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Article

Spatial Distribution of Sediment and Nutrient Loads in Urban Lake Rawa Besar, Depok, West Java, Indonesia

Mangapul Parlindungan Tambunan[1], Kuswantoro Marko[1,*], Ratna Saraswati[1], Rokhmatuloh[1], and Revi Hernina[1]

[1] Department of Geography, Faculty of Mathematics and Natural Sciences, Universitas Indonesia; mptgeoui@gmail.com

* Correspondence: kuswantoro@sci.ui.ac.id; Tel.: +62-21-7888 6680; Fax: +62-21-786 6819

Abstract: Lake Rawa Besar is an urban lake surrounded by dense settlements and market area. Currently Lake Rawa Besar is experiencing physical and ecology strain. This research's objectives are to determine the levels of sediment and nutrient, the distribution, also the relation to land use and human activities producing pollutant. Field surveys with 30 sample points and observations was needed scattered within the lake. Measuring the value of each parameter is carried out in national standardized laboratory. The result shows that sediment load of TDS is still below the standard limit for clean water, while TSS levels in the middle of lake exceed the standard limit. Nutrient loads, spesifically nitrate and phospate levels is below the standard limit. While turbidity and BOD levels have a uniform distribution pattern in the lake, exceed the standard limit for clean water, and have a positive correlation. High levels of turbidity and BOD are caused by household waste and human activities producing organic waste such as tofu factory, fowl manure, and garbage dump. Small sewage goes into the lake mediates pollutants inflow. Attention is needed by nearby people, also for the government, to sustain the ecological condition of the lake.

Keywords: urban lake; sediments, nutrients, landuse, pollutant sources

1. Introduction

Lake Rawa Besar is the second largest lake in Depok with 17 hectares area and has an important role as a catchment area. Its location which in the middle of the city is close to economic, government, and transportation activities. The lake is mentioned as urban lake because of its location surrounded by urban area and has area more than 20.000 m^2 [1,2]. Urban lakes are characterized by shallow, artificial, and hypertrophic lake [3,4,5] which continues to decline physically and ecologically so that it affects the quantity and quality of water [6].

The development of the area around Lake Rawa Besar cannot be separated from the history of the lake's emergence. The lake appeared beginning with the creation of pottery and brick businesses. The raw material is in the form of clay taken in the area by excavation so that over time the excavation becomes a large basin [7]. The breakdown of the Lake Pitara embankment in 1864 which was located in the upstream flowed into the basin to resemble a large swamp. The local community call it Lake Rawa Besar. The lake is not flowed by rivers in general. The availability of water is supplied by rainwater runoff in the area around the lake, the domestic sewage from the population around the lake, and can be made possible from groundwater [8].

Along with the development of Depok, the population has increased which is followed by an increase in land needs. This caused an uncontrolled change in land use around Lake Rawa Besar. From 1999 to 2003 land used for settlements and trade increased, which in 2003 occupied and traded land area by 64% and 12%, respectively [9]. The Depok City Environmental Agency (BLH) has noted that the original lake area of 25 hectares is now only 17 hectares due to the construction of dense and squatter settlements [8] on the banks of the lake by people who mostly come outside from Depok [10].

Previously research shows that there has been a decline in the water quality of Lake Rawa Besar in connection between the increase in settlement and trade land. In 2003 the parameters of ammonia, phenol, lead, BOD, COD and the presence of coli bacteria had exceeded the environmental quality standards [9]. Judging from the existence of the macrozoobenthos community, these waters have experienced interference with the criteria of being moderate to polluted [11,12], even can leads to the death of aquatic organisms [12]. The pressure on ecological condition of the lake is increasing and the sustainability of lakes is decreasing. This condition has the potential to lose the existence of the lake [13].

Lack of attention and management by the public, especially the government, has become the main cause of the problem of the decline in the quality of water [6]. Therefore, strong institutional coordination is needed by involving all interested parties, so that they have the power to set lake management policies [14]. For this reason, this study was conducted to determine the current water quality condition of Lake Rawa Besar based on the aspects of sediment and nutrient. Mapping the distribution of the values of each water quality parameter is done to determine the spatial distribution of parameter levels. In addition, the land use and community activities found in the lake's water catchment area were discussed to find out how it affects the quality of water in lake.

