The application of PlanetScope imagery to map out the trophic state of Cirata Reservoir, West Java

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Abstract. Cirata Reservoir is one of the cascade dams in the Citarum Watershed located in three regencies of West Bandung, Cianjur, and Purwakarta. Surface water condition of the Cirata Reservoir is occupied by floating net cages, thus the waste from those activities could affect its trophic state. The purpose of this study is to assess the ability of PlanetScope imagery to map out trophic state parameters and trophic state condition during the rainy season using the Trophic State Index (TSI) method by Carlson (1977). The Carlson’s TSI parameter contains water transparency (Secchi depth), chlorophyll-a, and total phosphorus based on the empirical formula generated from the regression model between image bands with field survey data. Results of the analysis showed that water transparency is strongly correlated with the red band \((R^2 = 0.60)\) with an accuracy level of 77.51-81.62%. Chlorophyll-a is strongly correlated with green band \((R^2 = 0.71)\) with an accuracy level of 34.69-58.31%, and the total phosphorus is strongly correlated with red band \((R^2 = 0.65)\) with an accuracy level of -66.71-5.11%. The result of the three parameters combination reveals that the trophic state of Cirata Reservoir is in the medium eutrophic to hypereutrophic with the largest distribution in the heavy eutrophic class. The results of the accuracy-test indicated that the PlanetScope imagery is able to be used to estimate the parameters of water transparency and chlorophyll-a, whereas the total phosphorus parameter got low accuracy.

Keywords: Cirata Reservoir, PlanetScope Imagery, Carlson’s TSI, Regression, Trophic State

1. Introduction
Cirata Reservoir is one of the cascade dams located in Citarum Watershed, West Java which is originally built for hydroelectric power. Since its first operation in 1988, there has been changes in the community’s lifestyle which initially, being a farmer and changed to being dependent on the utilization of Cirata Reservoir. However, uncontrolled Cirata Reservoir utilization caused a negative impact on water quality which has been declining since reservoir utilization due to pollution load. The causes of water quality degradation in Cirata Reservoir are due to the floating net cages cultivation which has gone uncontrollable, industrial waste in Citarum River upstream, household waste and leachate water from landfill [1].
The damaged condition of Citarum Watershed caused industrial material and erosion that was brought from the upstream into the reservoir, proven by the sediment value that reached 7.30 million m$^3$/year which has reached the initial assumption of 5.67 million m$^3$/year [2]. Secondly, the main problem of Cirata Reservoir is the presence of floating net cages cultivation which in 2018, has reached more than 80,000 and exceeded the capacity of 12,000 floating net cages [2]. Excessive fish feeds that are not eaten will be settled and caused sedimentation which then transforms into ammoniac [3]. If it rains continuously and there is no sunlight present, it will cause the mixing process and allows ammoniac to be brought up onto the surface which can be poisonous for the fishes. Additionally, the remaining fish feeds and waste from Citarum Watershed which entered into the water body of reservoir causes high nutrient load in the water and triggers eutrophication. Eutrophication is a process of water enrichment with nutrients needed by the plants and increases the primary productivity of water [3]. This causes Cirata Reservoir has rich in nutrients which is indicated by the presence of water hyacinth plants on the surface of water, which is seen during water sampling. The water quality of Cirata Reservoir is included in class IV, which is not good for the fishes and only good for irrigation [4].

Conventional methods to determine the trophic state of the waters require much time and cost. Remote sensing has an important role in phenomena extraction that occurs in the Earth’s surface, including hydrological phenomena. The sensor in remote sensing image is able to capture the spectrum of water reflection so the object characteristic in water can be known [5]. PlanetScope imagery is one of many remote sensing data that is a constellation of more than 120 active satellites in orbit with several bands that able to describe the entire surface of the earth every day. Band on imagery is the wavelength used by the sensor to identify objects on the surface of the earth. PlanetScope imagery which has five bands (red, green, blue, and near-infrared) can be applied to give information concerning the trophic status of Cirata Reservoir in decent spatial and temporal resolution, which is 3-5 meters and satellite orbit that requires one-day duration to capture the same region.

