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# Assessment of seasonal trophic state of tropical man-made lake, The Cirata Reservoir

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**Abstract**. Evaluation of 4-year data set (2013-2016) to define the trophic state of Cirata Reservoir among the seasons and its impact on the reservoir sustainability has been performed. Cirata is one of the cascade reservoirs located on the Citarum River, with the main purpose for electricity generation through a hydropower plant. Data were obtained from eleven sampling stations of monitoring programs in the Cirata Reservoir. The technique for water sample collection and analysis referred to SNI (Indonesian National Standard) 03-7016-2004 and standard method focussing on phosphate, Chlorophyll-*a* and transparency. This study indicated that the trophic condition of Cirata Reservoir, as a tropical man-made, was unique and dynamic compared to lakes in the temperate season. The results showed that the reservoir water in the last four years was already eutrophic whether in rainy, intermediate or dry seasons with Trophic State Index were 60.42; 59.00 and 57.32 respectively. This study showed that the inlet and centre area of the reservoir had a higher trophic index than the outlet area. This phenomenon indicated that the main sources of eutrophication in Cirata Reservoir came from both the catchment area of the reservoir (i.e. upper Citarum) and on-site the reservoir. Phosphate has been established as the nutrient that commonly limits the productivity in Cirata reservoir. Thereby, phosphate control is critical for the eutrophication mitigation in Cirata. To cope with this condition, strategies must be applied whether to control the phosphate utilization in the catchment or inside the reservoir area.

## 1. Introduction

Cirata is one of the cascade reservoirs located on the Citarum River, with the main purpose for electricity generation through the hydropower plant. Cirata is also known as a multifunctional reservoir for irrigation, water supply for drinking water, tourism, flood control and aquaculture. The existence of Cirata Reservoir located in Citarum River makes Cirata more vulnerable because of contamination by organic and inorganic pollutants originated from upstream Citarum.

The presence of large amounts of organic matter will contribute negatively to the sustainability of hydropower as electricity providers in Indonesia due to eutrophication. Globally, eutrophication has been recognized as the primary problem affecting surface water quality worldwide [1]. In general, nitrogen (N) and phosphate (P) are known as the causative agents of eutrophication in surface water such as lakes. The shifting of lake function to reservoir has an impact to change the eutrophication pattern. Timofti *et al* [2] stated that reservoirs or dams have the potential to change the nutrients in the river system and provide ideal conditions for eutrophication. Organic compounds pollution contributes to eutrophication by aquatic weed such as *Eichhornia crassipes* as a result of environmental degradation at the upstream area. Eutrophication in the reservoir is closely related to the sustainability of hydropower plants. The existence of water hyacinth in the reservoir caused the loss of water due to greater evaporation. Water hyacinth also has a large evapotranspiration rate losing water into the atmosphere at four to six times that is lost by open water [3,4]. Timer and Weldon [5] suggested that water hyacinth has a large surface area that contributes to a high rate of transpiration. In addition to that, the rate of water loss due to evapotranspiration can be as much as 1.8 times that of evaporation from the same surface without plants [6].

Eutrophication can be assessed through trophic status estimation. Trophic state is defined as the total weight of the biomass in a water body at a specific location and time [7]. Trophic state is an important property of the aquatic ecosystems and related with the anthropogenic influence on water quality and the ecological function of the ecosystem itself [8]. In terms of ecological function, the eutrophication makes water body becomes anaerobic due to decomposition of algae or water hyacinth; this can result in an adverse effect of decreasing the oxygen levels. This condition will cause the death of fish and other organisms [1,9].

Several indicators can be used for measurement of the trophic level on the surface water, among others is the Trophic State Index [10]. The Trophic State Index (TSI) has been employed in the trophic state analysis of lake in temperate, tropical and subtropical regions. These indexes provide how nutrient, light availability and other factors stimulate chlorophyll-*a* and contribute to the enrichment in the aquatic ecosystem [11]. Research on trophic levels on a lake in a tropical region that primarily served as a reservoir associated with energy security is still sparse. Therefore, no established rule associating nutrient limitation as a driving factor for eutrophication with tropical/subtropical. Compared with the temperate area, tropical/subtropical systems may have higher productivity throughout the year [12]. The aim of this study was to estimate the trophic level of Cirata Reservoir. The results of this study are important as a reference to support the sustainability assessment of reservoir in the tropical area.