2. Study Area

This research was carried out in the Lake Rawa Besar and the catchment area located in Depok Jaya Village, Pancoran Mas District, Depok, West Java. The location is located at coordinates 106,816 BT and 6.39 LS. The surface height of the study area is around 86-90 meters above sea level with a slope of 0-2%. The lake has an area of 170,000 m^2 with a length of about 1.2 km, a width of between 300-700 meters, and a depth of 1-2 meters [8]. However, the area of the lake experienced shrinkage due to being utilized as a slum settlement with an area of at least 25,000 m^2.

Lake Rawa Besar is located in an urban area surrounded by dense settlements. In the western part there is a regular housing namely Perumnas I, while in the eastern part there are irregular housing that do not have legal land ownership (illegal) with slum conditions. This illegal settlement is occupied by residents with non-permanent livelihoods such as market laborers, station coolies and street vendors, their income is relatively low. Unlike the residents who live in regular settlements, they have a higher income but are still classified as middle income.

This research area includes the lake of Rawa Besar Lake and its catchment area with the eastern boundary of Kampung Lio Road, north of Jalan Arif Rahman Hakim, west of Jalan Nusantara Raya, and south of Jalan Dewi Sartika. Determination of the catchment area of the lake is based on topographic aspects in the form of surface elevation and direction of water sewage flow. The total area of the study area is 4,830,000 m^2 or 48.3 hectares.

3. Methods

3.1. Field Sampling

Water sampling was carried out at noon on 14 August 2018 in the water body of Lake Rawa Besar using a small boat. Parameters taken were total dissolved solid (TDS), total suspended solid (TSS), nitrate as N, total phosphate as P, turbidity, and Biochemical Oxygen Demand (BOD). Because the shape of the lake extends from north to south, the sampling technique is divided into 10 segments. There are 3 samples in each segment so that the total number is 30 water samples. This amount is taken so that the distribution of samples is evenly distributed and can represent in each location characteristics such as close to regular settlements, irregular settlements, slums, vegetated land, and sources of pollutants. The water sample was then put into a dark glass bottle measuring

300 ml, stored in a cooler box and in less than six hours was stored in a cooler at 4 ° C in a test laboratory.

