIS environment. For each index‑parameter pair, a second-degree polynomial trendline was fitted using the following general model:

$$Y = aX2 + bX + c \quad (7)$$

where:

Y is the field-measured water quality parameter (SD, Chl-a, or TP),

X is the NDVI or RdEdNDVI value,

a,b and c are polynomial coefficients.

The coefficient of determination (R^2) was used to assess the goodness-of-fit for each polynomial model. The index that yielded the highest R^2 value for each parameter was identified as the most effective predictor. This method enables the selection of the optimal remote sensing indicator to estimate water quality conditions and infer the Trophic State Index (TSI) distribution across the reservoir. All statistical modeling and visualization were performed using Microsoft Excel.

3. RESULTS AND DISCUSSION

3.1. Overview of Satellite Imagery and Field Observations

High-resolution PlanetScope imagery was online downloaded from the website https://www.planet.com/explorer (Planet Labs PBC, 2025) (**Fig. 3**). Image data was acquired on April 15, 2025, at 03:30:33 UTC, during the dry season to minimize cloud contamination and ensure optimal atmospheric conditions. The selected image exhibited less than 10% cloud cover and underwent standard preprocessing steps, including radiometric calibration, geometric correction, atmospheric correction using surface reflectance products, and masking of non-water areas. The final imagery was clipped to the delineated boundary of the Mrica Reservoir to extract relevant water quality indices, specifically the Normalized Difference Vegetation Index (NDVI) and Red Edge NDVI (RdEdNDVI).

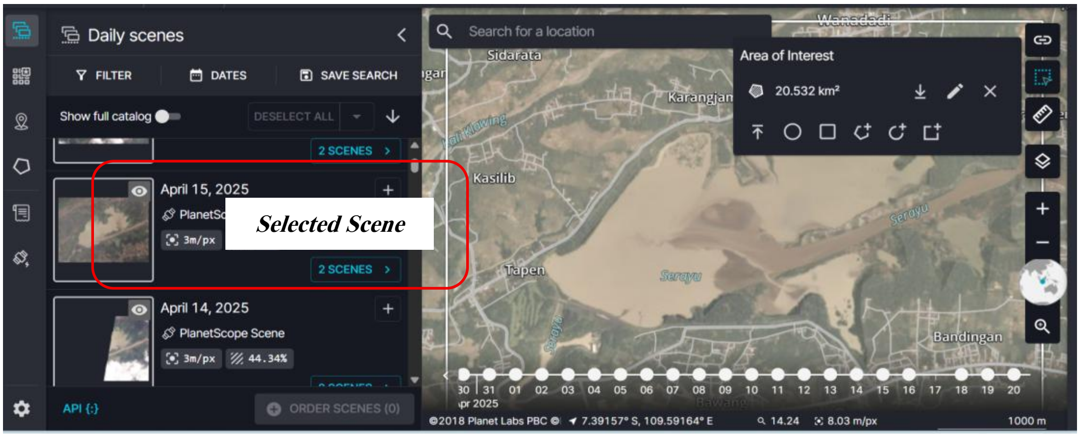

Fig. 3. Process of downloading the satellite imagery data on https://www.planet.com/ .

PlanetScope imagery was chosen for this study due to its high spatial resolution (~3 meters) and daily revisit frequency, which are essential for capturing fine-scale and timely changes in a medium-sized reservoir like Mrica, especially under frequent cloud cover in tropical regions. While Sentinel-2 offers a wider spectral range, its coarser resolution (10–60 meters) and lower revisit rate (5 days) limit its suitability for detailed water quality assessments in smaller inland waters. PlanetScope also provides sufficient spectral bands (Red, Red Edge, NIR) to calculate key indices like NDVI and RdEd-NDVI, making it a practical and effective choice for this application. Field observations (**Fig. 4**) were conducted on April 22–23, 2025, at six strategically selected sampling stations across the reservoir, covering the inlet, outlet, and central zones. These stations were chosen based on accessibility, hydrological significance, and representativeness of spatial variability.

