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Analysis of Carrying Capacity and Water Pollution in the Simporo Strait Area After a Flash Flood

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ABSTRACT

The Simporo Strait is located in the Hendo River Basin. The erosion rate in the Hendo river basin is 12,434,881 m^3/year, causing sediment discharge in the Hendo river by 0.00039 m^3/year. The high rate of erosion and sediment discharge in the watershed resulted in siltation in the Simporo Strait. In addition to the silting problems, in the Simporo Strait there has also been pollution of the TSS, BOD and COD parameters. This research was conducted in the Simporo Strait with the aim of analyzing the carrying capacity of the Simporo Strait waters for drinking water, recreation, freshwater fish farming, animal husbandry, and water for irrigating crops. The research method uses the water carrying capacity analysis based on water pollution index. The results of the study concluded that the waters in the Simporo Strait have been polluted by TSS, BOD, COD and PO_4, so they are not suitable for use as a source of drinking water (Class I) and for the purpose of recreation / tourism (Class II). The carrying capacity of the waters in the Simporo Strait does not support being used as a source of drinking water and a place for infrastructure / recreation facilities because it has been lightly polluted. The carrying capacity of the waters in the Simporo Strait still supports their use as a place for raising freshwater fish, livestock, and water to irrigate crops, because the results of the analysis obtained status meet the quality standards (good condition).

Keywords: carrying capacity, Simporo Strait, water pollution, flooding

INTRODUCTION

The morphology of Lake Sentani extends from east to west along a length of 26.5 km, with a width varying from 2–4 km around the Simporo strait, and a maximum width of 24 km in the western and eastern parts of the lake (Walukow, 2008; Walukow, 2010; Walukow, 2011a; Walukow, 2011b). The land area of Lake Sentani and its surroundings has a moderate slope, ranging from 17% to 52%. This allows sedimentation due to the erosion processes in the Lake Sentani area. Lake Sentani has 14 river basins, when it rains, the watershed becomes the inflow discharge of Lake Sentani. On the topographic map, 14 major rivers were identified in Lake Sentani (Setyabudi, 2015). This condition resulted in silting in Lake Sentani. Lake Sentani is threatened by division into two parts due to high sedimentation in the Simporo Strait. This sedimentation has resulted in silting, so that the depth in the Simporo Strait is 6 m. The depth of Lake Sentani outside the Simporo Strait is 52 m, with an altitude of 72 m above sea level. The Simporo Strait is located in the Genyem river basin, and is built by the closest watershed, namely the Hendo river basin and the Yahim river basin. The rate of erosion in the Hendo river basin is 12,434,881 m^3/year, the rate of erosion has resulted in sediment discharge in the Hendo River 0.00039 m^3/year. The rate of erosion in the Yahim river basin is 359,451.24 m^3/year, this erosion rate results in sediment discharge in the Yahim River 0.01140 m^3/year. The rate of erosion in the Genyem river basin was 153,237,940

m^3/year, resulted in sediment discharge in the Genyem River at 0.00486 m^3/year. The total erosion in 14 river basins is 1,180,196,701 m^3/year and a total sediment discharge is 0.03742 m^3/year (Setyabudi, 2015). The high rate of erosion and sediment discharge in the three river basins have resulted in silting in the Simporo strait.

Apart from the silting problems, the Simporo Strait has contaminated the TSS, BOD and COD parameters. These three parameters have exceeded the quality standards of Government Regulation No. 82 Year 2001 based on Class II designation, where the laboratory test results obtained te parameter values of TSS, BOD and COD reaching 55 mg/L; 5.4 mg/L and 35 mg/L, respectively (Walukow et al., 2020). Likewise, there has also been an increase in Cu, TDS and Posfat pollution loads in Lake Sentani, amounting to 0.08 tonnes/month, 287.70 tonnes/month and 1.71 tonnes/month, respectively (Walukow, 2010; Walukow, 2008; Walukow, 2010a; Walukow, 2010b). The NO_3 pollution load continues to increase from 41.98 tons/month to 45.22 tons/month (Walukow et al., 2019). The Pb contamination in the sediment is 28 mg/kg to 40 mg/kg (Walukow, 2017a; Walukow, 2017b). The polluted lake water quality shows that the carrying capacity of the lake to support human life or other living creatures has decreased.