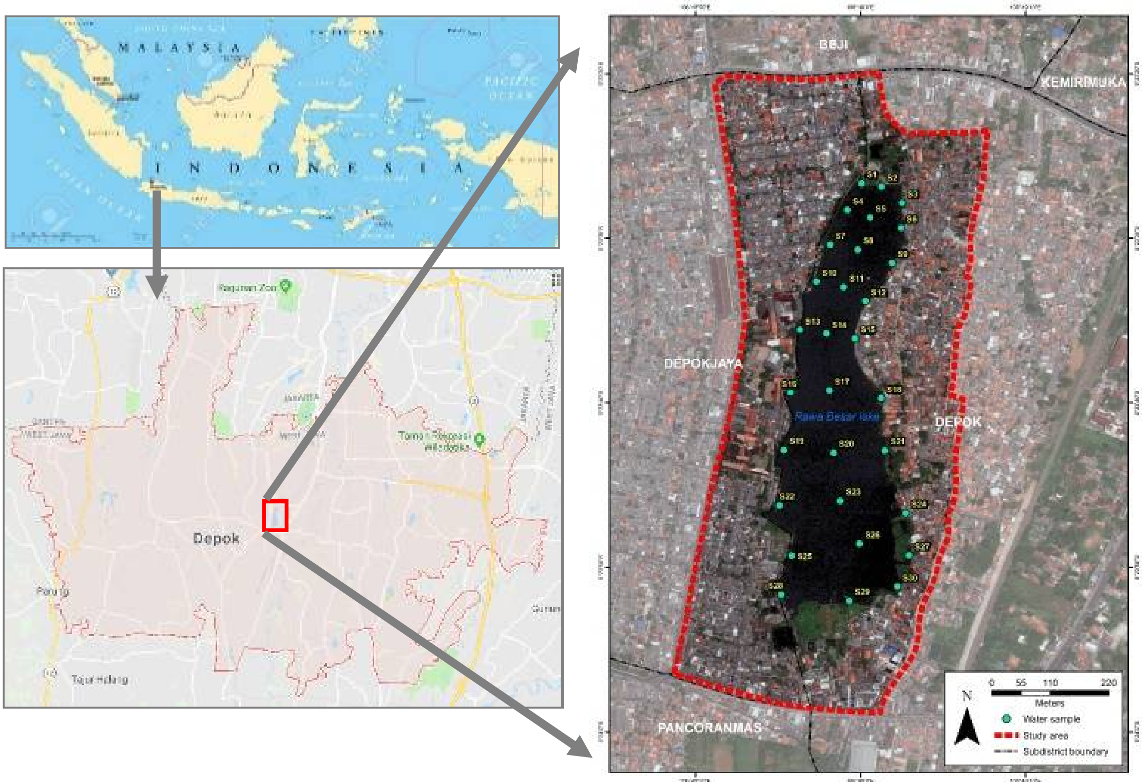

Figure 1. Location of Lake Rawa Besar surrounded dense settlemnets.

3.2. Sample Analysis

All samples are processed for 14 working days by a nationally accredited laboratory, PT. One Line Laboratory Services in Cibinong, West Java with AAS.LHP.IX.2018.1575 test contract number.

The measurement method of each parameter follows the instructions of the Indonesian National Standard (SNI) which refers to international standards named Standard Methods for Examination of Water and Wastewater [15].

- TDS is dissolved materials with a diameter of < 10 – 6 mm in the form of chemical compounds and inorganic materials in the form of ions that can be found in the waters [16]. TDS is measured by the gravimetric method by filtering water samples using a porous membrane filter 2.0 μm or smaller and heated 180 ° C for not less than 1 hour, the unit is mg / L;
- TSS are suspended materials with a diameter of> 1 μm consisting of mud and fine sand and microorganisms, which are mainly caused by soil erosion or soil erosion carried to the water body [16]. TSS was measured by gravimetric method using filter paper with a pore size of 0.45 μm and heated at 103 ° C to 105 ° C, the unit was mg / L;
- Nitrates are the main form of nitrogen in natural waters and are the main nutrients for the growth of plants and algae [16]. Nitrate as N was measured by spectrophotometric method using cadmium reduction column with a measurement range of 0.01 mg to 1.0 mg $NO3^{-}$-N / L with a path length of 1 cm or more, at a 545 nm wave length, the unit was mg / L;
- Total phosphate describes the total amount of phosphorus, both oarticulate and dissolved, inorganic and organic [16]. Total phosphate as P was measured by spectrophotometer method with ascorbic acid in water samples at a range of 0.01 ml P / L up to 1.0 mg P / L at a wavelength of 880 nm, the unit was mg / L;

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- Turbidity describes the optical properties of water which is determined based on the amount of light absorbed and emitted by the ingredients contained in the water. Turbidity is caused by suspended and dissolved organic and inorganic materials (eg silt and fine sand), as well as inorganic and organic materials in the form of palms and microorganisms [16]. Turbidity is measured by the Nephelometric method where the light source is passed to the sample and the intensity of the light reflected by the materials causing turbidity is measured by formazin polymer suspension as standard [16], the unit is NTU (Nephelometric Turbidity Unit);
- BOD depicts the levels of organic matter that can be decomposed biologically which is the result of decomposing dead plants and animals or the result from domestic and industrial waste [16]. BOD was measured using a solution of glucose-glutamic acid as standard control material at a temperature of 20 ° C ± 1 ° C for 5 days, the unit was mg / L.

3.3. Data Mapping and Interpolation

The mapping of the results of the analysis of water samples was carried out using ArcGIS software. First, the table data of the survey results for each sample location are converted into shapefile format. Second, interpolation is carried out using the Spline model [17,18] to produce spatial distribution of sediments and nutrients in the study area. The shapefile data is converted into raster format with a pixel size of 1 m 2, where each pixel contains the coordinates and parametric values. Third, the results of the interpolation are then clipped according to the lake boundary. Contour, label and color intervals are chosen to display better data.

3.4. Landuse Mapping and Pollutant Sources Identification

Mapping of land use and identification of pollutant sources is carried out to be able to link the influence of human activities on the distribution of these sediments and nutrients. Land and building usage data is obtained by digitizing high resolution satellite images with a scale of 1: 5000. Types of residential land use are made in more detail such as regular settlements, irregular settlements, and slums. This classification of settlements can be shown by the distribution of house buildings. Lake pollutant sources were identified by tracking the channels entering the lake, and the activities of influential residents such as food factories, landfills, livestock pens, fish cages, and other activities.