The Secchi Disk Depth (SDD) values ranged from 0.10 to 0.29 meters, indicating high turbidity levels throughout the reservoir, particularly near the inlet zone, which is likely affected by sediment and nutrient inflow from upstream. Total Phosphate (TP) concentrations ranged from 0.042 to 0.301 mg/L, with the highest value detected in the southern part of the reservoir, suggesting external loading from agricultural or domestic sources.

Chlorophyll-a (Chl-a) concentrations varied between 3.461 and 11.471 mg/L, with peak values observed in shallow and poorly circulated regions, indicating elevated phytoplankton biomass and potential eutrophication. These in situ observations reveal significant spatial variation in water quality parameters and suggest the influence of both hydrological inputs and morphological characteristics of the reservoir. The collected field data serve as a basis for validating satellite-derived indices and for calculating the Carlson Trophic State Index (TSI) to assess the overall trophic condition of the Mrica Reservoir.

Fig. 4. Field survey activity for collecting data in observation station.

3.2. Spatial Distribution of Water Quality Parameters

Water quality parameters exhibited notable spatial variation across the six observation points within the Mrica Reservoir (**Table 2**). The Secchi Disk Depth (SDD) values, indicative of water transparency, ranged from 10 cm (St-6) to 29 cm (St-3). The shallowest SDD observed at Station 6, located in the southwestern part of the reservoir, suggests high turbidity likely due to suspended sediments and possible inflow of particulates. Conversely, the highest water clarity was recorded at Station 3, situated in the central area of the reservoir, indicating relatively low turbidity.

Total Phosphate (TP) concentrations varied significantly, ranging from 0.042 mg/L (St-3) to 0.301 mg/L (St-6). The elevated TP levels in Station 6 suggest a potential point-source nutrient input or accumulation of phosphorus-rich sediments in this region. Stations closer to the central and eastern reservoir (e.g., St-1 to St-3) recorded lower TP values, generally below 0.06 mg/L, suggesting comparatively less nutrient enrichment in those areas.

Chlorophyll-a (Chl-a) concentrations, which indicate phytoplankton biomass and serve as a proxy for algal productivity, ranged from 3.461 mg/L (St-4) to 11.471 mg/L (St-2). The highest Chl-a level at Station 2 corresponds with a relatively moderate TP level (0.054 mg/L), suggesting that local conditions such as light availability or water retention time may favor algal growth. Meanwhile, Station 4, despite having a relatively high TP concentration (0.117 mg/L), recorded the lowest Chl-a value, possibly due to light limitation from high turbidity or water column instability. These spatial patterns indicate that nutrient enrichment and algal productivity do not always correlate linearly, as they are also influenced by physical parameters such as turbidity, depth, and water circulation. Station 6 consistently recorded the most degraded water quality conditions–low SDD, high TP, and moderate Chl-a–pointing to this area as a potential hotspot of eutrophication within the Mrica Reservoir.

Tabel 2.

Observation points in Mrica Reservoir.

Observation Point	Date	Hour *	Longitude (E) **	Latitude (S)**	SDD (cm)	TP (mg/l)	Chl-a (mg/l)
St-1	23-Apr-25	11.32	109,64031	7,38041	21	0,058	3,893
St-2	23-Apr-25	12.58	109,62009	7,37542	22	0,054	11,471
St-3	23-Apr-25	09.30	109,61272	7,38003	29	0,042	5,072
St-4	23-Apr-25	10.36	109,61528	7,38989	17	0,117	3,461
St-5	23-Apr-25	10.07	109,61076	7,38828	20	0,077	8,481
St-6	22-Apr-25	16.32	109,58548	7,41294	10	0,301	6,346