Several studies of the carrying capacity of waters abroad, involved quantitative research on the carrying capacity of groundwater resources, karst areas and irrigation (Setyabudi, 2015). Likewise, the carrying capacity of the lake has been studied based on the value of 'chlorophyll-a' in Lake Ercek, where the highest value of 'chlorophyll-a' is 6.970 mg/m^3 (May et al., 2015). The research on carrying capacity based on phosphorus in Ranu Grati lake obtained a value of 12,674.11 kg/year (Rajan et al, 2011). Furthermore, it has been found that the factors causing the decreased carrying capacity of Lake Vembanad result from solid waste, liquid waste, land reclamation, oil pollution, recreational activities, and excessive exploitation of natural resources (Akkus, 2013). However, the previous research has not conducted the analysis of the carrying capacity of the lake for drinking water needs (Class I), tourism / recreation (Class II) and fish farming (Class III) using the Pollution Index method. The advantage of the pollution index method is that the condition of the lake waters will be known precisely, namely lightly polluted, moderately polluted, heavily polluted or not. The carrying capacity analysis using the pollution index method can determine the exact need for drinking water, recreation and fish farming. The carrying capacity study based on the pollution index method is a finding and a novelty in this study. The benefits of this research can provide input to the government in managing forest function conversion, erosion, sedimentation, settlements, and waste so that the lake remains sustainable. Another benefit is that it can provide the information about the condition of the water quality status in the Simporo Strait to the public so that they can be careful in using lake water as a source of drinking water, cultivation and tourism. This study aims to analyze the carrying capacity of Lake Sentani in the Simporo Strait by using the pollution index method.

MATERIALS AND METHODS

This research was conducted using a quantitative descriptive approach. This approach is used to describe the condition of water quality in the Simporo Strait. The sampling location in the Simporo Strait is found in Simporo village. The material analyzed was Simporo Strait water quality data. The parameters analyzed were physicochemical parameters including TSS, BOD, COD, DO, PO_4 and Pb. The carrying capacity analysis method uses the pollution index (PI) method, which employed for the carrying capacity analysis for the designation of Class I, Class II and Class III.

The PI_j value can be determined by:

1) Prepare data *Ci* = concentration of water quality parameters measured by laboratory measurements,
2) Prepare *Lij* = water quality parameter quality standard based on Government Regulation Number 82 Year 2001,
3) Calculate *Ci* / *Lij*,
4) Calculate (*Ci* / *Lij*) R = average *Ci* / *Lij* of all parameters,
5) Calculate (*Ci* / *Lij*) M = *Ci* / *Lij* of each parameter with a maximum value,
6) Calculate the PI_j based on the formula:

$$PI_j = \sqrt{\frac{\left(\frac{C_i}{L_{ij}}\right)_m^2 + \left(\frac{C_i}{L_{ij}}\right)_R^2}{2}}$$

- $0 \leq PI_j \leq 1.0$ – good carrying capacity,
- $1.0 < PI_j \leq 10.0$ – does not meet the carrying capacity.

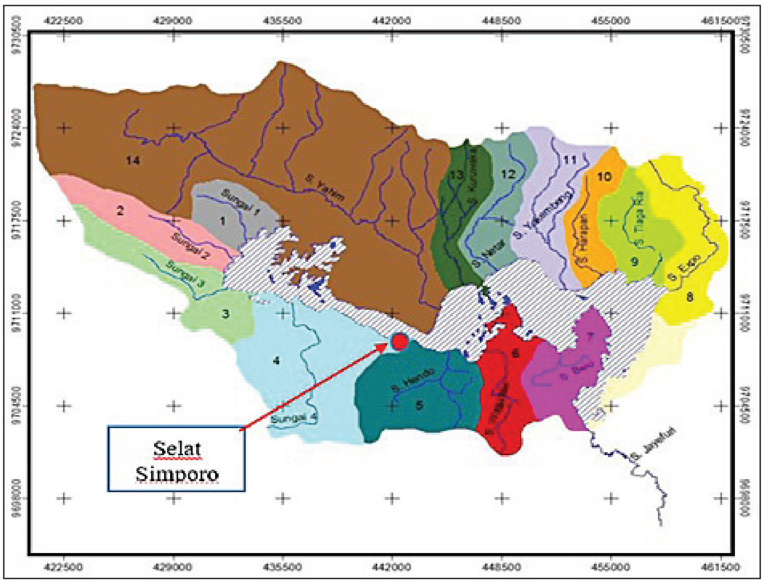

Figure 1. Research location

The calculation of the pollution load is determined by:

