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Research Paper

# An Analysis Of Surabaya River Carring Capacity Based On The Land-Use Differences

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**ABSTRACT**

Surabaya River has been indicated receiving a great pressure from the activities of people living and industries along the river. Currently, this river is still the major source of water supply for Water Source Department in Surabaya City ("PDAM Surabaya"). For this reason, the prediction of carring capacity in Surabaya River is needed. The ecosystem degradation is expected to decrease. The calculation is based on the differences of the existing land-use in the Surabaya watershed. The results of the load capacity demonstrate that the maximum BOD (Biologycal Oxygen Demand) and permitted BOD waste have a relatively wide tolerance span on some segments. Therefore, it takes a long time to reach critical points and positions on some segments. However, the maximum tolerance of BOD load and BOD of waste permitted in the dry season is lower than in the rainy season. Briefly, excessive waste disposal must be controlled to create a sustainable ecosystem in Surabaya River.

## 1. Introduction

As the second biggest city in Indonesia, the city of Surabaya is crossed by the Surabaya River which is a Brantas river basin. As the main river that passes through the city, downstream Surabaya has two parts, i.e Kali Mas dan Kali Wonokromo  At Jagir Dam, the Surabaya River is divided into the Mas River to north of the city and the Wonokromo River to east of the city. The length of the Surabaya River is about 41 km, flowing from the Mlirip Dam in Mojokerto to the Jagir Dam in Surabaya. This river actually functions as an estuary of three tributaries, i.e. Kedung Sumur, Marmoyo, and Kedurus. The first and second rivers have 99 km$^2$ and 300 km$^2$ respectively. The upstream of Marmoyo consists of the Kubuk and Mernung irrigation channels with 28 km$^2$ and 155 km$^2$ catchment areas. Meanwhile, the Kedurus River ends at Gunung Sari Dam in the Surabaya River and receives water in an area of 71 km$^2$.

Communities in the three cities (Sidoarjo, Gresik, and Surabaya) are very dependent on the Surabaya River because it is the main water source that supplies PDAMs (Regional Water Companies). The existing PDAM production capacity in Surabaya has reached 10,830 lt / sec. Production capacity of 4,250 lt / sec at Ngagel I, II, and III installations; 5,950 lt / sec at the Karangpilang I, II and III installations; 110 lt / sec in Umbulan Springs; 220 lt / sec at Pandaan Spring-water and others. Water discharge and the quality of the Surabaya River greatly have effects on the capacity of PDAMs in producing clean water.

Actually, many people live and industries operate in the Surabaya watershed. Almost all industries operating

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around this area still use Surabaya River water as a component of the production process. In addition, the Surabaya River has been used not only as a waste water disposal site for people living in watersheds, but also as a place for industrial waste disposal. Most industries operate without proper waste treatment facilities. As a result, Surabaya River has become a good place for waste disposal.

This study conducts an investigation of various land uses across the watershed which influences on carrying capacity. Investigation of river water quality is based on land use on its banks. For example in areas along the river that are used for what quality of settlements, or in what industrial areas. Furthermore, it can be predicted how much waste is dumped into the river, so that the river remains sustainable or not degraded. Therefore, the analysis of the carrying capacity inside based on different land uses across the watershed can support the importance of the Surabaya River. The result is expected as a reference for controlling river damage.

This study has been based on a survey quality of river water and wastewater, characteristics of river and river banks, land use on its banks. The measured water quality refers to several parameters, such as temperature, BOD (Biological Oxygen Demand), And DO (Oxygen Demand).

This paper is organized as follows: Literature review describes the references in the discussion to determine the carrying capacity of the river. Data collection and methodology are elaborated in Section ‘‘Methods”. Discussion Section is a description of the analysis of the phenomena found in the study. Section ‘‘Conclusions” presents conclusions and recommendations for further study.

## 1. Literature Reviews

One of the characteristics of a river is flow velocity which is approximately of 0.1 - 1 m / sec. The speed is influenced by landscape, bedrock type, and rainfall. The more complicated the landscape, the greater the size of the bedrock and the higher the rainfall results in the faster the river flow. Basically, riverbed sediments have different size and type of sediment that will influence on river water quality characteristics, water movement, and riverbed porosity.

