Reservoir's Water Quality Assessment Through Trophic State Model Using Multispectral Remote Sensing Data

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Abstract. Duriangkang Reservoir is a reservoir located in Muka Kuning Village, Tanjung Piayu, Sei Beduk Subdistrict which was built in 1990 and operated in 2001. Duringkang has the main function as the main source of clean water for the people of Batam. This study aims to determine the parameters obtained by using Landsat 8 OLI Imagery to assess the trophic status of the Duriangkang Reservoir and obtain distribution distribution data that has been generated in the process by using the calculation of the Trophic State Index (TSI) from Carlson. The results showed that Landsat-8 OLI imagery can be used as a predictor to extract parameters determining the trophic status of waters and Landsat 8 OLI imagery has the ability to map the distribution of brightness parameters very well (R2 = 0.8812) and total phosphorus quite well (R2 = 0.3829) in Duriangkang Reservoir. The distribution of trophic status in the Duriangkang Reservoir consists of 2 status classes Ultraoligotrophic and Oligotrophic. The Root Mean Squared Error (RMSE) of the brightness is 0.67 m and the RMSE of total phosphorus is 1,11 μg/L.

Keywords: TSI · Trophic Status · Water Quality · Remote Sensing Data

1 Introduction

Batam City has a land area of 1038.84 km^2 and has a population of 954 thousand people in 2010 and is estimated to increase to 1.8 million people in 2025. Along with the increase in population, the need for water will of course also increase every year. In 2025, it is estimated that water demand will increase to 6,630 l/s.

Water is one of the most important aspects of life. Water can be in the form of solid, liquid, and gas. Water is a part of life, which can be used for household purposes, maintain health, and support the continuity of life. Duriangkang Reservoir is a reservoir located in Muka Kuning Village, Tanjung Piayu, Sei Beduk Subdistrict which was built in 1990 and operated in 2001. Duriangkang Reservoir has a storage capacity of 107.2 million m^3 and functions as a raw water provider of 3,000 l/s with a production capacity

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of 3,000 l/s. Duriangkang Reservoir supplies clean water needs in surrounding area (Sei Beduk District, Tembesi, Batu Aji, Batam Kota, Lubuk Baja, dan Batu Ampar).

The catchment area is more than 7,000 ha and the water surface area is 1,200 ha, with rainfall from 2014 to 2017 decreasing from 1,900 mm/year to 1,800 mm/year. With this rainfall, it is feared that water sources in Batam are running low and unable to keep up with the increasing water demand. Apart from that, there are various illegal activities in the reservoir, such as floating net cages in the reservoir water bodies which can be a source of waste, forest logging, land clearing, illegal timber ships, illegal fishing, and even garbage left by the community. These illegal activities can reduce water quality in reservoirs. This is because the Duriangkang Reservoir functions as a single purpose in which the area around the reservoir cannot be used for various activities. The balance of the ecosystem in the reservoir really needs to be maintained, the countermeasures carried out by the government are by spreading tilapia which will balance the food chain in the reservoir and monitoring is also continuously applied, in order to reduce illegal activities.

Reservoirs have dynamic properties, this is influenced by chemical aspects and activities around the reservoir. Therefore, a regression model approach is needed from image information with field/in situ information that can be applied in the Duriangkang Reservoir to ensure an empirical formula so that monitoring of trophic status can be tested from the image using the Trophic State Index (TSI) calculation from Carlson. Landsat 8 OLI can produce trophic status data in the Duriangkang Reservoir with parameters that can be derived from the image, namely clarity, total phosphorus (TP), and chlorophyll-a and eutrophication limiting aspects using the Trophic State Index (TSI) procedure from Carlson with the aim of mapping the distribution of trophic status in the Duriangkang Reservoir through image analysis.

2 Methods

The location of the research was conducted in Batam Island, Riau Islands Province (1º05′LU 104º02′BT) using landsat 8 recording images. The location of the research is shown in Fig. 1.