$$BP = QC \tag{1a}$$

$$BP = \sum Q_i \cdot C_i \cdot 3600 \cdot 24 \cdot 30 \cdot 1 \cdot 10^{-6} \tag{1b}$$

where: BP – pollution load originating from rivers (tonnes/month),
Q_i – river discharge (m^3/s),
C_i – waste concentration parameter (mg/L).

Table 1. Relationship of pollution index (PI) values with lake water quality status

Pollution Index	Lake Water Quality Status
0 ≤ PIj ≤ 1.0	Good condition
1.0 < PIj ≤ 5.0	Lightly polluted
5.0 < PIj ≤ 10.0	Medium polluted
PIj > 10.0	Heavy polluted

The assimilation capacity measurement

Pollution in river estuaries can be mathematically written as follows:

$$y = f(x) \tag{2}$$

Mathematically, the linear regression equation can be written:

$$y = a + bx \tag{3}$$

where: x – parameter value at the river mouth,
y – parameter value in lake waters,
a – general mean/average,
b – regression coefficient for the parameters on the river.

Assimilation capacity is the ability of the water body to assimilate any waste or the ability to naturally recover (self-purify) the water body against any waste that enters the waters. The calculation of the assimilation capacity also aims to determine the maximum capacity of each pollutant load that enters the water body.

RESULTS AND DISCUSSION

Description of water quality in the Simporo Strait after flash floods

According to Law of the Republic of Indonesia Number 32 the year 2009, environmental pollution is the entry or inclusion of living things, substances, energy, and/or other components into the environment by human activities so that they exceed the established environmental quality standards. The laboratory test results show that the parameters in the Simporo Strait have exceeded the quality standards for class I designation, namely TSS, BOD, COD and PO_4. Water that can be used as drinking water has a BOD value of less than 2 mg/L; if the BOD concentration exceeds 2 mg/L, the water is said to be polluted. Likewise, if TSS exceeds the value of 50 mg/L, the water is considered polluted (Mahmudi et al., 2019). For PO_4, if the concentration exceeds 0.2 mg/L then the water is said to be polluted. Water is said to be polluted if COD exceeds the value of 10 mg/L.

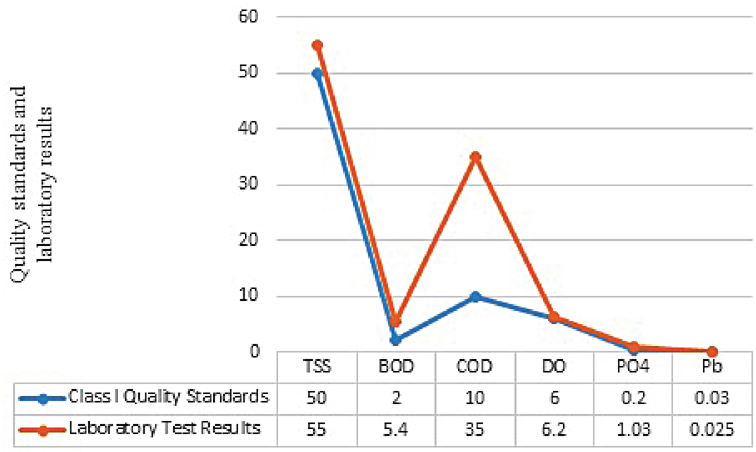

Figure 2. Water quality in Simporo Strait after the flash floods and Class I quality standards