## 2. Material and methods

### *2.1. Research site*

The study was conducted in Cirata Reservoir, located in West Java Province, from 2013 to 2016. The sampling points were located in the inundation area. Water samples were taken from 11 sampling points (see Figure 1) classified as inlet (station 5, 6, 11, 18), the central reservoir (station 1, 3, 4, 19, 20) and near the outlet (station 2, 9). In this study, the numbering of sampling stations was not sequential due to a simultaneous examination of physical and chemical water characteristics at another sampling point. The sampling locations were determined based on the environmental condition around Cirata Reservoir.

### *2.2. Research procedure*

This research was classified into two stages: (1) laboratory analysis of water samples and (2) assessment of Trophic State Index. The sampling of water from the reservoir was conducted quarterly, i.e. March, August and October, from 2013 until 2016. The selection of sampling months was based on the amount of rainfall which March represents the rainy season, August represents dry season while October represents intermediate (transition) season. Climatic data were obtained from 3 measurement stations namely Cirata, Jangari and Cipicung Station for the last 4 years, whereas the rainfall data were obtained from seven rainfall station i.e. Cikundul, Cibalagung, Cisokan, Cimeta, Cirata, Jangari and Cipicung.

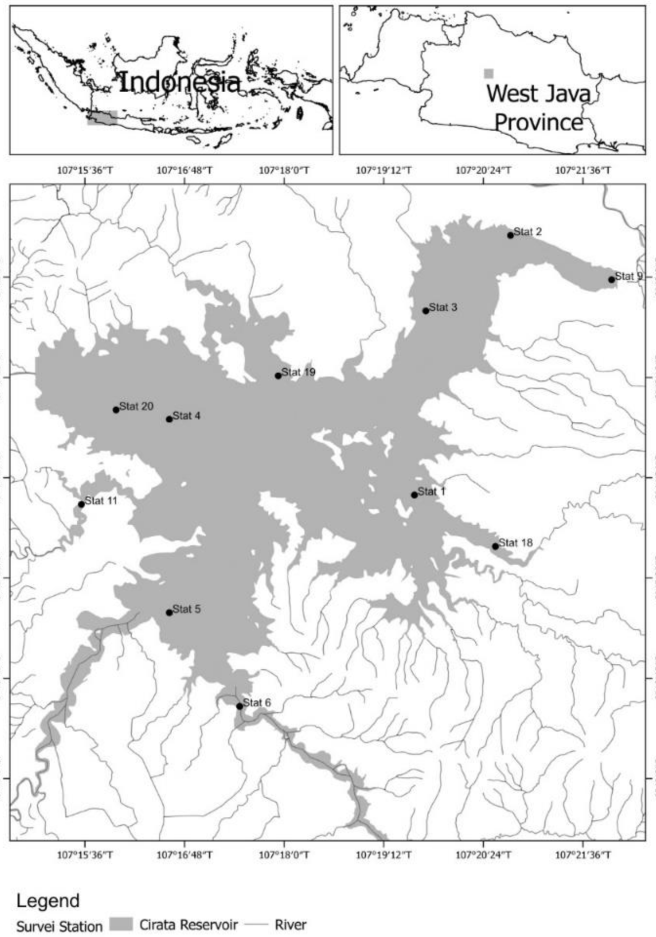


**Figure 1.** Water sampling points in the Cirata Reservoir: (1) Bandung Barat district zone, (2) intake area, (3) border of aquaculture-free area, (4) Purwakarta district zone, (5) Cisokan river-mouth, (6) Citarum river-mouth, (9) dam site, (11) Cibalagung river-mouth, (18) Cilangkap river-mouth, (19) midpoint zone of Purwakarta, and (20) midpoint zone of Cianjur.