The first data collection technique is to download data from Landsat 8 images on the website www.earthexplorer.usgs.gov using an existing account. The downloaded data is in the form of Landsat 8 OLI C2L1 data (Collection 2, Level 1) recorded on February 12, 2022. The Landsat has path 125 and row 59 which includes Batam Island and the surrounding waters [14–16].

In this study, sampling was carried out directly at the research location, namely the Duriangkang Reservoir Batam. Samples were taken in line with the distribution of sampling points. To obtain sample results, laboratory tests are required on the water samples taken. The sampling method used was purposive sampling method, which is sampling intentionally with the assumption that the sample taken can represent the population of the research location. The purposive sampling method is the determination of the location and respondents with certain considerations by the researcher. The consideration taken in using the purposive sampling method is that water sampling locations are in all areas of the reservoir, except for the Riau Islands intersection area, due to the large number of aquatic plants in the form of water hyacinth and other plants.

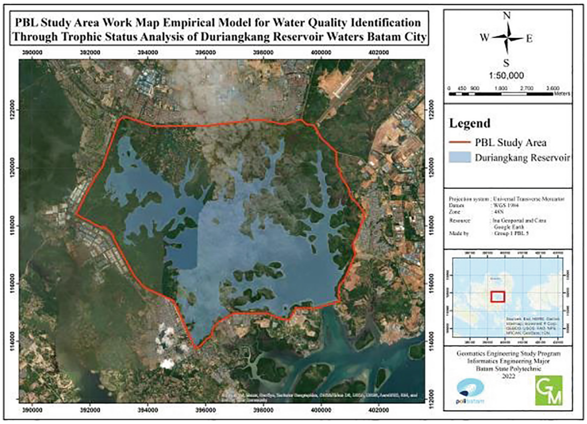

Fig. 1. Research location in Duriangkan Reservoir, Batam Island, Indonesia.

The next step is to reduce the area studied, which can be done by cutting the image. In this study, the area to be cut is located in the Duriangkang Reservoir area. The process uses band 2 (blue), band 3 (green), band 4 (red), band 5 (near infrared), band 6 (middle infrared 1), and band 7 (middle infrared 2), which is after that the geometric correction stage is carried out which is a correction that aims to reflect (correction) the image so that the image coordinates match the geographical coordinates. At this stage, the determination of the Ground Control Point (GCP) point is carried out, where the GCP point consists of X coordinates and Y coordinates. This correction is said to be successful when the Root Mean Square Error (RMS) value < 1. Radiometric correction is carried out after the geometric correction stages on the same channel.

The first parameter that determines the water quality of the reservoir extracted from remote sensing image data is the brightness of the water. A high level of brightness is beneficial for the life of phytoplankton to carry out the photosynthesis process so that it can develop properly. The low level of brightness dramatically affects the distribution and abundance of phytoplankton and chlorophyll-a in the waters. Extraction using an equation involves the ratio of reflectance in the blue channel (ETM1) and red channel (ETM3) on Landsat 7. Extraction at the concentration of water brightness can be carried out using the following algorithm [10, 12]:

$$Ln(SD) = 2.7753 * \left(\frac{ETM\,1}{ETM\,3}\right) - 5.2163 \quad (1)$$

$Ln\ (SD)$ = Natural logarithm of depth Secchi Disk Transparency
$ETM\ 1$ = Enhanced Thematic Mapper 1/band 2 on landsat 8
$ETM\ 3$ = Enhanced Thematic Mapper 3/band 4 on landsat 8

Next Parameter is Phosphate. It is a nutrient that is very important for the growth and metabolism of organisms. Phosphorus is harmless to humans, animals, and fish. However, too much phosphorus will cause an explosion of algae growth in the waters.

