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Research Article

Satellite Remote Sensing Using Earth Observing System in Environmental Monitoring for Hydropower & Floating Photovoltaic Reservoir (Case Study: Algae Blooming on Cirata Reservoir, West Java-Indonesia)

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Abstract

This paper describes the application remote sensing satellite for vegetation in the management of the Cirata Reservoir. This reservoir is a provider of raw water for the Cirata hydropower plant, which is the largest hydropower plant in Indonesia. In the next 2 years, the largest floating solar power plant in Indonesia and Southeast Asia will also be built here. The results of monitoring using Earth Observing System, the area of water hyacinth in the Cirata Reservoir is in the range of 100 to 400 hectares. Cleaning of water hyacinth per month is in the range of 25 to 75 hectares per month. This has not been able to compensate for the water hyacinth area cover that can develop, especially during the rainy season which has an impact on increasing the Water Level. Therefore, this paper also presents several management strategies that have been carried out. In Indonesia in particular, there are many reservoirs that have the potential for algae blooming disturbances and the potential for floating solar power plants in the future. The experiment conducted in Cirata can be an alternative in best practice management.

Introduction

The use of renewable energy to provide electricity is increasingly being echoed. The national mix target in 2025, which consists of a 23% new and renewable energy mix, 22% natural gas, 25% oil, and 30% coal. Meanwhile, in 2020 the new renewable energy mix was reached at 11.20%, natural gas at 19.16%, oil at 31.60%, and coal at 38.04% [1].

One of the implementations of the NRE (New Renewable Energy) power plant is currently running with the operation of the Cirata Reservoir since 1988. The source of water as raw material is used for the 1008 MW Cirata Hydroelectric Power Plant. In addition, in the next two years a floating solar power plant with a capacity of 145 MWac will also be built by utilizing the reservoir water area cover. Over time, the Cirata Reservoir, which was initially used primarily for electricity generation, is currently being used for fisheries, agriculture and tourism. The varied patterns of use of the reservoir and the surrounding land can also have an impact on the quality of the waters of the Cirata Reservoir.

The decreasing water quality of the Cirata Reservoir and the increasing level of water fertility (trophic state index), has an impact on the Cirata Reservoir, one of which is algae blooming in the form of water hyacinth. The cause can also come from the activities of floating net cages [2]. Dense water hyacinth causes a decrease in DO and pH [3]. Water hyacinth can easily develop in freshwater ecosystems that have a narrower space than the ocean and can easily spread through water bodies such as rivers and reservoirs [4]. This phenomenon can certainly have a risk impact on the operations of floating hydropower and solar power plants.

Studies in lakes and rivers have shown that water hyacinth alters water quality. Steps are often taken to manage the spread of these invasive species in order to reduce the impacts on environmental quality, boat navigation, and another operation of water infrastructure. Water hyacinth is one of the fastest growing macrophytes in the world and it can profoundly change the ecosystems that it invades. Water hyacinth reproduces extremely quickly by producing daughter plants on stolons; 10 plants can produce a mat of 650,000 plants in one growing season. This rapid growth, coupled with its ability to spread over the surface of a water body, degrades water quality by altering physical, biological, and chemical processes [5].

Water hyacinth can support other aquatic plants that then form "floating islands". can block water flows and damage machinery, such as hydropower turbines. Water hyacinth impacts hydropower generation by blocking water intake facilities. The macrophyte affected the production of hydro-electricity throughout Africa (e.g., Kafue Gorge Dam for 900 MW hydropower in Zambia & Owen Falls Dam for 180 MW hydropower in Uganda). Water coolers and generator were often damaged by the presence of patches of water hyacinth mat at Owen Falls Hydropower at the northern part of Lake Victoria, Uganda. This is the correlations between areas of water hyacinth infestation and the hydropower outage using reliable data. The use of renewable energy to provide electricity is increasingly being echoed. The national mix target in 2025, which consists of a 23% new and renewable energy mix, 22% natural gas, 25% oil, and 30% coal. Meanwhile, in 2020 the new renewable energy mix was reached at 11.20%, natural gas at 19.16%, oil at 31.60%, and coal at 38.04% [1]. One of the implementations of the NRE (New Renewable Energy) power plant is currently running with the operation of the Cirata Reservoir since 1988. The source of water as raw material is used for the 1008 MW Cirata Hydroelectric Power Plant. In addition, in the next two years a floating solar power plant with a capacity of 145 MWac will also be built by utilizing the reservoir water area cover. Over time, the Cirata Reservoir, which was initially used primarily for electricity generation, is currently being used for fisheries, agriculture and tourism. The varied patterns of use of the reservoir and the surrounding land can also have an impact on the quality of the waters of the Cirata Reservoir.