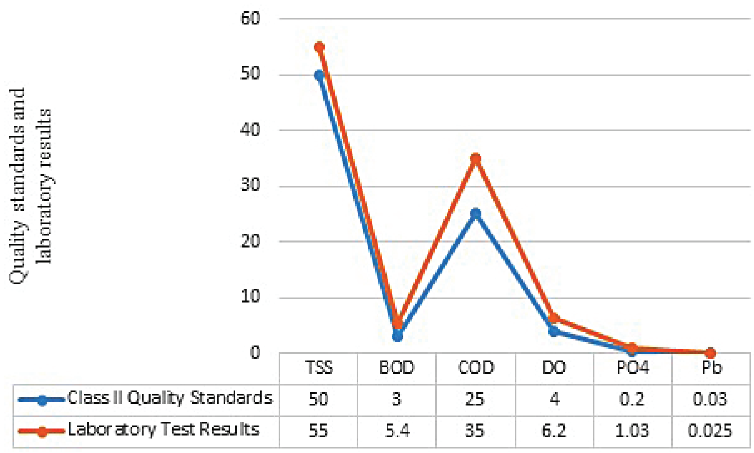

Figure 3. Water quality in Simporo Strait after the flash floods and Class II quality standards

The laboratory test results show that the parameters in the Simporo Strait have exceeded the quality standards for class II designation, namely TSS, BOD, COD and PO_4. This means that after the flash flood in the Simporo Strait, the TSS, BOD, and COD parameters deteriorated. Meanwhile, the parameters that have not exceeded the Class II quality standards are DO, PO_4 and Pb. This means that after the flash flood in the Simporo Strait, the DO and Pb parametersdid not deteriorate. The water that can be used as a place for water recreation facilities / infrastructure has BOD of less than 3 mg/L; if the BOD concentration exceeds 3 mg/L, then the water is said to be polluted. If TSS exceeds the value of 50 mg/L, the water is considered polluted (Mahmudi et al, 2019). For PO_4, if the concentration exceeds 0.2 mg/L then the water is said to be polluted. Water is said to be polluted if COD exceeds the value of 25 mg/L.

Carrying capacity of water based on pollution index in Simporo Strait after flash floods

According to Law of the Republic of Indonesia Number 32 the year 2009, the carrying capacity of the environment is the ability of the environment to support human life, other living things, and the balance between the two. The picture above shows that the water quality status in the Simporo Strait based on the Class I designation is lightly polluted based on the Class I designation. Class I is water designated for drinking water. This shows that the carrying capacity of the waters in the Simporo Strait does not support it as a source of drinking water, because it is lightly polluted. Class II is water which can be used for water recreation infrastructure / facilities, freshwater fish farming, livestock, water for irrigating crops, and / or other designations requiring the same water quality as the said use. The water quality status in the Simporo Strait based on the Class II

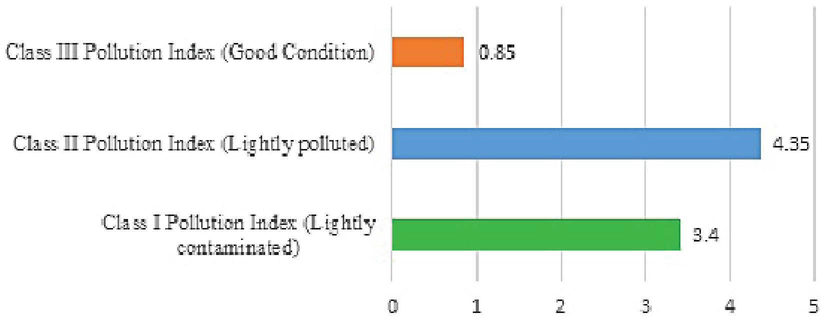

Figure 4. Index of water pollution in the Simporo Strait

designation has also been lightly polluted. This means that the carrying capacity of the waters in the Simporo Strait does not support its use as a place for water recreation infrastructure / facilities. Class III water can be used for the cultivation of freshwater fish, animal husbandry, water for irrigating crops, and / or other designations requiring the same water quality as the said use. The status of water quality in the Simporo Strait based on Class III designation is in good condition (meets quality standards). Thus, the carrying capacity of the waters in the Simporo Strait can still be used as a place for freshwater fish cultivation, livestock, and water to irrigate crops.

On the basis of the results of theanalysis above, it can be seen that the TSS, BOD, COD and PO_4 parameters in the Simporo Strait have exceeded the quality standards for class I (drinking water) and class II (tourism / recreation) designations. Therefore, the waters in the Simporo Strait have been polluted by TSS, BOD, COD and PO_4. The waters in the Simporo Strait are not suitable for use as a source of drinking water (Class I) and for the designation of recreation / tourism areas (Class II).