4. Results and Discussion

4.1. Spatial Distribution of Sediments and Nutrients

Turbidity was measured as an indication of suspended sediment (TSS) in the waters [16,21,22]. The sediment load measured in this study consisted of TDS, and TSS, not including the sediment load of the bottom of the lake. This is done as an initial investigation knowing what factors greatly affect sedimentation in Lake Rawa Besar. Is it due to erosion or more due to the activities of residents in the catchment area. For that reason, BOD and nutrient load such as Nitrate as N and Total Phosphate as P are discussed in this study to determine the relationship of nutrient content with human activities.

Based on the results of laboratory testing, the value of each parameter is then compared to the standard of clean water standards set by the Ministry of Health Regulation Republic of Indonesia No. 32 of 2017 [23] shown in Table 1. In addition, spatially will be discussed based on the results map interpolation of the water sample (Figure 2).

- TDS values range from 105 to 132.7 mg / L. All samples showed the TDS value was still below the standard limit of clean water which is 1000 mg / L /. However, the TDS value tends to increase in the middle of the lake, while in the southeast part the TDS value shows the lowest.

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- TSS values range from 14.3 to 97.4 mg / L. A total of 13 samples (43%) showed that the TSS value exceeds the standard limit of clean water, which is 5 mg / L. The TDS value is spread extending in the middle to southeast part of the lake.
- Nitrate-N values range from 0.23 to 1.20 mg / L. All water samples showed that the Nitrat-N value was still below the standard limit of clean water, ie 10 mg / L. However, the spatial value of Nitrate-N shows higher in the north and south lakes, as well as in the middle.
- The Total Phosphate-P value ranges from 0.014 to 0.118 mg / L. All samples showed the Total Phosphate-P value was still below the standard limit of clean water, which was 0.2 mg / L which spread evenly throughout the lake waters. There are only 2 samples whose values are above 0.1 ie in the samples S13 and S28 located on the edge of the middle west lake, and southwest.
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- BOD values range from 1.83 to 5.97 mg / L. From the 30 samples, 25 samples (87%) showed that the BOD value was above the standard limit of clean water, which was 2 mg / L. The BOD value is evenly distributed in the lake waters, except in a small part of the northern lake waters.

Tabel 1. The amount of sediment and nutrient content of Lake Rawa Besar and the limit of clean water standards

No.	Value element	TDS (mg/L)	TSS (mg/L)	Nitrate-N (mg/L)	Total Phosphate-P (mg/L)	Turbidity (NTU)	BOD (mg/L)
1	Minimum	105.0	14.3	0.23	0.014	12.7	1.83
2	Maximum	132.7	97.4	1.20	0.118	207.0	5.97
3	Average	121.9	51.1	0.67	0.020	102.0	3.75
4	St.dev	6.3	23.5	0.22	0.025	50.2	1.35
5	Standard limit for clean water	1000	50	10	0.2	25	2
6	Number of samples over the standard	0	13	0	0	28	25
7	Percentage of samples over the standard	0 %	43.3 %	0 %	0 %	93.3 %	83.3 %