**Western Indonesian Time Zone (UTC+7),*
*** Datum EPSG: 3857 (WGS 84/Pseudo Mercator)*

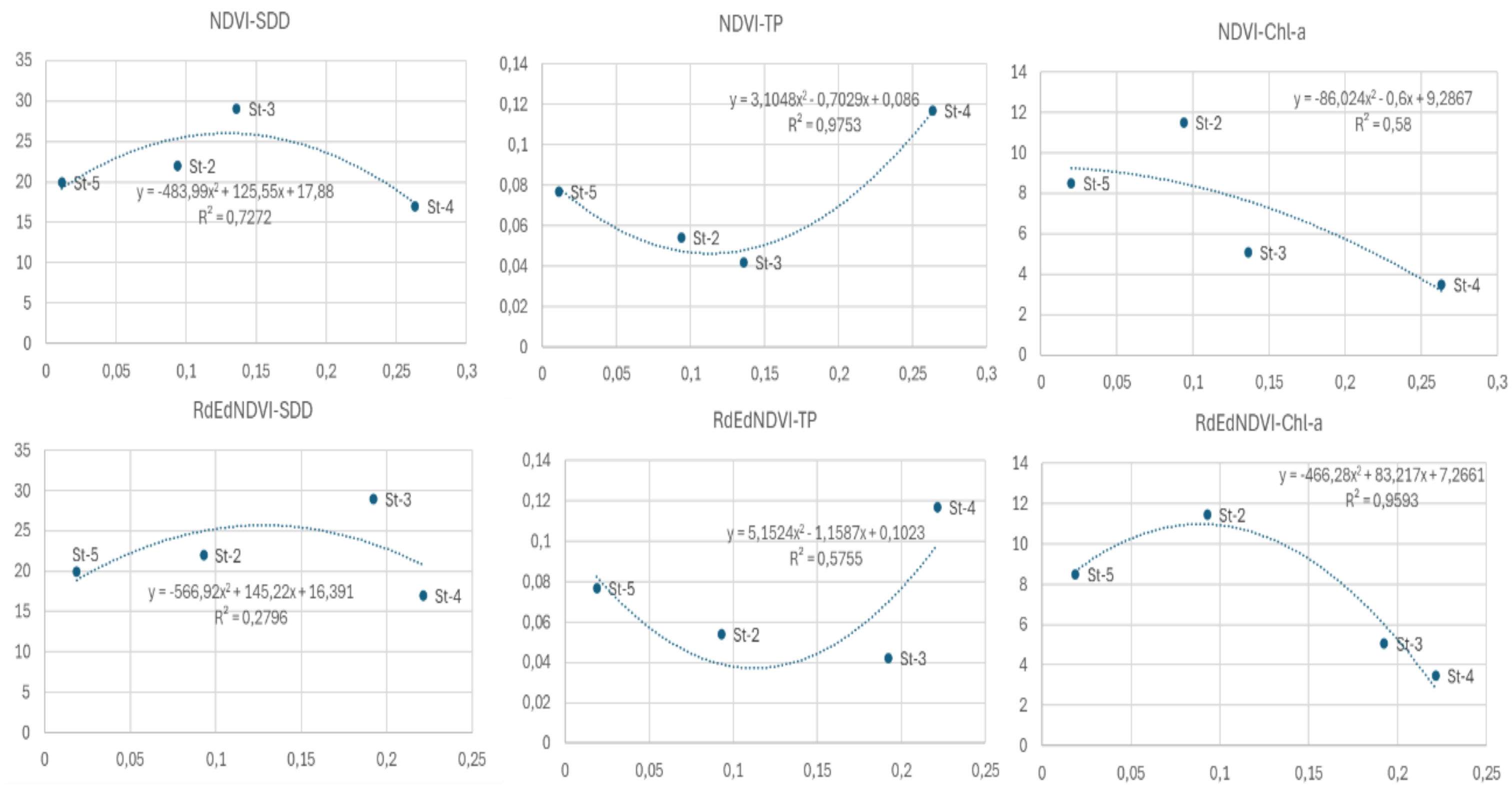

Fig. 5. Polynomial regression graph for each parameter and Satellite-Derived Indices.

3.3. Relationship Between Satellite-Derived Indices and Field Parameters

Polynomial regression analysis (**Fig. 5**) was conducted to examine the relationship between satellite-derived indices (NDVI and RdEdNDVI) and field-measured water quality parameters (SDD, TP, and Chl-a). Results showed that NDVI correlated most strongly with Total Phosphate (TP), yielding a high R^2 of 0.975, followed by SDD (R^2 = 0.727) and Chlorophyll-a (R^2 = 0.579). In contrast, RdEdNDVI showed the strongest correlation with Chl-a (R^2 = 0.959), while its relationships with TP (R^2 = 0.575) and SDD (R^2 = 0.280) were moderate to weak.