TSS is the number of particles suspended in water (Nurrohman et al., 2019). TSS is an organic and inorganic material in the form of fine sand or mud. The high TSS in the Simporo Strait may be caused by several factors, such as erosion, land conversion, agriculture, settlement and sand mining. A high TSS value is caused by various factors such as land use, the process of lowland farming and settlements in the downstream area, as well as natural factors such as the shape of the watershed (Rossi, 2019). The TSS value will increase if there is a change in land cover / change in land cover that is used to from ponds, settlements and shrubs (Parwati et al., 2017). Conversely, the TSS value will decrease if there is an increase in forest area (eg mangroves, CA Cycloop). The changes in land cover in the catchment area result in erosion and eventually lead to sedimentation. Anthropogenic activities cause soil erosion and have a negative impact on the degradation of surface water quality; therefore, it is necessary to manage water catchments (Haseena, 2017; Issaka et al., 2017). The conversion of residential, mining and agricultural land has resulted in high erosion and resulted in sedimentation, then the sediment enters the river and there is a flash in the Simporo strait. The source of TSS pollution from combined channels and rainwater discharge, then TSS that is in the water during rain, can cause ecotoxic effects on aquatic organisms. TSS can absorb hazardous substances such as heavy metals, PAH, and organic materials; then, TSS containing these harmful substances will settle into sediment (Asmaranto et al., 2017).

BOD and COD in the Simporo Strait likely come from residential and agricultural wastewater. This condition can be exacerbated if the area lacks wastewater treatment plant capacity (Rossi et al., 2019). The BOD, BOD_5 and COD parameter are sourced from domestic wastewater and fermented domestic wastewater. Domestic wastewater, yogurt fermented wastewater and yeast fermented domestic wastewater can produce biohydrogen electric energy. The electrical power output increases along with COD, BOD and BOD_5 (Parwati et al., 2017).

The high PO_4 in the Simporo Strait is probably caused by domestic activities, agricultural activities, livestock activities, and erosion. Anthropogenic activity is the main source of PO_4 and NO_3 pollution. Anthropogenic activities are referred to as human and industrial activities (Khan et al., 2011). The high level of PO_4 and NO_3 contamination in river and lake areas causes problems such as toxic algae blooms, hypoxia, fish mortality, loss of biodiversity, loss of species, loss of aquatic plants, loss of water plants and coral reefs. The dominant factors affecting the PO_4 pollution are industrial activities, agricultural activities, livestock activities, population density, soil types, rock types, climate and rainfall patterns (Adesuyi et al., 2015). The reduced concentrations of PO_4 nutrients, nitrogen and ammonia were caused by the stability of the water treatment system and the wastewater treatment system. A decrease in the volume of wastewater discharged into river water and soil, as well as an increase in the volume of treated wastewater are key to improving the surface water conditions (Fadiran et al., 2008).

The results of the above-mentioned analysis indicate that the TSS, BOD, COD and PO_4 parameters have exceeded the quality standard for the designation of drinking water sources (Class I) and the results of the pollution index analysis have been lightly polluted. This means that the carrying capacity of the waters in the Simporo Strait cannot be used as a source of drinking water, because it is lightly polluted. The TSS, BOD, COD and PO_4 parameters have exceeded the quality standard for the designation of water recreation areas (Class II) and the results of the pollution index analysis have been lightly polluted. This also means that the carrying capacity of the waters in the Simporo Strait does not support its use as a place for water recreation infrastructure / facilities. However, the carrying capacity of the waters in the Simporo Strait still supports its use as a place for cultivating freshwater fish, livestock, and water to irrigate crops, because the results of the analysis obtained the status of meeting quality standards. Therefore, the waters in the Simporo Strait can only be used as a place for freshwater fish cultivation, livestock, and water to irrigate crops.