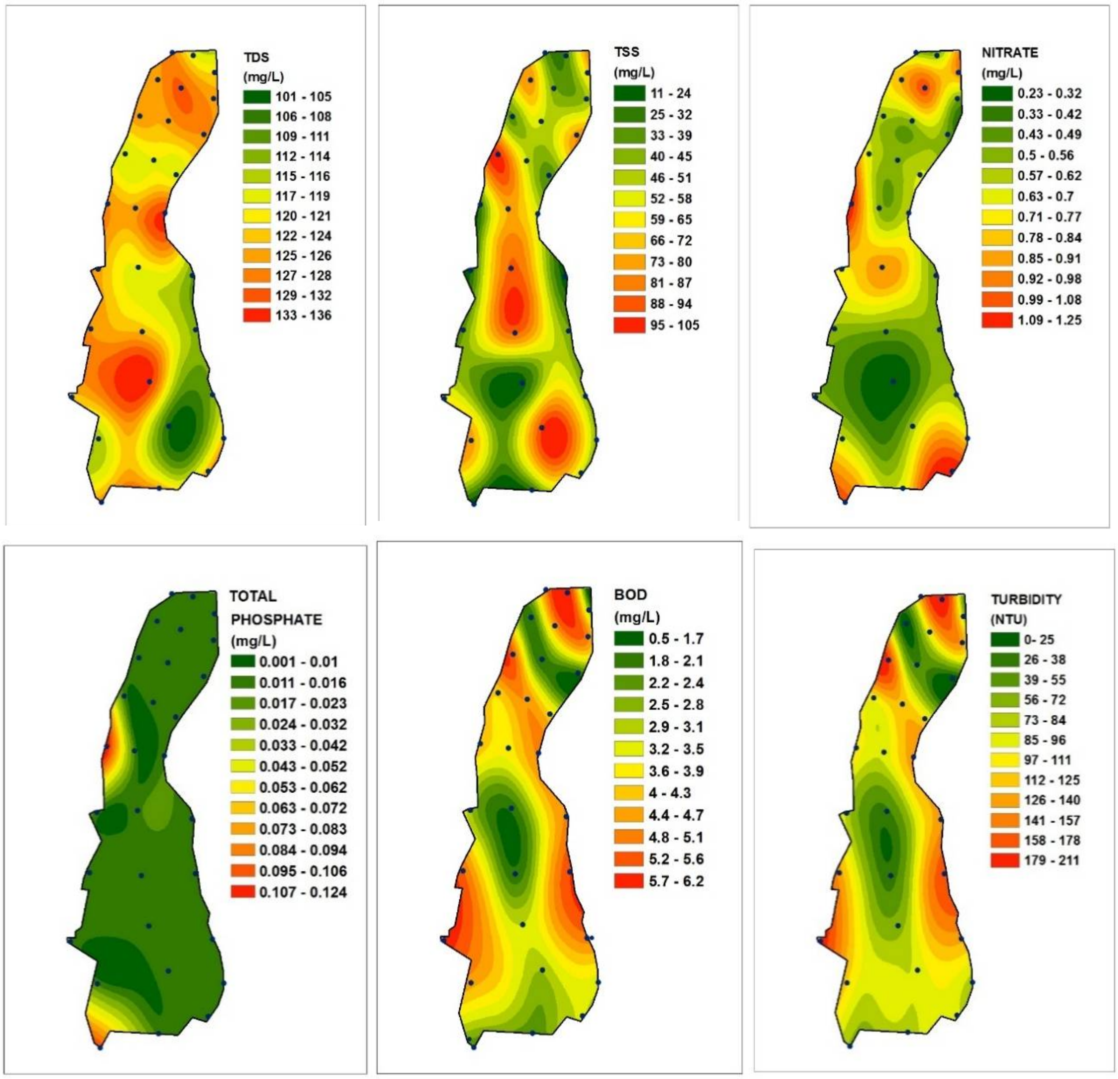

Figure 2. Result of interpolation of the sediment and nutrient content of Lake Rawa Besar water samples

4.2. Correlation between Parameters

Table 2 shows the results of the calculation of Pearson correlation between parameters. The results show that between turbidity and TSS has a weak negative correlation (r = -0.36). This is very different from the results of previous researchers' studies which stated a strong positive correlation between the two parameters [16,19,20,21,22]. The high value of turbidity and TSS is not always accompanied by a high TDS value or a strong positive correlation [16]. The results of the correlation between TDS and TSS and turbidiy show a weak negative correlation with r = -0.28 and r = -0.21.

The value of the correlation between the parameters of turbidity and BOD is indicated by the value of a positive linear correlation (r = 0.95 and R^2 = 0.90). While the correlation between sediment parameters and nutrients shows a weak correlation (0.25 < r < 0.5), even uncorrelated (r < 0.25). This shows that the amount of turbidity in the waters of Lake Rawa Besar is strongly influenced by the presence of organic material in the lake waters. In addition, the correlation between nutrient parameters is indicated by the existence of a moderate positive correlation between the value of nitrate-N and phosphate-P (r = 0.53) which is also indicated by the determination value R2 which is quite low at 0.28 as shown in Figure 3. Comparison between the value of nitrate and phosphate is greater than 16: 1, which means phosphorus is a limiting factor for eutrophication [16].