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Year	*Outage (h)*	*Mat area (ha)*
1990	54	0
1991	68	0
1992	76	0
1993	63	800
1994	226	2130
1995	293	3080
1996	367	3670
1997	336	3880
1998	563	3720
1999	148	3190
2000	3	2280

Source: (Kateregga & Sterner, 2007).

Table 1: Water Hyacinth - Induced Outages at Owen Falls Hydropower.

Table 1 above, indicated that the longest outages occurred in 1996-1998 [8]. According to the Uganda Electric Board (UEB), power outages and manual removal of water hyacinth were costing about US$1 million per annum. While weed-harvesting efforts freed the dam from water hyacinth, it continued to flow down into the protective screens of turbines and the cooling system so that the turbines were often shut down in order to clean the screens and filters [2].

As the operator of the hydropower plant and its reservoir, PT Pembangkitan Jawa Bali (PJB) needs to adapt, one of which is in terms of monitoring algae blooms. The reservoir area, which reaches 6200 hectares, requires a more comprehensive monitoring mechanism. This is where the role of remote sensing implementation is needed to detect and estimate the extent of algae blooming. After analyzing the distribution of the algae blooms, a strategy for mitigating and controlling the impacts is carried out. In this paper, a method for processing satellite image data without using GIS (Geographic Information System) applications in general will be presented.

Methods & experimental set-up

Water quality monitoring

Water quality samples were taken from 2019-2020. The analysis used to determine the level of water fertility is the Trophic State Index method [9]. The Classification of trophic state index is available on Table 2.

$$TSI\ Chlorophil\text{-}A = 9.1 \times \ln(Chlor.a) + 30.6 \qquad (1)$$

$$TSI\ (Phospate) = 14{,}42 \times \ln(Phospate) + 4{,}15 \qquad (2)$$

$$TSI\ (Secchi\ Disk) = 60 - 14{,}41 \times \ln(Secchi\ Disk) \qquad (3)$$

$$TSI\ average = (TSI\ (CA) + TSI\ (P) + TSI\ (SD))/3 \qquad (4)$$

Parameter TSI = Trophic State Index; Parameter Chlor.a (CA) = Chlorophyll A in mg/l; Parameter Phospate (P) in mg/l; Parameter Secchi Disk in metre.

No.	Status	TSI Score
1	Olygotrophic	< 40
2	Mesotrophic	40-50
3	Eutrophic	50-70
4	Hypereutrophic	>70

Source: (Carlson, 1977).

Table 2: Classification of Trophic State Index.

In addition, an analysis was carried out by measuring average of Dissolved Oxygen (DO), Biochemical Oxygen Demand (BOD) and pH parameters from time series data at the monitoring location as follows on Table 3 and Figure 1:

No.	Location	Coordinate (Decimal Degrees)	
		Longitude	Latitude
1	Cicendo Estuary	107°20.128’	06°45.322’
2	Aquaculture Zone	107°19.496’	06°44.442’
3	Cisokan Estuary	107°16.117’	06°46.123’
4	Citarum Estuary	107°17.463’	06°47.152’
5	Cibalagung Estuary	107°15.563’	06°44.717’
6	Cikundul Estuary	107°14.499’	06°43.121’

Source: (PJB, 2021).

Table 3: Location of Water Quality Monitoring.