Water samples for phosphate and Chlorophyll-*a* assessment were collected at the surface reservoir. The collection technique referred to SNI (Indonesian National Standard) 03-7016-2004, Sampling Procedures for Water Quality Monitoring of Rivers and Lakes. Transparency was measured using Secchi Disk, while the phosphate concentration was measured based on Standard Method APHA AWWA WCPF (2005) – SM 4500-P D Stannous Chloride Method [13]. To determine Chlorophyll-*a*, water samples were filtered and extracted in 90% methanol and centrifuged to remove turbidity. The concentration of Chlorophyll-*a* was determined on a spectrophotometer using wavelengths of 665 and 650 nm [14]. The Chlorophyll-*a* content was estimated using the following equations:

$$\text{Chlorophyll-}a = (16.5 \times A665) - (8.3 \times A650) \quad (1)$$

The data obtained were used to assess the Trophic Level Index expressed in TSI refers to Carlson's Trophic State Index (TSI) [10]. The formulae used were:

$$\text{TSI - P} = 14.42 \times \text{Ln}\,[\text{TP}] + 4.15 \text{ (in µg/L)} \quad (2)$$

$$\text{TSI - C} = 30.6 + 9.81 \text{ Ln}\,[\text{Chlor-a}] \text{ (in µg/L)} \quad (3)$$

$$\text{TSI - S} = 60 - 14.41 \times \text{Ln}\,[\text{SD}] \text{ (in meters)} \quad (4)$$

$$\text{Average TSI} = [\text{TSI (P)} + \text{TSI (Chlor-a)} + \text{TSI (SD)}]/3 \quad (5)$$

where TP is total phosphate, chlor 'a' is chlorophyll-*a* and SD is transparency

The classification of the Trophic Level Index is presented in Table 1.

**Table 1.** Classification of Trophic Level [10].

| TSI | Classification | Description |
|---|---|---|
| < 30 | Oligotrophic | Clear water, dissolved oxygen throughout the year in the hypolimnion |
| 30-40 | Oligotrophic | Deep lakes still exhibit classical oligotrophy, but some shallower lakes will become anoxic in the hypolimnion during the summer |
| 40-50 | Mesotrophic | Water moderately clear, but an increasing probability of anoxia in hypolimnion during summer |
| 50-60 | Eutrophic | The lower boundary of classical eutrophic, decreased transparency, anoxic hypolimnion during summer, macrophyte problems evident and warm water fisheries only |
| 60 -70 | Eutrophic | The dominance of blue-green algae, algal scum probable, extensive macrophyte problems |
| 70-80 | Hypereutrophic | Heavy algal blooms possible throughout the summer, dense macrophyte beds but extent limited by light penetration |
| > 80 | Hypereutrophic | Algal scum, summer fish kills, few macrophytes, the dominance of rough fish |

### *2.3. Data analysis*

To see if there were any differences between Trophic Index Value, phosphate and Chlorophyll-*a* in different seasons, ANOVA Single Test was employed. Whereas to see if there were any correlation between parameters, regression test was also employed. Statistical analysis was performed using Microsoft Office Excel 2013.

## 3. Result and Discussion

### *3.1. Climate factor and Trophic State Index*

Climate data such as temperature, solar radiation, evaporation and rainfall can be seen in Table 2. The statistical analysis of rainfall shows that there was a significant difference in rainfall between the sampling months of March, August and October (p value < α; 0.000748 < 0.05). Moreover, our study shows that there was no correlation between TSI and its attributes to climatic factors which covered temperature, solar radiation, evaporation and rainfall.

**Table 2**. Average monthly of climate data at Cirata Reservoir.

| No | Sampling Month | Temperature (°C) | Solar radiation (cal/day) | Evaporation (mm) | Rainfall (mm) |
|---|---|---|---|---|---|
| 1 | March 2013 | 18.4 | 5.4 | 2.89 | 204.1 |
| 2 | March 2014 | 15.71 | 5.4 | 2.9 | 344.8 |
| 3 | March 2015 | 21.3 | 5.8 | 2.8 | 338.4 |
| 4 | March 2016 | 27.3 | 6 | 3.6 | 395.7 |
| 5 | August 2013 | 14.93 | 8 | 4.3 | 37.5 |
| 6 | August 2014 | 16.13 | 3.5 | 2.5 | 97,4 |
| 7 | August 2015 | 24.34 | 7.3 | 4 | 4.4 |
| 8 | August 2016 | 24.34 | 7.3 | 4 | 4.4 |
| 9 | October 2013 | 14.05 | 7.67 | 3.2 | 212.1 |
| 10 | October 2014 | 23.8 | 7.2 | 3.8 | 40.2 |
| 11 | October 2015 | 28.44 | 7.7 | 4.5 | 42.5 |
| 12 | October 2016 | 28.44 | 7.7 | 4.5 | 42.5 |