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Tabel 2. Correlation between sediment and nutrient parameters

Parameters	Turbidity (NTU)	TDS (mg/L)	TSS (mg/L)	Nitrate, P (mg/L)	BOD (mg/L)	Phosphate, P (mg/L)
Turbidity	1					
TDS	-0.21	1				
TSS	-0.36	-0.28	1			
Nitrate	-0.23	0.13	-0.04	1		
BOD	0.95	-0.16	-0.31	-0.26	1	
Phosphate	-0.07	0.18	-0.32	0.53	-0.11	1

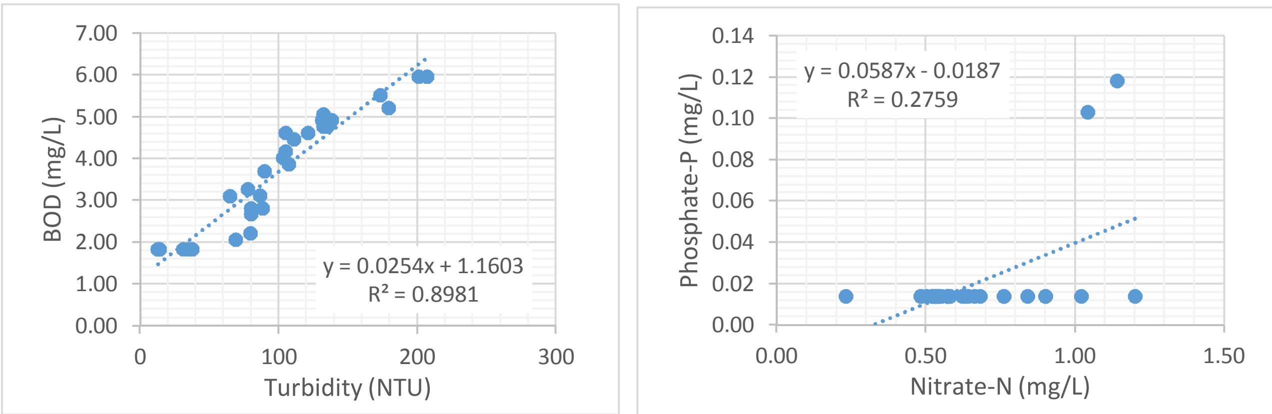

Figure 3. A pair of parameter's scatter plot which have bigger correlation value than the other

4.2. The effect of landuse and human activities to the sediment and nutrients loads

This study produced findings that were different from previous studies, namely the absence of a strong correlation between Turbidity and TSS, but a strong positive correlation between Turbidity and BOD. This can indicate that the level of turbidity of the water in the waters of Lake Rawa Besar is not affected by the erosion process from the area around the lake. The lake's catchment area is mostly in the form of built-up land such as settlements, trading, and school areas so that the amount of soil erosion due to small rainfall. In contrast to natural lakes where sediment concentration (TSS) is strongly influenced by soil erosion due to rain [24]. The existence of settlements that produce household waste water is a major cause of high BOD values so that water becomes cloudy [25]. The high BOD concentration can be caused by the high amount of chlorophyll A in lake waters [26].

Figure 4 shows the data on land use, most of which are dominated by built land in the form of regular settlements (38.4%), irregular dense settlements (42.5%), slums (5.2%), school areas (10.4), market areas (2.9 %), and only a small portion of vegetated land and wetlands (3.5%), as shown in Table 3. Regular settlements spread in the northwest and southwest of the lake, irregular dense settlements evenly distributed in the eastern part of the lake, slums scattered in the southwestern part of the lake, the school area is in the western part of the lake, vegetated and wet lands are scattered in the southern part of the lake, while the market area is in the southern part of the lake about 100 meters from the lake.