Figure 1: Water Quality Map Station (*Source*: PJB, 2021).

Experimental Set-Up for Monitoring Algae Blooming

Sentinel-2 image data is effectively used for areas that are not too large such as lakes or reservoirs, because it has high spatial resolution and short recording time. Image generated by Sentinel-2 satellite has a spatial resolution of 10 meters for 4 bands, 20 meters for 6 bands, and 3 the remaining bands have a spatial resolution of 60 meters. The Sentinel-2 satellite image also has 13 bands multispectral, which is divided into visible spectrum (coastal aerosol, red, green), near infrared, and shortwave infrared [4]. This method is presented in the following diagram on Figure 2:

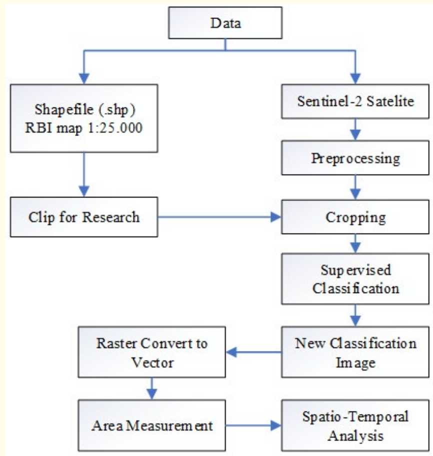

Figure 2: Water Hyacinth Monitoring Using GIS (*Source*: Rosyidy et.al., 2019).

EOS (Earth Observing System) provides satellite imagery used is derived from Landsat 8 and Sentinel satellites. So that the water hyacinth can be detected more clearly, then use a band combination with the type of healthy vegetation. Through the combination of waves or bands used to identify vegetation in the water, we can estimate the area and position of the water hyacinth. This method is presented in the following diagram on Figure 3:

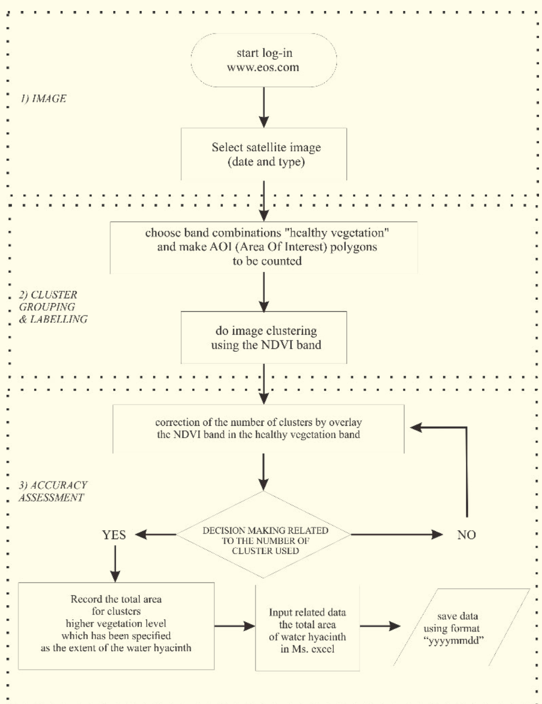

Figure 3: Research Framework (*Source*: PJB, 2021).

Result and analysis

Water Quality of Cirata Reservoir

The level of water trophic measured using the Trophic State Index method, indicates that the water conditions at the monitoring site are in hypertrophic conditions (score > 70). The Aquaculture Zone representative used in the analysis is the KJA zone in West Bandung Regency (KBB), which is observed to be in the most trophic condition. Here's the order: Aquaculture Zone > Cicendo Estuary > Cisokan Estuary > Citarum Estuary > Cibalagung Estuary > Cikundul Estuary (Figure. 4). This is in accordance with the trend conditions of the water hyacinth movement area (presented in the mapping section on the distribution of water hyacinth). The presence of water hyacinth can also have an impact on increasing BOD, DO being down and pH tends to be acidic.