Then the algae will form a new layer on the surface of the water, this can inhibit oxygen and sunlight into the water which can affect the ecosystem in these waters. Extraction of the total phosphorus using the following algorithm [13, 17, 18]:

$$Ln(TP) = -21.45 * (\frac{TM\,3}{TM\,2}) - 14.42 * (\frac{TM\,1}{TM\,3}) + 42.99 * (TM\,1) + 27.1 \quad (2)$$

$Ln\ (TP)$ = Natural Logarithm of Total Phosphorus
$TM\ 1$ = Thematic Mapper 1/band 2 on landsat 8
$TM\ 2$ = Thematic Mapper 2/band 3 on landsat 8
$TM\ 3$ = Thematic Mapper 3/band 4 on landsat 8

The last parameter extracted from remote sensing data is Chlorophyll-A. The content of chlorophyll-a can shows the impact of various activities carried out. Therefore, chlorophyll-a can be used as a related indicator to be able to describe an ecosystem that is affected by ecosystem controllers such as nutrients, as a monitor in waters, and can be maintained naturally, to extract surface chlorophyll-a concentration values from Landsat satellite imagery. 8 used the following algorithm [1, 2, 5]:

$$C = 0.2818 * (\frac{TM\,4 + TM\,5}{TM\,3})3.497 \quad (3)$$

C = chlorophyll-a concentration (mg/m^3)
$TM3$ = Reflectance Value Thematic Mapper 3/band 4 on landsat 8
$TM4$ = Reflectance Value Thematic Mapper 4/band 5 on landsat 8
$TM5$ = Reflectance Value Thematic Mapper 5/band 6 on landsat 8

Trophic State Index is the basis for determining trophic status by taking into account the mass of algae (Carlson, 1977). Determination of trophic status using TSI can be done by measuring three parameters, namely, chlorophyll-a, water brightness, and Total Phosphorus, with TSI scores ranging from 0–100 [3, 4, 6, 7].

TSI calculations are classified into 7 classes. The classification is based on the classification according to the Ministry of Environment in 2008 which was adopted from the Carlson classification (1977) where the classification is used as the basis for determining the eutrophic class in the tropics [8, 9, 11, 13].

Calculations based on TSI Carlson on each parameter with the purpose of identifying its trophic status. Here is the TSI calculation:

$$TSI(SD) = 60 - 14.41\ Ln\ \text{Secchi Depth (meter)} \quad (4)$$

$$TSI(\text{TP}) = 14.42\ Ln\ \text{Total Phosporus } (\mu\text{g/L}) + 4.15 \quad (5)$$

$$TSI(\text{CA}) = 9.81\ Ln\ \text{Chlorophyll} - A(\mu\text{g/L}) + 30.6 \quad (6)$$

$$CTSI = \frac{TSI(SD) + TSI(TP) + TSI(CA)}{3} \quad (7)$$

CTSI = Carlson Trophic State Index
TSI (SD) = TSI Brightness calculation result
TSI (TP) = TSI calculation results of Total Phosphorus
TSI (CA) = Chlorophyll-a TSI calculation results

Table 1. Carlson Classification (1977)

Score	Trophic Status	Description
<30	Ultraoligotrophic	The water fertility is very low, the water is clear, the dissolved oxygen concentration is high throughout the year, and reaches the hypolimnion zone.
30–40	Oligotrophic	Low water fertility and clear water is possible due to periodic anoxic restrictions in the hypolimnetic zone.
40–50	Mesotrophic	Moderate water fertility, moderate water brightness, increasing changes in anoxic properties in the hypolimnetic zone, aesthetically still supports water sports activities.
50–60	Mild eutrophic	High water fertility, decreased water brightness, anoxic hypolimnetic zone, problems with aquatic plants occur, only fish are able to live in warm water, support water sports activities but need treatment.
60–70	Moderate eutrophic	High water fertility. Dominated by blue-green algae, clumping, and aquatic plant problems are widespread.
70–80	Heavy eutrophic	High water fertility, algae blooms occur, and aquatic plants form layers such as hypereutrophic conditions.
>80	Hypereutrophic	Water fertility is very high, algae clumps occur, fish deaths often occur, aquatic plants are slightly dominated by algae

3 Results and Discussion

The first index transformation performed on processing this data after geometric correction and radiometric correction is Water Brightness transformation. Brightness extraction was carried out in band ratio bands 2 and 4, where the extraction results were obtained in the form of brightness levels in the waters studied which had the lowest depth of 0.38 m and the highest depth of 1.47 m. Based on the classification [14], the Duriangkang Reservoir consists of one class, namely high. This shows that the distribution of water brightness in the reservoir is high because it is <2.5 m.