The use of polluted water for drinking water is very dangerous for human health. Safe drinking water is a basic necessity for all human beings. Approximately 3.4 million people die worldwide each year from the diseases related to contaminated water, such as cholera, typhoid, polio, ascariasis, cryptosporidiosis and diarrheal diseases (Kanownik et al., 2019). The water that is polluted by defecation (feces) makes people infected with hepatitis, skin infections, cholera, intestinal disease, typhoid and polio. The condition in Bangladesh is that more than 45,000 children under five die every year from diarrhea caused by dirty water (polluted water). The effects of water pollution on ecosystems are species mortality, reduced biodiversity, and loss of ecosystem services (Hasan et al., 2019; Praven et al., 2016, Issaka et al., 2017). Prevention of water pollution in the Simporo Strait is: 1) Environmental education in the community on a large scale, 2) Disposing of waste in the right place, 3) Prohibition of washing clothes in rivers and lakes, 4) Prohibition of throwing feces into rivers and lakes, 5) Boiling water for consumption, 6) Prohibition of land use change that does not pay attention to soil and water conservation techniques, 7) Prohibition of land conversion that is not in accordance with regulations or spatial planning, 8) Prohibition of throwing garbage in rivers and lakes.

Pollution load on the Yahim River

The pollution status of the lightly polluted Yahim River is caused by an increase in the pollution load. On the basis of the figure above, it can be seen that the TDS and TSS pollution load in the Yahim river continued to increase from 2017–2019. The TDS pollution load increased from 24637.93 tonnes / month to 11600.82 tonnes / month. Likewise, after the flash flood, the TDS pollution load increased from 24306.48 tons / month to 11,100.82 tons / month. The TSS pollution load increased from 2872.58 tons / month to 5524.20 tons / month. Likewise, after the flash flood, the TSS pollution load increased from 5082.26 tons / month to 5524.20 tons / month. However, the TDS and TSS parameters

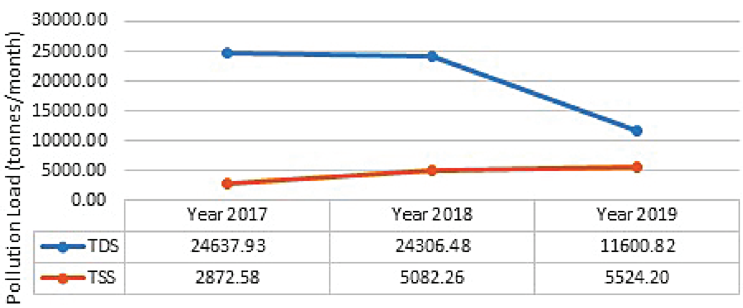

Figure 5. Pollution loads of the Yahim River for TDS and TSS parameters

of river water quality after the flash flood have not exceeded the water quality standard according to Government regulations Number 82 the year 2001, where the TDS and TSS measurements were 105 mg/L and 50 mg/L, respectively. The increased pollution load can be caused by the increasing concentration of the TDS and TSS parameters in the Yahim river. The increase in the TDS and TSS concentrations was caused by activities in the upstream and central part of the Sentani watershed (DAS). The activities that cause high TDS are the presence of domestic waste and small industrial waste. Meanwhile, the high concentration of TSS was caused by erosion in the upstream and middle part of the Sentani watershed. TDS contains organic and inorganic substances with a diameter of $<10^{-3}$ µm which are present in aqueous solutions. TSS is a material or suspended material that causes water turbidity consisting of mud, fine sand and microorganisms which are mainly caused by soil erosion or erosion carried by water bodies. The turbidity caused by TSS will further inhibit the penetration of sunlight into water bodies. As a result of the reduced penetration of sunlight into water bodies, the photosynthesis process carried out by phytoplankton and other aquatic plants is hindered. The high concentration of TSS in water results in a reduced DO concentration. The high concentration of TSS will cause the fish to die because TSS occupies the gill organs of the fish.

Assimilation capacity of lake waters around the Yahim River

The high pollution load in the Yahim River decreases the ability to recover naturally from Lake Sentani, which is known as self-purification. The natural recovery ability can be analyzed using the assimilation capacity value.

The value of TDS assimilation capacity in Lake Sentani, Yahim river estuary area of 289266 tons / month is obtained based on the regression equation $y = 0.0032x + 74.345$. The value of the pollution load in Lake Sentani is to the left of the value of the assimilation capacity, this indicates that Lake Sentani has not been polluted by the TDS parameter. This condition also shows that Lake Sentani is still able to carry out self-purification of the TDS parameters. Figure 6 shows that the TDS parameters still meet the quality standards of the Republic of Indonesia Government Regulation Number 82 the year 2001.