Cikundul Estuary is the region where water hyacinth is the most rare. Based on the graph above (Figure 5), the level of chemical pollution is low (the lowest BOD), the DO is monitored the highest. While the Aquaculture area, the highest BOD, the lowest DO was monitored and the lowest pH. Water pollution that occurs in the Cirata Reservoir is one indication of a decline in reservoir quality both as a main function and its function as public waters.

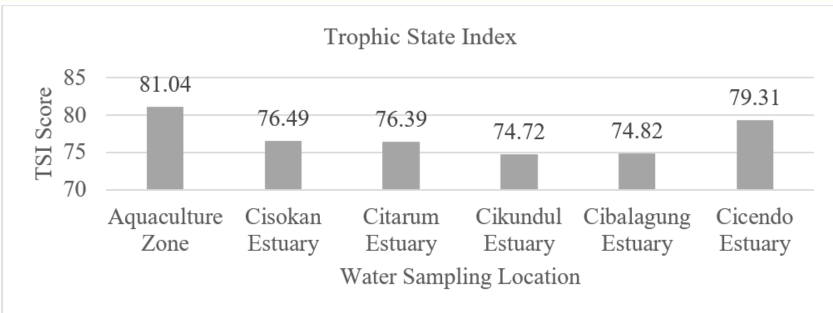

Figure 4: Trophic State Index of Cirata Reservoir (*Source*: PJB, 2021).

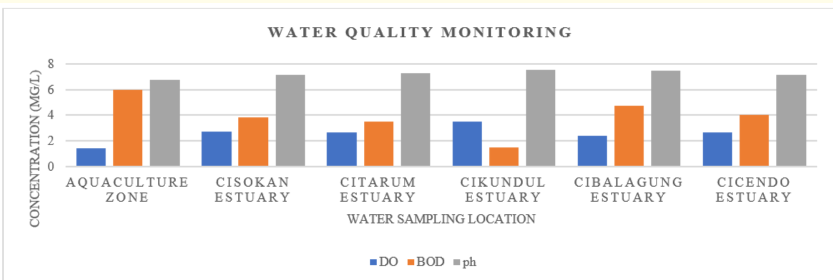

Figure 5: DO, BOD and pH paramaters (*Source*: PJB, 2021).

Water Hyacinth Mapping & Monitoring

The Earth Observing System (EOS) provides several choices of satellite types and the choice of data generated. In a 1 month period, on average there are 4 data from different times (Figure 6). The water hyacinth display that appears on the satellite image is validated with the conditions in the field. As a result, there is a match between the position of the water hyacinth in the photo in the reservoir and that taken from the satellite (Figure 7). It is necessary to set a band combination to make it easier to analyze the water hyacinth area and surrounding areas such as reservoirs and land. In the combination band, a healthy vegetation type is selected using an algorithm formula (B81, B11, B02). The red part is the appearance of the water hyacinth after the band adjustment (Figure 8).

Figure 6: EOS Interface (*Source*: PJB, 2021).

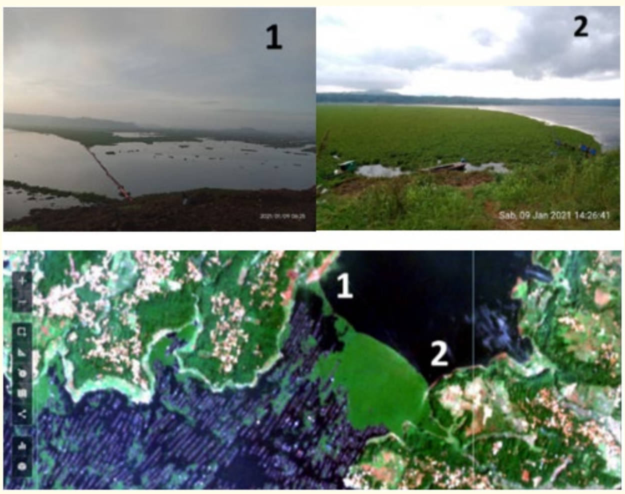

Figure 7: EOS Validation between EOS (bottom) from field survey (top) (*Source*: PJB, 2021).