The regular monitoring shows that the Cirata Reservoir was in a eutrophic state in the last four years (2013 -2016) based on Trophic State Index estimation (see Table 3). Based on estimations, the TSI value ranged between 52.6 – 63.4, with an average of 59.05 (see Figure 2). This value is classified as the lower boundary of classical eutrophic [10].

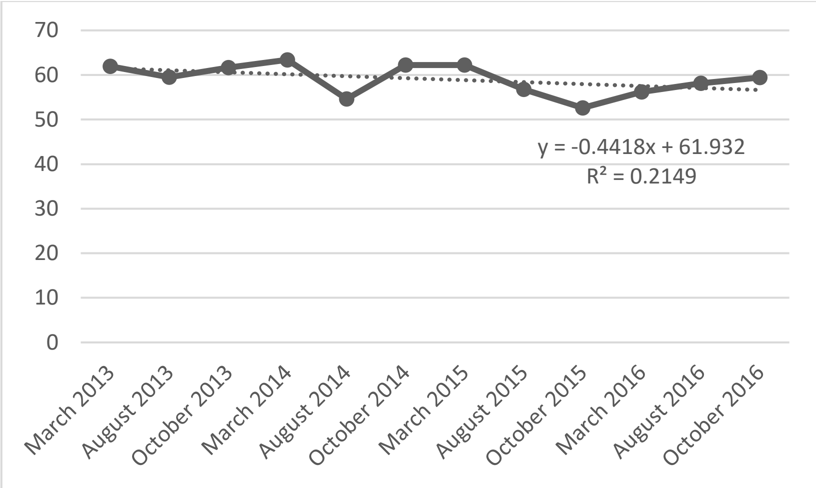


**Figure 2**. Trophic index pattern in Cirata Reservoir 2013–2016.

**Table 3.** Trophic State Index in several sampling locations in Cirata Reservoir.

| Station | Phos-phate(μg/L) | Trans-parency (m) | Chloro-phyll-*a* (μg/L) | TSI | | | | State |
|---|---|---|---|---|---|---|---|---|
| | | | | Phosphate (μg/L) | Trans-parency (m) | Chloro-phyll-*a* (μg/L) | Average | |
| Station 1 | 157.00 | 0.82 | 2.28 | 76.22 | 63.21 | 38.57 | 59.33 | Eutrophic |
| Station 2 | 133.33 | 0.89 | 2.98 | 72.52 | 63.70 | 37.97 | 58.06 | Eutrophic |
| Station 3 | 134.92 | 0.95 | 4.85 | 72.51 | 61.21 | 40.80 | 58.17 | Eutrophic |
| Station 4 | 129.25 | 0.81 | 7.03 | 71.67 | 63.44 | 42.90 | 59.34 | Eutrophic |
| Station 5 | 83.50 | 0.69 | 6.19 | 65.36 | 65.89 | 45.60 | 58.95 | Eutrophic |
| Station 6 | 124.25 | 0.79 | 4.90 | 70.31 | 63.94 | 42.89 | 59.05 | Eutrophic |
| Station 9 | 120.00 | 0.92 | 4.70 | 69.15 | 61.54 | 40.81 | 57.17 | Eutrophic |
| Station 11 | 158.67 | 0.51 | 7.05 | 72.75 | 70.20 | 44.20 | 62.38 | Eutrophic |
| Station 18 | 123.33 | 0.89 | 4.73 | 69.47 | 62.93 | 44.20 | 58.87 | Eutrophic |
| Station 19 | 116.33 | 0.95 | 2.16 | 70.85 | 61.15 | 37.16 | 56.38 | Eutrophic |
| Station 20 | 84.33 | 0.75 | 4.44 | 67.91 | 64.65 | 43.31 | 58.63 | Eutrophic |