The best-fitting equations for NDVI were:

$$TP = -0.703(NDVI) + 3.105(NDVI^2) + 0.086 \quad (8)$$

$$SDD = 125.55(NDVI) - 483.99(NDVI^2) + 17.88 \quad (9)$$

Meanwhile, RdEdNDVI produced the most reliable model for estimating Chl-a:

$$Chl\text{-}a = 83.217(RdEdNDVI) - 466.276(RdEdNDVI^2) + 7.266 \quad (10)$$

These results indicate that NDVI (**Fig. 6a**) is a reliable indicator of nutrient levels (TP), possibly reflecting nutrient-induced changes in water color or algal presence. Conversely, RdEdNDVI (**Fig. 6b**) sensitivity to Chl-a is attributed to its red-edge band, which is more responsive to variations in algal pigments, especially in shallow or productive waters.

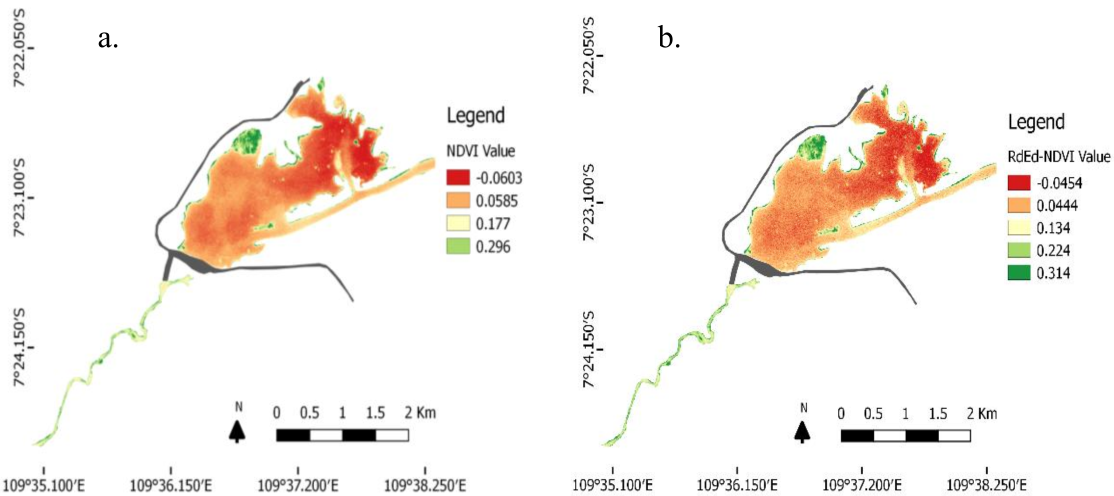

Fig. 6. Distribution map of Satellite-Derived Indice in Mrica Reservoir

Overall, the analysis confirms that both NDVI and RdEdNDVI can be used to estimate key water quality parameters, although their effectiveness varies depending on the parameter. NDVI is better suited for detecting nutrient-related signals such as TP, while RdEdNDVI is preferable for algal biomass (Chl-a) estimation. The relatively lower correlation with SDD suggests that water clarity is influenced by multiple factors, including inorganic particles, which are less detectable via spectral indices. **Fig. 7** shows the spatial distribution of Secchi Disk Depth (SDD), Total Phosphorus (TP), and Chlorophyll-a (Chl-a) in Mrica Reservoir derived from satellite imagery.