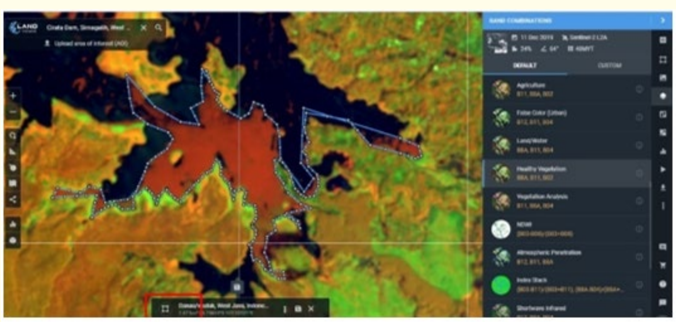

Figure 8: Setting Band Combination (*Source*: PJB, 2021).

The water water calculation process is carried out by clustering using the Normalized Difference Vegetation Index (NDVI) or EVI (Enhanced Vegetation Index) formula. The results of the calculation of the area in hectares will appear along with the type of classification (Figure 9).

Figure 9: Measuring Area using NDVI or EVI (*Source*: PT PJB, 2021).

Comparison of methods in processing satellite image data for calculating the area of water hyacinth, between PJB's Method & LAPAN-UI's [4] Method on Table 4. Satellite image of both method are available on Figure 10 & 11.

No.	***Description***	***PJB***	***Lapan & UI***
1	Satellite	Landsat-8 & Sentinel-2A	Sentinel-2
2	Satellite source	EOS (https://eos.com)	USGS (https://earthexplorer.usgs.gov)
3	Software	EOS (https://eos.com)	GIS (QGIS, ArcGIS
4	Additional data	-	shp file RBI map (http://tanahair.indonesia.go.id)
5	Classification method	Band healthy vegetation (B8A,B11,B02)	Band false color (B12,B08,B04)
6	Supervised method	NDVI (Normalized Difference Vegetation Index	MLC (Maximum Likelihood Classification)
7	Calculation method	Drawing AOI & Adjust Cluster (Area of Interest)	Drawing AOI & Convert raster to vector)

Table 4: Comparison Methods.

Figure 10: Calculation using PJB method (*Source*: PJB, 2021).

Figure 11: Calculation using LAPAN-UI method (*Source*: Rosyidy, 2019).

Method	***Satellite***	***Date***	***Area (Ha)***
PJB	Landsat-8	23/08/2018	107.77
LAPAN-UI	Sentinel-2	18/08/2018	106.44
Different (Ha)			1.33
Different (%)			1%

Table 5: Comparison Calculation Result.

This comparison (Table 5) is also aimed at testing the accuracy of the methods that have been used and proven in Indonesia, namely in this case the method that has been developed by LAPAN & UI. So from this comparison, it is concluded that the method developed by PJB using EOS can be implemented to create time series data. Based on satellite imagery monitoring that has been carried out from January 2020 to June 2021, it can be seen the extent of water hyacinth in the Cirata Reservoir (Figure 12). The aquaculture zone area in the middle of the reservoir (orange in the chart) is observed the most and is often covered by water hyacinth. This also proves that there is a correlation of this satellite data with the results of water quality measurements that have been carried out. The higher the trophic state index score, the more water hyacinth can breed, and the lower the DO value, followed by a decrease in the pH value of water quality [10].

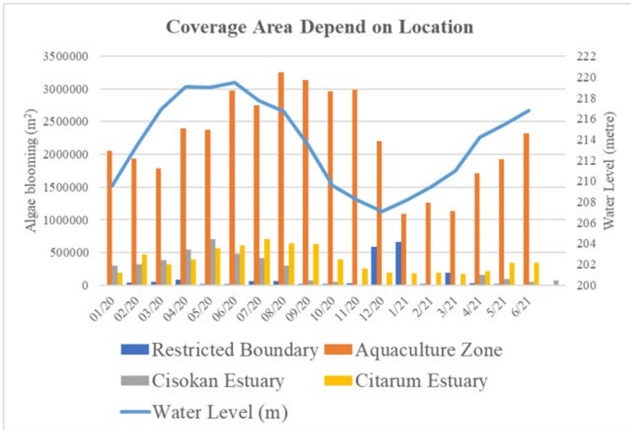

Figure 12: Algae Blooming Area Distribution (*Source*: PJB, 2021).