Chlorophyll-a concentration is a data processing carried out at the next stage. Chlorophyll-A in the Duangkakang reservoir has a maximum concentration of 25 g/L and a minimum concentration of −1.51 g/L. Based on the classification [14], Duriangkang Reservoir consists of three classes, namely low, moderate, and good. The chlorophyll concentration was quite good at 6 g/L to 20 g/L spread over the northwest part of the reservoir. Likewise, the concentration of 2 g/L to 6 g/L has a relatively good concentration. The Durangkang Reservoir itself is also dominated by concentrations <2 g/L in almost all areas of the Durangkang Reservoir.

The last parameter that is carried out in data processing to find Carlson TSI is the distribution of total phosphorus. Based on the calculation results of the transformation, it was obtained that the total phosphorus extraction in the waters of the Durarangang reservoir had the highest concentration of 21 g/L and the lowest concentration of − 1.57 g/L. Based on the classification [14], the Duriangkang Reservoir consists of one

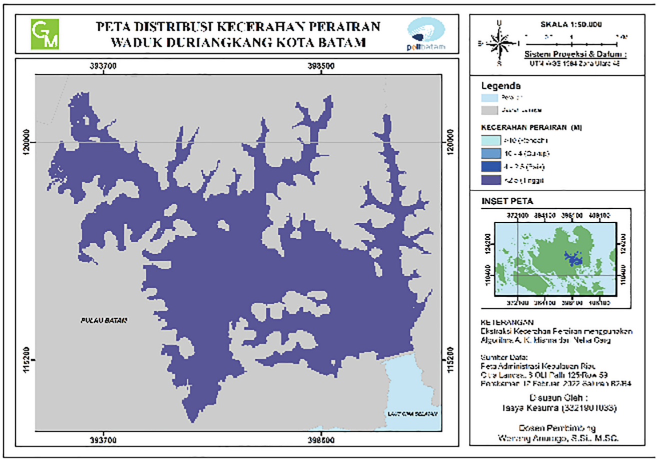

Fig. 2. Water Brightness Distribution Map.

class, namely low. This is because the total phosphorus image extraction results have a concentration of <150 g/L.

Calculation of the trophic status index in the Duriangkang Reservoir uses calculations from Carlson. Where the trophic class of water is determined based on the calculation score that has been set by Carlson is contained in Table 1. The trophic status index based on Carlson consists of three parameters, namely water brightness, Chlorophyll-A, and Total Phosphorus.

The brightness parameter in the Duriangkang Reservoir shows that the reservoir is in a light eutrophic, moderate eutrophic, and heavy eutrophic condition. The class that dominates the reservoir is mild eutrophic, where this class consists of 72% of the lake area with water brightness ranging from 93 cm to 121 cm, then 21% of the area is moderate eutrophic with water brightness ranging from 63 cm to 92 cm and 7% The other area is heavy eutrophic with water brightness ranging from 34 cm to 62 cm.

Eutrophic conditions in the reservoir indicate that the water is in a cloudy condition, one of the causes of cloudy water is weather conditions. On the day of sampling, the weather conditions at that time were rain and strong winds. This causes certain substances to be mixed in the water such as mud or other microorganisms. In addition, the decrease in brightness is caused by activities in the Duringkang reservoir such as illegal boats, illegal logging on the edge of the reservoir, and even the existence of illegal fish cages that are widely scattered in the reservoir body. This is what causes a decrease in the intensity of the brightness in the Durangkang Reservoir (Figs. 2, 3, and 4).

The brightness of low water can affect the intensity of the entry of sunlight into the water, so this affects the photosynthetic activity in the water. Photosynthesis carried out by certain microorganisms is highly dependent on the intensity of sunlight and if this activity is disturbed, the oxygen levels in the waters will also be disturbed so that it can have a negative impact on life in the waters themselves.