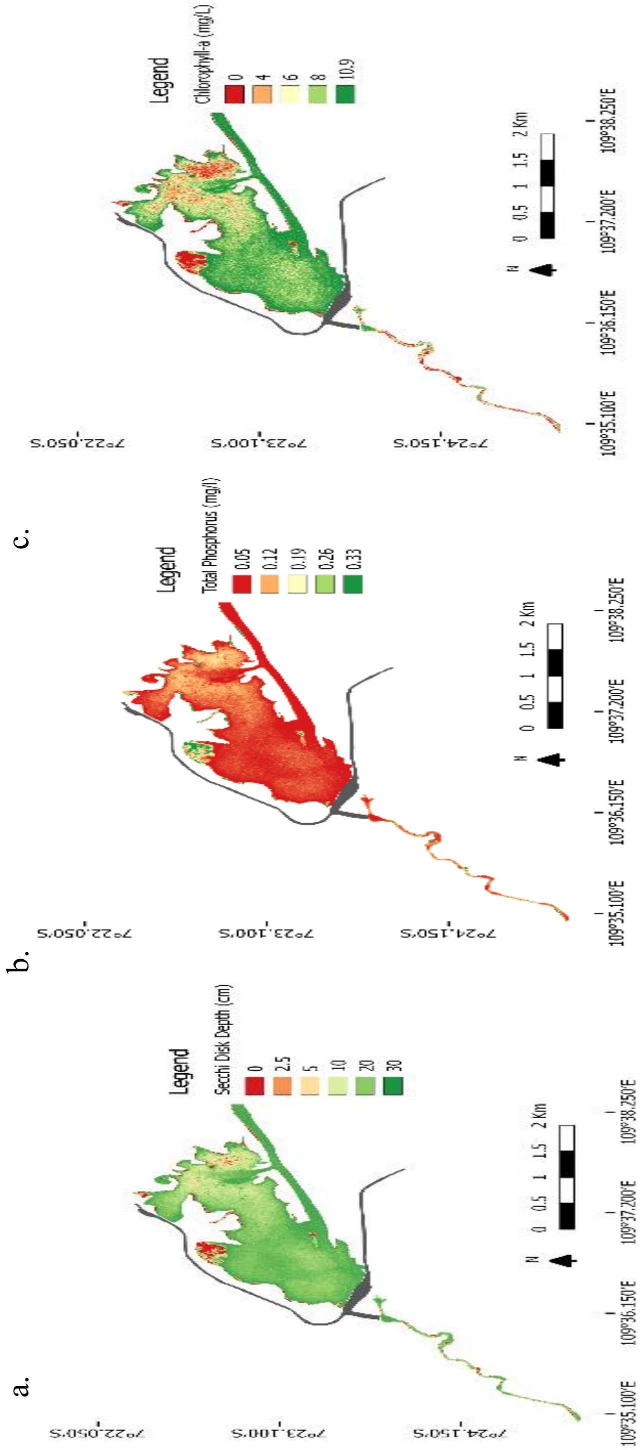

Fig. 7. Distribution map of Satellite-Derived parameters: a. SDD, b.TP and c. Chlorophyll-a.

Water clarity (SDD) is highest in the northern and central areas, while the southern region appears more turbid. TP and Chl-a concentrations are elevated in the southern and southwestern parts of the reservoir, indicating higher nutrient input and algal productivity near inflow areas. These patterns suggest a more eutrophic condition in the southern section, effectively captured through remote sensing analysis.

3.4. Trophic State Index (TSI) Analysis

The spatial distribution of the Carlson Trophic State Index (CTSI) across Mrica Reservoir is illustrated in **Figure 8**. The map reveals clear spatial variability in trophic conditions, with values ranging from moderately eutrophic to hypereutrophic.

Higher CTSI values are predominantly concentrated in the northern and inlet regions of the reservoir, which correspond to areas receiving direct nutrient inflow from upstream catchments.