The result shows that in general, Cirata Reservoir was in the eutrophic condition in the inlet, central reservoir and near outlet area. The highest average of TSI index was found in inlet area followed by central reservoir area with high density floating net cage. Moreover, statistical analysis using ANOVA shows that the TSI Value both in the rainy, dry and intermediate season was significantly different (p value $< \alpha$; $0.02 < 0.05$) with the highest average occurred in the rainy season (March) and the lowest occurred in the dry season (August). This contradicts several studies that were conducted at the lake in four seasons where lakes in the dry season tend to have a higher trophic level (only eutrophic) than in rainy seasons that have a wider range of trophic levels (e.g. oligotrophic, mesotrophic and eutrophic) due to drought condition and nutrient enrichment [15].

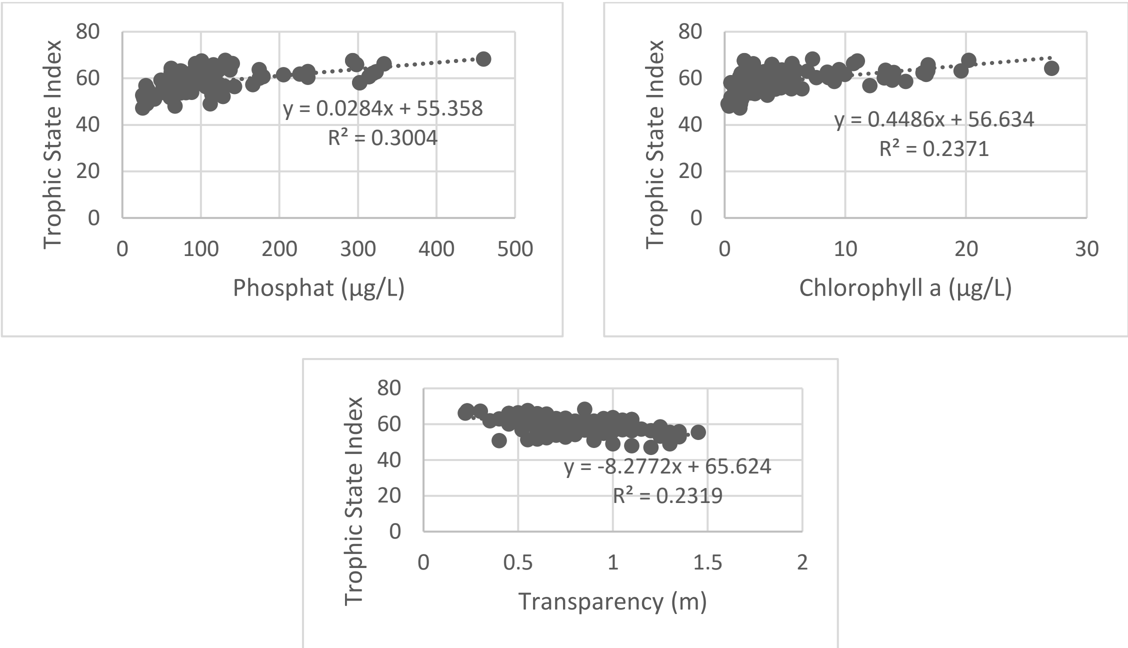


**Figure 3.** Regression analysis between phosphate, Chlorophyll-*a* and transparency toward Trophic State Index.

*3.2. Correlation between phosphate, Chlorophyll-a and transparency with Trophic State Index*

Regression analysis shows that there were correlations between phosphate, Chlorophyll-*a* and transparency with TSI (see Figure 3). Moreover, estimation shows that weather in rainy, dry or intermediate season, the phosphate content (p value < α; 0.014 < 0.05) and Chlorophyll-*a* (p value < α; 0.04 < 0.05) were significantly different (see Table 4). The highest phosphate content was found in the inundation area (central and near outlet). whereas, Chlorophyll-*a* with highest average concentration was found at the inlet area.