Trophic status is a condition or response based on the nutrient condition in the water [6]. According to Carlson’s Trophic State Index (TSI) trophic state in the water can be determined using the parameter from the image and field data which are in the form of water transparency (Secchi depth), chlorophyll-a and total phosphorus [7]. Result obtained of each parameter are empirical formula which applied on the image and can be used for trophic state mapping of Cirata Reservoir. That is because the pixel value in the image is the reflection of waves from objects on the surface of the earth, so the image can be used to see the state of the object [5]. Moreover, PlanetScope imagery has a short recording time lag so that it can be used to compensate for dynamic water conditions. The aim of this research is to test the ability of PlanetScope imagery for map out the trophic status parameter which are water transparency, chlorophyll-a and total phosphorus in Cirata Reservoir.

2. Methods
2.1 Research location
Administratively, the research locations are located in three regencies in West Java, which are Regency of Cianjur, Purwakarta and West Bandung. Cirata Reservoir is located between two other reservoirs, the Jatiluhur Reservoir in the north and Saguling Reservoir in the south (figure 1).
2.2 Sampling and laboratory analysis
A field survey was carried out on 13-14 February 2019 to take the information on trophic status parameters, which are water transparency, chlorophyll-a, and total phosphorus. Field sampling activities held has a gap of nine days from image data used for modeling, which is 4 February 2019. The measurement of water quality is carried out by taking water samples obtained from the surface. This is because of the value of the image is a reflection from the surface of an object. Sampling was carried out at 45 location points (figure 2), but only 38 representative samples from 38 location points were analyzed, and then divided into two parts, 20 samples for modeling and 18 samples for validation.
2.2.1 Water transparency (Secchi depth)
Measurement of water water transparency was carried out by using a Secchi disc. Measurement was carried out by entering the Secchi disc into the water with a rope and next, measuring the length of the rope. The longer the measured length the higher the value of water transparency, oppositely the shorter the measured length the lower the value of water transparency.

2.2.2 Chlorophyll-a
Chlorophyll-a measurement was done by taking water samples of 250 ml which then was analyzed in the laboratory. Chlorophyll-a measurement uses spectrophotometry method and 90% acetone based on APHA Standard Method [8].

2.2.3 Total Phosphorus
Total phosphorus measurement was based on the APHA Standard Method [8] by taking 250 ml of samples to be analyzed in the laboratory. Determination of total phosphorus used two methods which are persulfate method to oxidize the phosphor compound in the samples and then proceeded with the ascorbic acid method.

2.3 Statistical analysis
The statistical analysis was carried out using IBM SPSS Statistics software and Microsoft Excel. Statistical analysis was carried out by four steps i.e. normality test, correlation test, regression and accuracy test.

2.4 Carlson’s TSI calculation
Result of water transparency, chlorophyll-a, and total phosphorus distribution obtained from the transformation of empirical formula resulted from regression process and then converted using ENVI Classic software into Carlson’s TSI equation, which are:

\[
\text{TSI on Water Transparency} = 60 - 14.41 \ln \text{Secchi Depth (m)}
\]  
\[
\text{TSI on Chlorophyll-a} = 9.81 \ln \text{Chlorophyll-a (μg/L)} + 30.6
\]  
\[
\text{TSI on Total Phosphorus (TP)} = 14.42 \ln \text{Total Phosphorus (μg/L)} + 4.15
\]

To achieve the trophic status value of all parameters, they are continued into the equation:

\[
\text{CTSI} = \frac{\text{TSI (TP)} + \text{TSI (Chl-a)} + \text{TSI (SDT)}}{3}
\]

Trophic status values obtained are classified into 7 classes of Carlson’s TSI which are ultraligotrophic, oligotrophic, mesotrophic, low eutrophic, moderate eutrophic, heavy eutrophic and hypereutrophic which will be symbolized using ArcGIS 10.3 software.