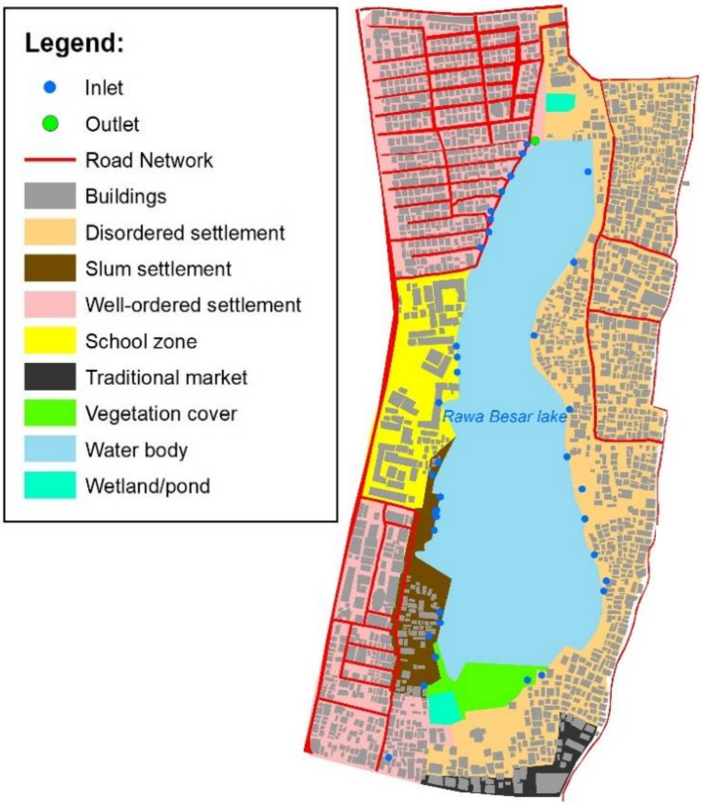

Figure 4. Land use in Lake Rawa Besar Catchment Area, Depok

Based on the results of the field survey on the physical condition of Lake Rawa Besar and the activities of the surrounding population, information was obtained that most of the lake's edge had been concreted (Figure 5-a), except in the southern part of the lake which was still overgrown with vegetation (Figure 5-b). This will reduce the rate of erosion on the edge of the lake, both caused by splashing and the pounding of lake water.

(a) (b)

Figure 5. (a) Concretion on the western edge of the lake, (b) Shrubs on the south bank of the lake

At the edge of the lake there have been identified at least 37 inlets in the form of small sewage sourced from surrounding land use. A total of 31 small sewers are sourced from residential areas. When observed during the day, there is no water flowing continuously into the lake through the small sewage. Nor is it found a river body that goes to the lake.

Based on the results of interviews with community leaders around the lake, some residents dumped their household waste into the lake through the small sewage. In addition, 29 locations were found as sources of polluting the lake water. As many as 18 locations of pollutant sources are found in irregular dense settlements consisting of 4 fish livestocks, 7 fowl livestocks, 1 iron workshop, 2 wood sawmill, 1 tofu factory, 2 garbage dump, and 1 food store, as shown in Table 3.

Table 3. Area of each type of land use around Lake Rawa Besar

No.	Landuse type	Area (m^2)	Percentage (%)	Number of inlet sources to the lake	Type and number pollutan source
1	Traditional Market	10,034.9	2.9	0	
2	School Zone	35,450.0	10.4	4	- 2 fish livestocks - 4 fowl livestocks
3	Slum settlement	17,552.2	5.2	11	- 1 water flower - 1 fish livestock - 1 fowl livestock
4	Disordered settlement	144,780.3	42.5	11	- 4 fish livestocks - 7 fowl livestocks - 1 iron workshop - 2 wood sawmills - 1 tofu factory - 2 garbage dumps - 1 small food store
5	well-ordered settlement	130,619.5	38.4	9	- 1 garbage dump - 1 small food store
6	Vegetation cover	8,339.3	2.4	2	
7	Wetland/pond	3,649.1	1.1	-	
	Total	350,425.3	100.0		

Source: Data proceeded using Quickbird imatery in 2017

As for the results of laboratory tests stated that of the six parameters, three parameters have a value that exceeds the standard limit of clean water. That is, the waters of Lake Rawa Besar have experienced pollution or decreased water quality when viewed from the value of tubidity, TSS, and BOD. A strong correlation between turbidity and BOD is also shown by spatial distribution patterns of the values of the two parameters which are almost the same.