**Table 4.** Average phosphate, transparency and Chlorophyll-*a* in different season at Cirata Reservoir.

| Sampling Month | Parameter | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Phos-phate (µg/L) | TSI Phos-phate (µg/L) | Trans-parency (m) | TSI Trans-parency (m) | Chloro-phyll-*a* (µg/L) | TSI Chloro-phyll-*a* (µg/L) | TSI | State |
| March 2013 | 74.88 | 66.02 | 0.81 | 63.09 | 15.45 | 56.74 | 61.97 | Eutrophic |
| March 2014 | 121.75 | 73.31 | 0.63 | 67.11 | 8.98 | 49.78 | 63.40 | Eutrophic |
| March 2015 | 276.88 | 82.89 | 0.67 | 67.09 | 2.19 | 36.69 | 62.23 | Eutrophic |
| March 2016 | 105.09 | 71.02 | 1.02 | 60.44 | 2.53 | 37.07 | 56.18 | Eutrophic |
| August 2013 | 143.38 | 72.27 | 1.07 | 59.21 | 8.20 | 47.06 | 59.51 | Eutrophic |
| August 2014 | 65.88 | 62.66 | 0.80 | 63.98 | 2.37 | 37.31 | 54.65 | Eutrophic |
| August 2015 | 66.13 | 64.53 | 1.11 | 59.13 | 7.95 | 46.61 | 56.76 | Eutrophic |
| August 2016 | 82.82 | 67.70 | 0.63 | 67.11 | 3.14 | 39.49 | 58.10 | Eutrophic |
| October 2013 | 90.63 | 69.08 | 0.65 | 67.74 | 6.56 | 48.10 | 61.64 | Eutrophic |
| October 2014 | 276.88 | 82.89 | 0.67 | 67.09 | 2.19 | 36.69 | 62.23 | Eutrophic |
| October 2015 | 35.00 | 55.16 | 0.71 | 65.42 | 3.05 | 37.26 | 52.62 | Eutrophic |
| October 2016 | 171.09 | 77.59 | 0.91 | 61.74 | 2.65 | 39.00 | 59.44 | Eutrophic |

However, the phosphate presence in Cirata Reservoir was expected to not only caused by activities in upstream Citarum but also from activities in the reservoir itself. Moreover, regression analysis shows that there was no correlation between rainfall—that was closely related to water discharge—with phosphate content in Cirata Reservoir. In other words, the increasing water discharge due to high rainfall, which also was suspected to transport phosphate into Cirata Reservoir form upper region, had no significant effect on the trophic level at Cirata Reservoir. The floating net cages are common in the Cirata reservoir since inundation take placed in 1988, hosting tilapia, common carp, catfish, and pangasius. The number of cages is continuously increasing and, according to the last census, the population of the cages had reached 68,000 units in 2013 [16]. Fish aquaculture (floating net cage) on the Cirata Reservoir utilizes great amounts of nutrient-rich feed material. Adding to this, research by Garno [17] estimated that, during the last five years, the floating net cages in the Cirata Reservoir had generated as much as 145,334 tons/yr of organic waste, containing 1,041.4 tons phosphate loading in Cirata Reservoir. This statement was consistent with our analysis that in the area where the floating net cage existed, the total phosphate content was up to 157 μg/L (see Table 3).

Chlorophyll-*a* is a green pigment possessed by organisms and its presence identical with the presence of algae in the water and related to the trophic state. In this study, the highest average Chlorophyll-*a* content was found in the inlet area and the lowest was found in the area near the outlet. The results are somewhat different from previous research about spatial distribution of Chlorophyll-*a* a in the Cirata reservoir in 2013 using remote sensing conducted by Syahras *et al* [18] that were shows central area of reservoir marked as darker colours which represent higher Chlorophyll-*a* content, followed by near outlet and inlet area that were marked as light colour (medium Chlorophyll-*a* content). This difference shows that trophic level at lakes is very localized and specific as it is related to natural and climatic factor as stated by Liu *et al* [19].