River water quality derives from the combination of the quality of water entering the river flow and the reaction of the river passing through rock minerals. The quality of water is a system consisting of three sub-systems. The first sub-system is material passing river water, various soils and rocks depending on spatial patterns and chemical composition. The second sub-system is flow characteristics, i.e. laminar or turbulent. Meanwhile, the third sub-system is the process of changes including physical, chemical, biological processes or all processes that cause changes in water quality.

Chemistry substance of river water is not only from waste but also lithology around the river. This lithology is a source of chemicals in river water. In addition, rainwater can contribute as a source of other chemicals. Basically, river water pollutants is classified into the locations of pollutants sources, i.e. point sources and non-point sources; history of river formation; and types of pollutants such as organic pollutants, volatile pollutants, neutral pollutants, and acid pollutants.

Distribution of river pollutants from their sources will continue to decrease along with the transfer of pollutants that keep away from their sources according to self-purification of the river. It relies on the river's ability to purify itself not exceed the threshold of the river's ability to purify naturally. Purification process depends on time, distance, type of pollutant, and the physical condition of the river. Several other factors, such as flow, time, downstream movement, air temperature, and aeration also influence the purification process. This requires filtering, sorption, chemical processing, decomposition and dilution.

The ability of a river to purify itself is determined by the river pollution load capacity. There are two main processes in the phenomenon of self-purification, i.e. deoxygenation and atmospheric reaeration. The assumption for this process is the same river cross section along the flow, constant velocity, the same oxygen and BOD concentration values in lateral or vertical directions for all river cross sections. Meanwhile, the effects of algae and sludge are neglected and the velocities of deoxygenation and reaeration are constant. In the analysis, wastewater entering the river is distributed equally to all river cross sections. Such conditions cannot be achieved at the point of disposal. However, this assumption can be fulfilled by wastewater flows to downstream.

Several studies related to environmental capacity of river conducted by Lu et al (2017), Ayandiran et al (2017), Gupta et al (2017). The first research is investigated in Huai'an City in the Huaihe watershed (Lu et al, 2017). This study aims to calculate the supporting capacity of river environment from 2005 to 2014 applying the Analytic Hierarchy Process (AHP) method. The results reveal that social factors significantly influence the supporting capacity of river environment with relatively consistent changes. The number of populations and urbanization rate are the main pressure on water environmental capacity in Huai'an City.

TA Ayandiran, OO Fawole, and SO Dahunsi (2017) conducted a study to build a water quality database in the Oluwa River, Southwest Nigeria, from April 2011 to March 2012. They proved that all physical parameters have not exceeded the Nigerian Industrial Standards (NIS) for water drinks. All heavy metals are above the level permitted by NIS and WHO standards for drinking water. In addition, all chemical parameters observed in the dry season are completely different from those in the rainy season, except BOD.

In 2017, Nidhi Gupta, Pankaj Pandey, and Jakir Hussain conducted a study in the Narmada River, Madhya Pradesh state. They show that water quality is very good in the dry and rainy season. Unfortunately, poor water quality for drink occurs during the rainy season. This condition occurs due to poor sanitation, turbulent flow, soil erosion, and relatively high anthropogenic activity.

In contrast to previous studies, Richa Bhardwaj, Anshu Gupta, and J.K. Garg (2017) conducted a study to investigate heavy metal pollution in the Yamuna River, Delhi in December 2013 - August 2015. They found that the average high concentration of all heavy metals was Fe> Cu> Zn> Ni> Cr> Pb> Cd. This study also proves that the Najafgarh and Shahdara disposal channel are considered as two potential sources responsible for heavy metal contamination in the Yamuna River.

Meanwhile, Carolien Kroeze, Silke Gabbert, Nynke Hofstra, et al (2016) provides a mathematical model to simulate the flow of pollutants from land to sea in global scale. A multi-pollutant modelling approach is used to understand and to manage problems related to water quality. On the one hand, pollutants often come from many sources with many effects. On the other hand, the existing spatial models generally focus on one type of pollutants. Therefore, a new model is needed to analyse the combination of pollutants that influences surface water. The model can serve as an integrated basis for assessing the quality and quantity of water.