Regarding the extent of water hyacinth covering the water area, 25-75 hectares of water hyacinth have been cleaned per month (Figure 13). The tools used are excavators (2-4 units), harvester machines (3 unit) and feeder boats (2-8 units).

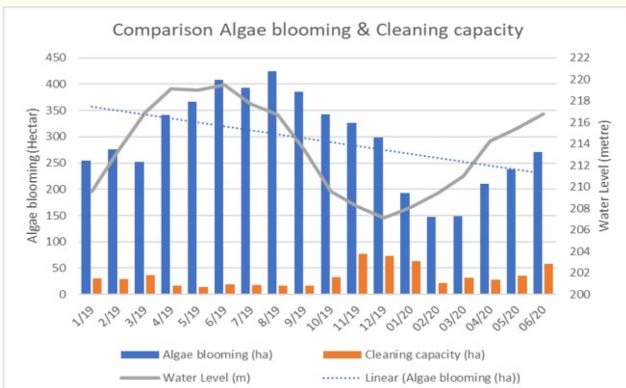

Figure 13: Comparison Algae Blooming & Cleaning Capacity (*Source*: PJB, 2021).

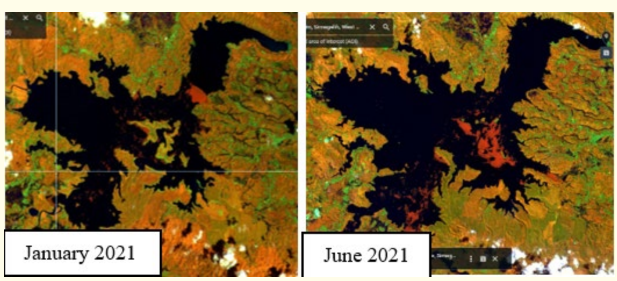

Figure 14: Satellite Image on 2021 (*Source*: PJB, 2021).

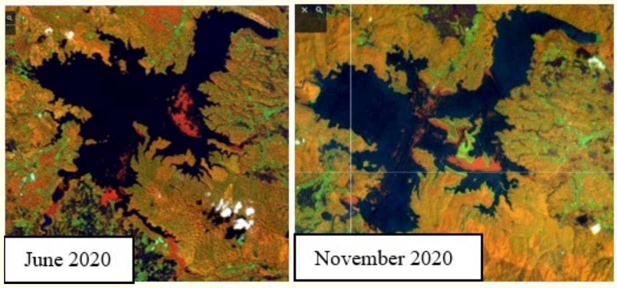

Figure 15: Satellite Image on 2020 (*Source*: PT PJB, 2021).

Water hyacinth can also change positions as shown in the figure (Fiqure 14 and 15). Based on these data, it is known that the level of cleaning carried out has not been able to reach all areas of water hyacinth. Therefore, several control strategies are needed [11], namely:

1. Reduction of floating net cages according to the carrying capacity.
2. Cluster arrangement or position of floating net cage.
3. Cleaning site block creation.
4. Collaboration cleaning with multiple parties.
5. Restriction of water area with portable trash boom.
6. Prevention of the entry of water hyacinth into the intake hydropower & floating photovoltaic area with permanent trash boom in the danger zone & intake.

Emphasizes the ability of program implementers, selection of alternative solutions using the CARL method with regard to Capability (C), Accessibility (A), Readiness (R) and Leverage (L) of proposed solutions between scale of values 1-5. The highest score on Table 6 & Figure 16 is the most likely solution to run.