The trophic class on the total phosphorus parameter consists of one class, namely the Ultraoligotrophic class. This class covers 99% of the area of the Durangkakang

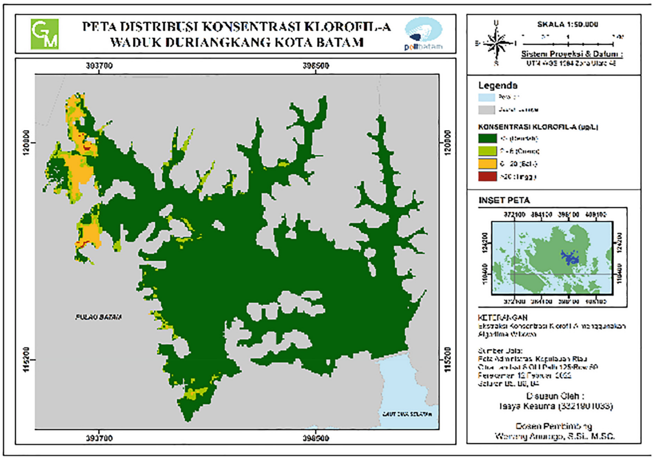

Fig. 3. Chlorophyll-a concentration Distribution Map.

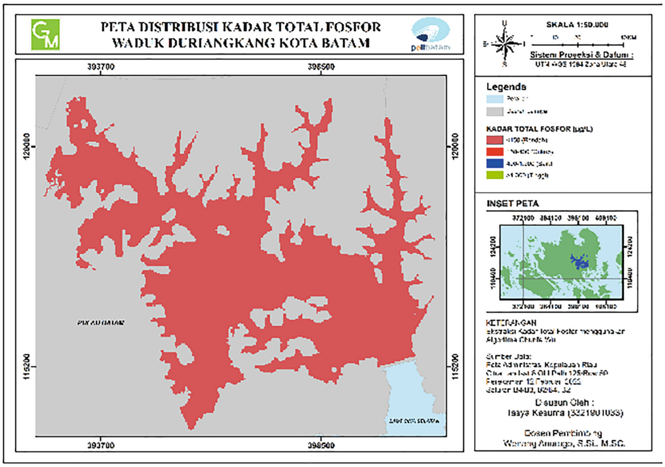

Fig. 4. The distribution of total phosphorus.

reservoir with the characteristics of low water fertility, clean water, and high dissolved oxygen throughout the year. The low-class score on this parameter can be proven in the actual total phosphorus content of the reservoir where the lowest level is 0.06 g/L and the highest is 0.34 g/L. Durangkang reservoir is dominated by total phosphorus content of 0.27 g/L to 0.34 g/L and in the reservoir body/middle of the reservoir, it has levels of 0.20 g/L to 0.27 g/L.

The low total phosphate content in the reservoir is thought to come from rainwater which is used as the main source of raw water storage. Apart from that, there are no industrial activities that come into direct contact with the reservoir, such as goods and