3. Results and Discussion
3.1 Statistical analysis
The normality test using the Kolmogorov-Smirnov method from 20 samples states that the data used for statistical analysis are normally distributed. The result of water transparency parameter obtained the highest correlation with red band that is -0.62 with minus value indicates that the relationship of water clarity on the field with the value of water transparency is negatively correlated. The greater the value of water clarity in the field, the smaller the value in the image will be. Therefore, the red band is
a good variable to be used in regression analysis. The result of regression analysis is $R^2 = 0.38$ was obtained. By removing two outlier points, the value of $R^2 = 0.60$ with an empirical formula of:

$$y = -0.0046x + 3.7077$$

The result of chlorophyll-a parameter obtain the highest correlation with green band that is $0.65$. Regression result of 20 samples resulted in the value of $R^2 = 0.43$ thus there are 2 outlier points are erased and value of $R^2 = 0.71$ with empirical formula is obtained:

$$y = 0.0106x - 5.8542$$

The result of the total phosphorus parameter obtains the highest correlation with red band that is $0.41$. Regression result of 20 samples resulted in the value of $R^2 = 0.13$. There are 2 outlier points are erased and the value of $R^2 = 0.65$ with empirical formula is obtained:

$$y = 0.0003x - 0.173$$

The accuracy test is carried out on all trophic status parameters by using 18 validation samples. Accuracy result obtained for water transparency is $77.51$-$81.62\%$, chlorophyll-a with $34.69$-$58.3\%$ and total phosphorus with $-66.71$-$5.1\%$. Results of accuracy testing in the parameter of water transparency and chlorophyll-a resulted in a large value. However, for the parameter of total phosphorus resulted in a small value. It is assumed that this happened due to estimation of total phosphorus is more difficult compared to the estimation of water transparency and chlorophyll-a where the estimation of water transparency can be determined from the reflection of the pixel value. If the value is small, it reflects a turbid condition and vice versa, if the value is large, it reflects a clear condition. On the other hand, the chlorophyll-a parameter with the presence of algae which is a plant can be connected with vegetation reflection through wavelength in the image.

Total phosphorus presence is hard to detect by remote sensing approaches using imagery. However total phosphorus has a relationship with water quality parameters such as chlorophyll-a, turbidity and total suspended matters (TSM) and water transparency [9]. Total phosphorus estimation using chlorophyll-a corresponds with the theory that the presence of total phosphorus limits the growth of algae. In this research, the presence of total phosphorus is not only consumed by algae but also water hyacinth which caused difficulty in proving this theory, hence accuracy resulted from total phosphorus is small.
3.2. Trophic state parameters

3.2.1 Water transparency

Figure 3. Map of TSI distribution based on water transparency in Cirata Reservoir on January 04, 2019.

TSI results of water transparency obtained are four classes which are dominated by low eutrophic and moderate classes. After eliminating total area of floating net cages and cloud covered area, a total area of 5,543,000 m² for was eutrophic zone, 4,163,000 m² was moderate eutrophic zone, 92,000 m² was heavy eutrophic zone and 58,000 m² was the hypereutrophic zone (figure 3). Heavy eutrophic zone and hypereutrophic located in the west part, where reservoir area in the west covered by clouds is possibly classified in heavy eutrophic class and hypereutrophic because in that area, it is filled with floating net cages activities and inlet which is located in Cikundul River and it carries many waste entering the body of the reservoir.