S. Barinova, Na Liu, Jiyang Ding, et al. (2016) conducted an ecological analysis of 77 phytoplankton species preferences in Songhua. This analysis aims to assess the dynamics of river water quality with biological indicator methods. The results show that algae community structure and species abundance change in line with increasing the total of species and community productivity. Algae diversity is strongly influenced by aquatic nutrition as the main variable, especially phosphate and nitrate concentrations. Water quality changes dramatically from Class III with low pollutants at the top station, while Class IV and V are polluted at the bottom station

Insufficient studies about prediction of how much waste is dumped into the river. Here with, this study will be as a benchmark for how much waste can be discharged into the river. The river water is not polluted and can be utilized by the people living on its banks and The water supply for Water Source Department in Surabaya City (PDAM).

## 2. Methods

Data is collected by investigating river characteristics in the field. Data consists of river dimensions, flow velocity, and discharge. These data will be analyzed in the chemistry laboratory.

Data obtained from 24 river water samples and 8 wastewater samples. On one hand, 24 water samples were collected from 12 sample collection stations in two seasons. Each station consists of 1 sample of river water in the dry season and 1 sample in the rainy season. On the other hand, 8 wastewater samples were only collected from 4 stations where each sample was collected at the end of the rainy season and at the height of the dry season. The measured water quality refers to several parameters, such as temperature, BOD (Biological Oxygen Demand) and DO (Oxygen Demand). In addition, primary water quality data is also compared to secondary data generated from water quality monitoring conducted by Tirta I Malang Public Company.

## 3. Results and Discussions

Measurements at the end of the rainy season show that the average speed in the upstream of Surabaya river is relatively greater than in the downstream because the maximum speed reaches 112.35 cm / sec. The average velocity reduces when the river body becomes narrower

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and the direction of the flow is winding upstream and moving straight downstream. The average downstream flow rate decreases because the water hyacinth plants inhibit the flow. In addition, the maximum average discharge of the Surabaya River can be seen at Gunung Sari Station. Meanwhile, measurements at the peak of the dry season is found that the average velocity of the river flow was 63.99 cm / sec in the average discharge of 23.18 $m^3$ / sec. Muara Kali Tengah Station has the


**Fig. 1.** Locations of sample collection and distribution of measurement segments in Surabaya River.

highest average flow rate, while Kali Anyar Station has the lowest flow rate.

At the end of the rainy season, measurements show that all BOD values at all measurement stations are still below the quality standard, except those at Kali Anyar and Karang Pilang stations. They also show that DO values continue to decline from upstream to downstream of the Surabaya River, even though they do not decline consistently. At upstream, the DO value is relatively good, not more than 5. Thus, the ecosystem in upstream Surabaya is relatively better than downstream. Field observations also support this finding that community activities put intensively pressure on downstream of Surabaya River. Various types of land use and the high number of people living at downstream in Surabaya River show tremendous pressure on downstream water quality, as seen in Fig. 1.

The average BOD measured at the peak of the dry season at the Sungai Marmoyo, Perning, Gunung Sari and Joyoboyo stations has exceeded the quality standard threshold. In contrast, the average DO value in upstream Surabaya is still relatively better than downstream.

Secondary data report that the average discharge at the Mlirip gate of measurement station reaches 20.07 $m^3$ / sec. Meanwhile, the average flow rate at Gunung Sari and Perning is 26.01 $m^3$ / sec and 43.96 $m^3$ / sec respectively. At the end of the rainy season, the Surabaya River discharge is 23 $m^3$ / sec. Basically, the average discharge of the Surabaya River is around 20 $m^3$/ sec - 50 $m^3$ / sec. From secondary data, the average DO values in upstream Surabaya River are relatively better than downstream. Most of the Surabaya River BOD averages are below the quality standard except some parts of the river due to many people's activities, especially in the industrial area at river banks.

This finding also shows that the largest population, homes, and companies around the Surabaya watershed are in Surabaya City, compared to other cities crossed by the Surabaya River. This condition is caused the use of intensively the watershed and river bodies of Surabaya with 35 types of land use as clarified in Table1- Table 3.

To determine the loading capacity, the Surabaya River is divided into several segments based on the direction of river flow to downstream. In one segment, the quality of the first river water is assumed as an input for the quality of the second river water. In the next segment, the results of mixing these two rivers will be input for the third river and so on. Thus, the formation of pollution load capacity will be carried out sequentially based on the downstream direction of Surabaya River.