The presence of Chlorophyll-*a* is highly correlated with the presence of organic material such as phosphate. In general, the phosphate contents are always in line with chlorophyll-*a* contents [19]. Research by Galvez and Sanchez [20] and Lambou *et al* [21] shows that systematically, chlorophyll-*a* values increased with an increase in phosphate with high correlation ratio (range from 0.90 to 0.99) but in this study, the result shows that the higher the phosphate content, the lower chlorophyll-*a* content. This anomaly occurred allegedly due to the presence of water hyacinth in Cirata Reservoir. Sampling sites covered with water hyacinth generally had lower planktonic diversity than uncovered sites due to water hyacinth characteristics that block sunlight and accumulates the pollutants like nitrate and phosphate as essential elements for water hyacinth growth [23,24]. In line with Matthews *et al* [29], water hyacinth was discovered to inhibit some planktonic green algae in a shallow Portuguese lake [24]. Adding to this, water hyacinth that was removed from Brazillian and Mexican reservoirs are known to significantly increase the total phytoplankton [25,26,27]. In normal condition, vegetative reproduction of water hyacinth in Cirata Reservoir may result in doubling within 16 days [16]. With this capability, in 2014 using remote sensing, the spatial distribution of water hyacinth at Cirata reservoir was 1% of total inundation area or equal with 62 Ha.

Gasparini *et al* [8] state that in the tropical and subtropical lake, the prediction of the trophic state is more difficult due to nutrients dynamic affected by environmental factors. Eutrophication in the tropical area is known to be more tolerant of the excessive phosphate concentration [28]. Our estimation shows that deviation between TSI(Chl) and TSI (TP) were less than 0, or in other words, the total phosphate concentration was higher than Chlorophyll-*a*. This value indicated that at Cirata Reservoir, phosphate is not the limitation for lake productivity. The results contradicted with several studies that indicated that phosphate was commonly known as a nutrient limiting factor for algal growth [29,30]. This phenomena probably occurred due to the presence of water hyacinth as a barrier for algal growth due to its property that will shade the lake and provoke the death cell of algal [31], and these phenomena were discovered in Cirata Reservoir. Further research is required to understand which nutrient that act as the limiting factor of productivity at Cirata reservoir.

As stated by Mailu [32], many large hydropower plants are suffering from water hyacinth due to it entering the turbine and threats the sustainability of power generation. Eutrophication in Cirata

Reservoir is a threat to the sustainability of the Cirata Hydropower Plant. One of the factors that act as a driving factor for eutrophication in Cirata Reservoir is pollution of organic compounds. The continuity of the hydropower plant and Cirata Reservoir is highly dependent on the condition of the upper Citarum watershed where the socio-economic activities are various. Previous studies showed that the upper Citarum Basin has been experiencing a serious environmental degradation due to massive land conversion for settlement and agriculture [33], pesticides and fertilizers pollution from intensive horticulture and paddy field [34], and domestic waste from urban centres [35]. The agriculture surrounding reservoir also contributes to the pollution in the Cirata Reservoir. The use of inorganic fertilizers such as nitrogen and phosphate are negatively contributed to eutrophication. Research by Kinouchi *et al* [36] showed that phosphate derived from fertilizer in agricultural activities is a compound that is easily carried to the river.

Several strategies must be applied to cope with the eutrophication since Cirata Reservoir is classified as a eutrophic lake. Since the phosphate that flows into Cirata Reservoir is categorized as non-point source pollution, the eutrophication countermeasure must be run through an integrated mechanism which covers upper Citarum such as controlling pollution from agriculture in the catchment area and reservoir itself through adopting eco-friendly aquaculture and reduction of floating net cages.

## 4. Conclusion

The driver factor related with the trophic state in the tropical reservoirs such as climate, phosphate and chlorophyll-*a* has a different pattern from the lake or reservoir from the temperate season. This study indicates that tropical reservoirs are more dynamic in term of trophic state and its attributes. This dynamic condition will threaten the sustainability of electricity generation and energy supply in Cirata Reservoir. The integrated mechanism must be established to deal with the eutrophication, with focus on the restoration of the catchment area and reservoir itself.

## Acknowledgment

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