Alternative Solution	***C***	***A***	***R***	***L***	***Total***	***Priority***	***Due Dates***
Reduction of floating net cages	1	1	2	4	8	6	long-term
Cluster arrangement or position of floating net cage	2	2	2	3	24	5	long-term
Cleaning site block creation	4	4	4	5	320	2	short-term
Collaboration cleaning with multiple parties	4	3	4	5	240	3	short-term
Restriction of water hyacinth area using portable trash boom	2	3	4	4	96	4	long-term
Prevention using permanent trash boom in the danger zone & intake	5	4	5	5	500	1	short-term

(*Source*: PT PJB, 2021)

Table 6: Scoring Using CARL Method.

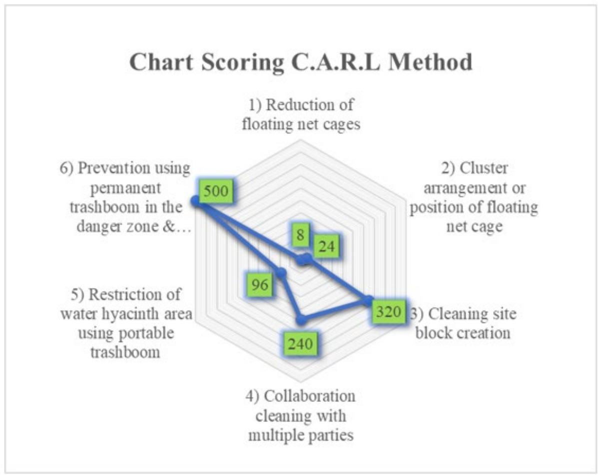

Figure 16: Score Chart of Control Strategies (*Source*: PJB, 2021).

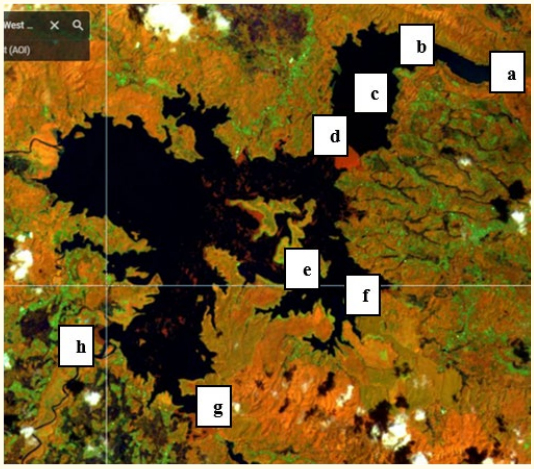

Figure 17: Important area on the map (*Source*: PJB, 2021).

The above image caption (Figure 17) is explained as follows:

a. Location of Cirata Dam.
b. Location of Cirata Intake.
c. Location of Floating Photovoltaic.
d. Cleaning area and permanent trashboom of the hazard zone delimiting area.
e. One of the choice of portable trashboom installation area. One of location floating net cages for fishery.
f. Citatah Cleanup Area (Example documentation on Figure 18).
g. Citarum Cleanup Area.
h. Cisokan Cleanup Area.

Figure 18: Example of Cleaning Area on Cirata Reservoir (*Source*: PJB, 2021).

Conclusion

Based on the results of this paper that have been made it can be formulated conclusions related to research above:

1. Earth Observing System can be used as an alternative method for monitoring water hyacinth without using GIS software with a difference of 1% compared to existing methods.
2. The area of water hyacinth cover in the Cirata Reservoir based on satellite data monitoring for 2020-2021 is in the range of 100-400 hectares. The higher the water level from the reservoir, the more or wider the distribution of water hyacinth in the reservoir area will be.
3. The cleaning capacity that can be done per month using excavator equipment, harvester machines and feeder boats can reach 25-75 hectares per month.
4. The water surface area of the reservoir that is covered by the most water hyacinth has the highest trophic status. The lower the DO value, the lower the pH and the higher the BOD. This is found in the floating net cage area.
5. Monitoring results from satellite data are useful in formulating reservoir management strategies, especially in the function of supporting the use of renewable energy.

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