3.2.2 Chlorophyll-a

TSI results of chlorophyll-a obtained is one class, which is a hypereutrophic with a total area of 10,327,000 m² (figure 4). This is caused by a factor of nutrients loading in Cirata Reservoir contributed by many things, one of them is floating net cage activity which produces waste from remaining fish’s feed and fishes waste. Another factor is utilization of land which is not profitable for Cirata Reservoir such as industries upstream which throw their waste into the river and carried into the water in the reservoir. There are agriculture activities, plantation and the lands surrounding the reservoir using fertilizer, which eventually carried into the reservoir along with domestic waste. Among many factors, nutrients supplier in Cirata Reservoir has only a single outlet of water discharge from the reservoir which is hydroelectric power plant door and water discharge process is controlled by the hydroelectric power plant’s authorities hence to balance out between materials going and out is harder. The consequence of this issue caused algal bloom because of the presence of nutrients from
total phosphorus is available in a large amount. In the research of trophic state and carrying capacity of floating net cages in the cirata reservoir using the STORET method, the chlorophyll-a content in the Cirata Reservoir was 0.23-3.54 mg/l, which are in moderate eutrophic to hypereutrophic status [8].

3.2.3. Total Phosphorus
TSI results of total phosphorus obtained three classes which are dominated by low and moderate eutrophic class whereas heavy eutrophic class has only a few at the borders of the reservoir. This is possibly caused by shallow water body thus the image recorded is many ground residues appear in the water surface. After eliminating the areas used for floating net cages and covered by clouds, area of the three classes obtained are low eutrophic class 6,797,000 m², moderate eutrophic 3,470,000 m² and heavy eutrophic 48,000 m² (figure 5).

![Figure 4. Map of TSI distribution based on Chlorophyll-a in Cirata Reservoir on January 04, 2019.](image-url)
TSI value of total phosphorus and TSI chlorophyll-a is not equal. TSI chlorophyll-a is in hypereutrophic class, whereas the TSI value of total phosphorus are in a low and heavy eutrophic class where total phosphorus should limit algae growth. However, not only in the condition where algae contain chlorophyll-a that consumes total phosphorus but also, water hyacinth. Therefore, the content of total phosphorus is below chlorophyll-a.

3.3 Trophic state of Cirata Reservoir

Processing result of the three TSI parameters obtained value of 65.04-87.06 after being classified into classes of trophic state using the Carlson method, which are moderate eutrophic, heavy eutrophic and hypereutrophic classes. Moderate eutrophic class is located in the east area and some parts at the north with an area of 2,701,000 m$^2$. There are no floating net cage activities in north area, whereas land utilization in this region is dominated by forests and tall trees.

Heavy eutrophic class dominates the south, west and north areas of the Cirata Reservoir with an area of 6,949,000 m$^2$. In the south and west area, they are dominated by floating net cages activities and land utilization in this area, is dominated by anthropogenic activities such as industrial, plantation, field and houses. On the other hand, in parts of the northern area, the moderate eutrophic class is located at an area nearby hydroelectric power plant. Hypereutrophic class is located at the edge of west area and is a class with a narrow area with 481,000 m$^2$ (figure 6). In this area, it is highly dominated by floating net cages activities and land utilization in this area is the same as an heavy eutrophic class which is dominated by anthropogenic activities. The obtained area does not include the area contained floating net cages.
4. Conclusions

The statistical analysis result shows that models using PlanetScope Image and field survey can be used to map out the parameters of trophic status, which are water transparency, chlorophyll-a and total phosphorus. However, accuracy test results show that only water transparency and chlorophyll-a models have good accuracy, whereas total phosphorus produces low accuracy.

Modeling with Carlson’s TSI produces 3 classes of distribution about trophic status in Cirata Reservoir, which are moderate, heavy eutrophic and hypereutrophic classes. The heavy eutrophic class has an area of 11% of total area Cirata Reservoir, but the area of the trophic state produced does not include the area contained floating net cages. The trophic state of Cirata Reservoir condition suggests that policies regarding the handling of Cirata Reservoir is required because of eutrophic condition in the reservoir’s water can harm its habitat of reservoir.

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