The value of TSS assimilation capacity in Lake Sentani, Yahim river estuary area of 38.0548 tons/month is obtained based on the regression equation $y = 0.0027x + 31.532$. The value of the pollution load in the Sentani Lake is to the right of the assimilation capacity value; this indicates that the Sentani lake has been polluted by the TSS parameter. This condition also shows that Lake Sentani is not able to carry out self-purification of the TSS parameters. Figure 7 shows that the TSS parameters still meet the quality standards according to Government Regulation Number 82 the year 2001.

Model of lake water pollution control policy in the Simporo Strait and Yahim River areas

Due to the high level of pollution in the Yahim River and Simporo Strait waters, a pollution control policy model is needed. Policy model of controlling pollution of the Yahim River and waters in the Simporo Strait of Danau Sentani are clean lake movement and anti-pollution socialization, Pilot villages, sharing expertise and experiences in handling waste and erosion, developing information systems, as well as combining research and development. According

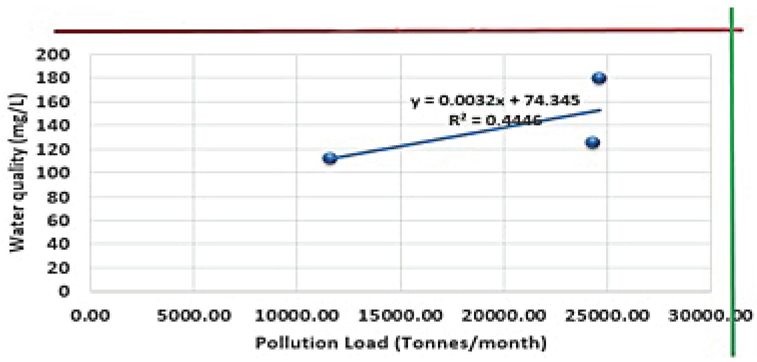

Figure 6. TDS Parameter assimilation capacity

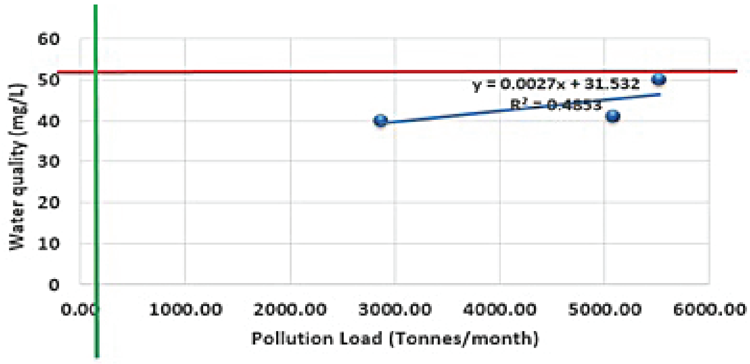

Figure 7. TSS Parameter assimilation capacity

to Isnugroho (2001), the efforts to control water quality so as not to be polluted are through: (1) Prevention of damage to water resources by means of establishing permits for wastewater disposal based on a water quality master plan that reaches the water quality targets according to quality standards; (2) Efforts to tackle pollution to prevent the spread of pollution that occurs and (3) Efforts that must be made to restore the condition of water resources and the polluted environment. Furthermore, according to Tarigan (2008) and Law Number 24 Year 1992 articles 16 and 17, information systems are important to increase stakeholder participation. On the basis of the results of the Interpretative structural modeling analysis, a water pollution control policy model is obtained.

CONCLUSIONS

The waters in the Simporo Strait have been polluted by TSS, BOD, COD and PO_4; thus, they are not suitable for use as a source of drinking water (Class I) and for the designation of recreation / tourism areas (Class II).

The carrying capacity of the waters in the Simporo strait does not support it to be used as a source of drinking water because it has been lightly polluted. Likewise, the carrying capacity of the waters in the Simporo Strait does not support its use as a place for water recreation infrastructure / facilities, because it has been lightly polluted. The carrying capacity of the waters in the Simporo Strait still supports its use as a place for cultivating freshwater fish, livestock, and water to irrigate crops, because the results of the analysis obtained the status of meeting quality standards (good condition)

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