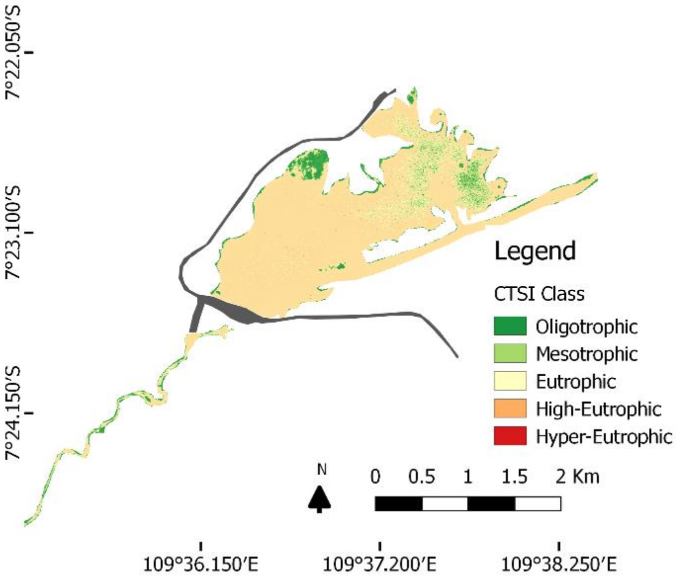

Fig. 8. Distribution of CTSI in Mrica Reservoir at April 15th 2025.

Station 6, located at the southern outlet, recorded the highest CTSI value of 76.4, classifying it as hypereutrophic. This suggests severe nutrient enrichment and likely frequent algal blooms. Other stations, such as St-2 and St-5, also fall within the eutrophic range (CTSI > 60), indicating considerable biological productivity and reduced water clarity. In contrast, the central and northern portions of the reservoir, represented by St-3 and St-1, showed comparatively lower CTSI values (59.8 and 63.4), though still within the eutrophic range.

The spatial interpolation highlights a degradation gradient from the inlet toward the outlet, implying that nutrient inputs are not well-distributed and may accumulate in stagnant or shallow zones. These findings align with earlier studies in other Indonesian reservoirs where land use pressures–particularly agriculture and settlements–contribute to elevated trophic conditions. Moreover, the variability in TSI values observed within Mrica Reservoir reflects the known challenges of applying standardized trophic indices in tropical systems, as highlighted by Cunha et al. (2021), who reported that traditional TSI interpretations may deviate significantly in tropical/subtropical contexts due to regional ecological and climatic factors.

This trophic state mapping underscores the importance of targeted management efforts in the upstream watershed to mitigate nutrient loading. Without intervention, areas such as the northern reservoir may experience further ecological stress, including reduced oxygen levels, harmful algal blooms, and impaired water usability.

The trophic status patterns and the correlation between NDVI-based indices and chlorophyll-a in Mrica Reservoir are consistent with findings from tropical reservoirs in Vietnam. For example, in Tri An and Dau Tieng reservoirs, NDVI derived from satellite imagery also showed strong correlations with chlorophyll-a concentrations, particularly during the dry season when algal blooms are more prominent (Hoang & Thi, 2025). This similarity underscores the broader applicability of vegetation indices for eutrophication assessment in Southeast Asia's tropical freshwater systems.

3.5. Implications of Remote Sensing for Water Quality Monitoring

This study demonstrates that vegetation indices derived from PlanetScope imagery—particularly NDVI and RdEdNDVI—can effectively estimate key eutrophication indicators. NDVI showed strong correlations with Total Phosphate ($R^2 = 0.975$) and Secchi Disk Depth ($R^2 = 0.727$), while RdEdNDVI had a slightly better relationship with Chlorophyll-a ($R^2 = 0.959$), likely due to its sensitivity to shallow water turbidity. These findings suggest that high-resolution remote sensing provides a viable alternative for spatially comprehensive monitoring, especially where field data are limited.

PlanetScope's 3-meter resolution and daily revisit capability offer significant advantages for detecting rapid or localized changes in small reservoirs like Mrica. Remote sensing reduces fieldwork dependence and enables monitoring of inaccessible zones. The effectiveness of red-edge indices in tropical aquatic environments has also been highlighted in recent studies (Liu et al., 2024), supporting their broader applicability.