Figure 6 shows the distribution of locations suspected to be water pollution sources of Lake Rawa Besar. High turbidity and BOD values such as the S2 and S21 sample locations can be caused by the existence of a landfill that is not managed properly. Organic materials in the trash can enter the lake waters, especially when it rains. In addition to these two locations, the value of turbidity and high BOD is found in locations adjacent to the fowl and fish livestocks, as seen in the sample locations S3, S18, S19, and S22. The existence of food store and tofu factory near the sample locations of S1, S10 and S15 is also possible to have contributed organic matter from leftover food or pulp that is dumped into the lake waters. The high distribution of TSS values (> 50 mg / L) spread in the middle to the southeast of the lake. This can be caused by land use in the form of vegetated land. Vegetated land indicates the presence of a soil layer on the surface. The potential for erosion is quite large, both caused by rain and by the behavior of lake water. In addition, the presence of 37 small sewers as an inlet into the lake has played a role in bringing a number of sediments and organic material from the settlements in the lake catchment area. At locations S13 and S28 the eutrophication process occurs with the emergence of water hyacinth and algae plants [27]. This is indicated by higher phosphate values compared to other locations. Rain has a share in carrying sediment and nutrient loads from land to lake water bodies [5].

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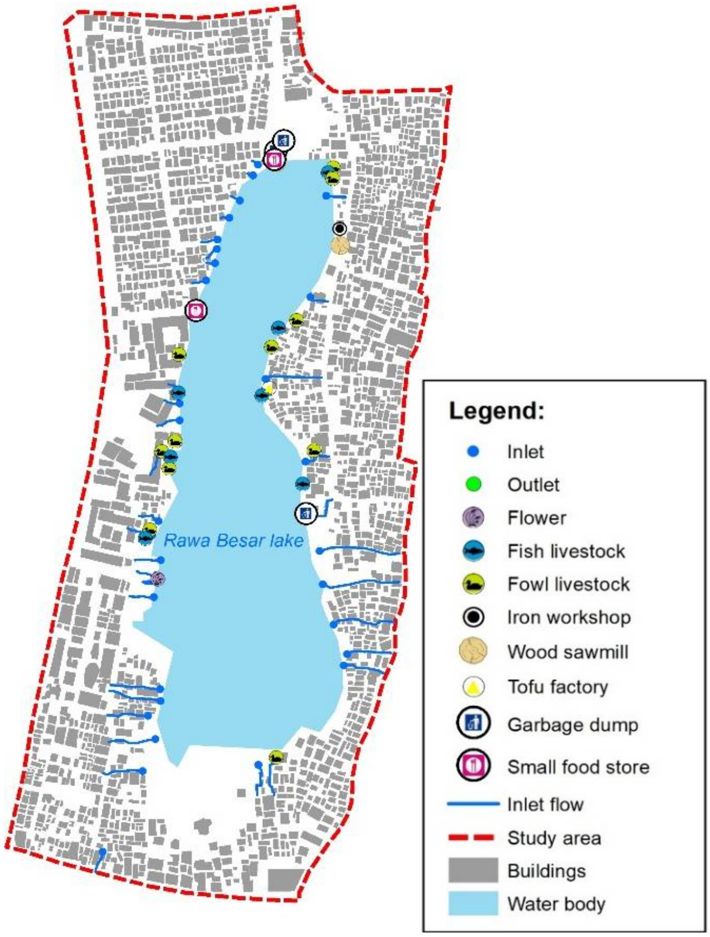

Gambar 6. Inlet sewages location and water pollution sources surrounding Lake Rawa Besar. (Source: Field Survey, 2018)

5. Conclusions

Sediment loads represented by TDS and TSS are spread in unequal patterns. TDS levels in the lake are still below the standard limit of clean water, while TSS levels in the middle of the lake exceed the standard limit. The nutrient load represented by nitrate and phosphate is dispersed in almost the same pattern, ie higher levels are spread on the edge of the lake, even though both are still below the standard limit. The turbidity and BOD levels have a uniform distribution pattern in the lake waters, the level exceeds the standard limit of clean water, and has a strong positive correlation. The high levels of turbidity and BOD are caused by household waste and community activities that produce organic waste such as tofu factory, fowl manure, and garbage dump. The existence of a small sewage that goes into the lake waters mediates the entry of pollutants into the lake. That way, the sediment load from soil erosion is stated to be within the controlled limits due to the construction of the area around the lake.

Author Contributions: In conducting this study, Mangapul P. Tambunan: conceptualization; Kuswantoro Marko, methodology, analysis, software, writing; Ratna Saraswati, resources; Rokhmatuloh, funding acquisition; Revi Hernina, survey, project administration.

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