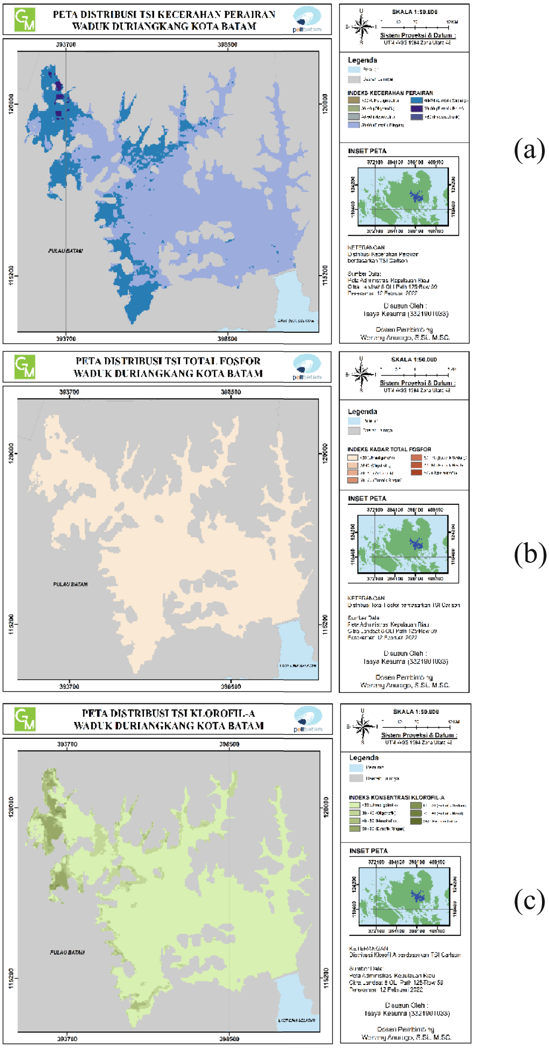

Fig. 5. TSI distribution per-parameters **a**) Water Brightness TSI Distribution, **b**) TSI Phosphorous Distribution, and **c**) Chlorophyll-A TSI Distribution.

medicine production companies, and therefore the Durangkang reservoir is not used as a final disposal site for industrial activities.

The results from Carlson's calculations for Chlorophyll-a show that the Duangkakang reservoir consists of 5 classes, namely ultraoligotrophic, oligotrophic, mesotrophic, mild eutrophic, and moderately eutrophic. Ultraoligotrophic conditions indicate that the fertility of the water is very low with a fairly high concentration of dissolved oxygen throughout the year, this condition covers 84.9% of the reservoir area or around 2012–8 Ha. In the oligotrophic class, it shows that the waters in the reservoir are clean and there

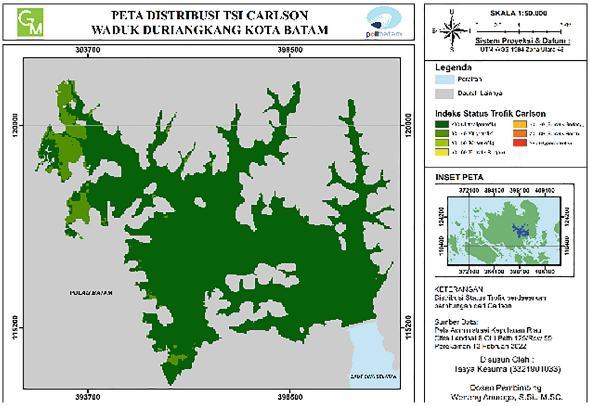

Fig. 6. TSI Carlson of Duriangkang Reservoir Map.

are no aquatic plants such as water hyacinth, this condition covers 8.9% of the reservoir area of around 212.3 Ha.

Mesotrophic conditions in the reservoir indicate moderate water fertility and moderate water brightness. This is supported by data on the brightness of the waters in this area ranging from 93 to 121 cm. The northwest area of the reservoir includes mild eutrophic conditions with an area of 2.73% or around 64.7 Ha, where water fertility is quite high, water clarity is low, and problems with aquatic plants occur. This is evidenced in this area, The water brightness parameter shows the presence of low water brightness ranging from 34 cm to 62 cm and quite a lot of scattered aquatic plants in the form of water hyacinths. Moderately eutrophic conditions exist in the middle of a mild eutrophic area, where in this condition water fertility is high and there are aquatic plants in the form of water hyacinth which is dense and has fast growth, this severe eutrophic condition covers 1.8 Ha of the area of the Duangkakang reservoir.

Based on Carlson's calculations, the Durangkang reservoir consists of two trophic classes, namely Ultraoligotrophic and Oligotrophic with a trophic index having a score of 7.71 to 39.46. The scores that have been obtained do not have a wide range of values so the variations in trophic status produced by the parameters of brightness, chlorophyll-a, and total phosphorus in the reservoir are not diverse enough and only consist of 2 classes (Figs. 5 and 6).

4 Conclusion

Based on the processing of the distribution of trophic status using the Carlson equation, the Durangkang Reservoir consists of 2 classes, namely Ultraoligotrophic and Oligotrophic waters which include very low water fertility, clear water, high dissolved oxygen concentration throughout the year and reaches hypolimnion zone and low water fertility, clear water is possible. Periodic anoxic restriction in the hypolimnetic zone with scores <30 and 30–40 on the trophic status table.

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