However, limitations include cloud cover, mixed-pixel effects, and the inability to capture vertical water column variability. Calibration with field measurements remains essential. Despite these constraints, this approach aligns with similar research in Vietnam (Hoang & Thi, 2025) and holds potential for integration into Indonesia's national water quality monitoring framework. To enhance the practical use of remote sensing for water quality monitoring, we recommend a monthly satellite observation schedule, particularly during dry and post-rainy seasons when eutrophication risk is highest. Satellite-derived indices (e.g., NDVI, RdEdNDVI) should be integrated into local government GIS systems to support real-time visualization and spatial analysis for reservoir management. For accuracy, quarterly field validation is advised, with 12–20 sampling points measured for key parameters (e.g., Chlorophyll-a, SDD, TP) timed closely with satellite overpasses. This combined approach ensures consistent, scalable, and policy-relevant monitoring of reservoir health.

3.6. Limitations and Recommendations

This study acknowledges several limitations that may affect the accuracy and generalizability of the results. While PlanetScope offers high spatial resolution, its limited spectral range—particularly the absence of blue and shortwave infrared bands—reduces its sensitivity to water quality parameters such as turbidity and chlorophyll-a. Additionally, residual cloud cover (even below 10%) can introduce atmospheric noise, necessitating careful image pre-processing. The use of a single-date image restricts the ability to capture temporal variability in eutrophication dynamics, which can fluctuate significantly over days or weeks due to rainfall, runoff, or biological activity. As a result, the model may only reflect short-term water quality conditions, limiting its predictive robustness.

Field data collection posed additional challenges. Sampling was conducted over two consecutive days, potentially leading to temporal mismatches with the satellite overpass. Moreover, the limited number of sampling stations ($n = 6$) reduces the statistical power of the regression model and increases uncertainty in model coefficients. With such a small sample size, the coefficient of determination (R^2) may be unstable due to overfitting or the influence of outliers.

For spatial interpolation, techniques like IDW or Kriging become less reliable in areas far from sampling locations, with potential interpolation errors exceeding 20–30%, particularly in zones of rapid change such as inlets and outlets (Sferlazza et al., 2022). The importance of adequate spatial coverage has also been emphasized in coastal and wetland mapping applications, where undersampling can significantly distort feature representation (Wang et al., 2024; Costantino et al., 2020).

To address these limitations, future research should incorporate multi-temporal imagery across different seasons or hydrological events to better capture dynamic eutrophication trends. Integrating Sentinel-2, with its broader spectral capabilities, can enhance the sensitivity of spectral indices to water quality variations (Pahlevan et al., 2017; Wang et al., 2024). The use of machine learning algorithms, such as Random Forest or Support Vector Regression, may also improve model robustness, especially when field data are sparse. Finally, increasing the number of in-situ sampling stations (ideally >15–20) and synchronizing them with satellite overpass times would significantly improve the accuracy of validation efforts and reduce interpolation uncertainty.

4. CONCLUSIONS

The application of high-resolution PlanetScope satellite imagery in assessing the trophic state of Mrica Reservoir through the integration of remote sensing indices and field-based measurements has been discussed in this paper. By analyzing NDVI and RdEdNDVI alongside key water quality parameters‒SDD, TP, and Chl-a, we identified strong correlations between satellite-derived indices and trophic indicators. NDVI was found to be particularly effective in estimating TP concentrations, while RdEdNDVI showed high sensitivity to Chl-a, highlighting their complementary utility for monitoring eutrophication.

The spatial distribution of CTSI revealed significant variation within the reservoir, with several zones‒particularly near the outlet and southern sections‒classified as eutrophic to hypereutrophic. These areas are likely influenced by anthropogenic nutrient loading and hydrological stagnation. Remote sensing provided valuable insight into spatial patterns that might be missed through limited field sampling alone, emphasizing its role in complementing traditional monitoring approaches.

Despite inherent limitations such as spectral constraints and cloud interference, the use of PlanetScope data proved beneficial for detecting spatial heterogeneity in water quality conditions. The integration of satellite imagery with in-situ data offers a cost-effective, scalable, and timely approach for supporting water resource management, especially in data-scarce regions.

Future efforts should focus on expanding temporal analysis, incorporating machine learning for predictive modeling, and enhancing field validation to improve the reliability of remote-sensing-based trophic state assessments. This approach has strong potential to be replicated in similar reservoirs across Indonesia, aiding in the development of sustainable freshwater management strategies.

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