The Surabaya load capacity illustrates that some segments have a maximum BOD load and permitted BOD waste within a relatively large tolerance range. In addition, the time to reach the critical point and the position of the critical point itself are also relatively large. However, the tolerance for maximum load of BOD and BOD waste permitted at the peak of the dry season are relatively smaller compared to at the end of the rainy season.

## 4. Conclusion

The conclusions from the results of the analysis of the pollution load capacity in the Surabaya River are as follows:

a. Measurements show that the average DO in the dry season is greater than in the rainy season. In addition, the DO value of secondary data is greater than the data obtained from the measurements. The BOD values is opposite with the value for DO.
b. DO values decrease from upstream to downstream of the Surabaya River. This phenomenon is measured at the end of the rainy season and at the height of the dry season. Thus, the ecosystem in

upstream of Surabaya River is relatively better than downstream. This condition is caused by more intensive downstream pressure than in the upstream area. The various types of land use and the total number of people living on the downstream of Surabaya River are pressures on Surabaya River.

c. The results of loading capacity in the Surabaya River show that the maximum load of BOD tolerated and BOD waste permitted at the peak of the dry season is smaller than the value at the end of the rainy season. Therefore, excessive waste disposal must be controlled to sustain the Surabaya River ecosystem.

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**Table 1.** Wastewater quality on Land Use Zone Group 01

| Company code L1.1 | | | | | Company code L1.2 | | | | |
|---|---|---|---|---|---|---|---|---|---|
| No | Parameter | Unit | Standard | Results | No | Parameter | Unit | Standard | Results |
| 1 | BOD | mg/l | 70,00 | 69,87 | 1 | BOD | mg/l | 70,00 | 30,55 |
| 2 | COD | mg/l | 150,00 | 121,26 | 2 | COD | mg/l | 150,00 | 52,00 |
| 3 | TSS | mg/l | 70,00 | 28,00 | 3 | TSS | mg/l | 70,00 | 9,00 |
| 4 | Pb | mg/l | 0,10 | 0,00 | 4 | Pb | mg/l | 0,10 | 0,00 |
| 5 | pH | - | 6-9 | 7,16 | 5 | pH | - | 6-9 | 7,80 |
| Company code L1.3 | | | | | Company code L1.4 | | | | |
| No | Parameter | Unit | Standard | Results | No | Parameter | Unit | Standard | Results |
| 1 | BOD | mg/l | 70,00 | 68,44 | 1 | BOD | mg/l | 50,00 | 27,40 |
| 2 | COD | mg/l | 150,00 | 118,00 | 2 | COD | mg/l | 100,00 | 48,00 |
| 3 | TSS | mg/l | 70,00 | 16,00 | 3 | TSS | mg/l | 200,00 | 22,00 |
| 4 | Pb | mg/l | 0,10 | 0,00 | 4 | Zn | mg/l | 10,00 | 0,08 |
| 5 | pH | - | 6-9 | 7,71 | | | | | |
| Company code L1.5 | | | | | Company code L1.6 | | | | |
| No | Parameter | Unit | Standard | Results | No | Parameter | Unit | Standard | Results |
| 1 | BOD | mg/l | 60,00 | 58,00 | 1 | COD | mg/l | 100,00 | 41,00 |
| 2 | COD | mg/l | 100,00 | 98,00 | 2 | TSS | mg/l | 50,10 | 22,00 |
| 3 | TSS | mg/l | 50,00 | 49,00 | 3 | TDS | mg/l | 1500,00 | 1350,00 |
| 4 | Fat liquid | mg/l | 5,00 | 0,16 | 4 | pH | - | 6-9 | 8,19 |
| 5 | Sulfide ($H_2S$) | mg/l | 0,50 | 0,10 | | | | | |
| 6 | pH | - | 6-9 | 7,72 | | | | | |

Note:

a. Land Use Zone Group 01 is an area with residential land use, the waste analyzed is domestic waste

b. Land Use Area Group 02 is an area with industrial land use areas that already have WWTP (Wastewater Treatment Plants) with good environmental performance

c. Land Use Zone Group 03 is an area with industrial area land use that has not had WWTP (Wastewater Treatment Plant) with poor environmental performance.

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**Table 2.** Wastewater quality on Land Use Zone Group 02

Company code L2.1

| No | Parameter | Unit | Standard | Results |
|---|---|---|---|---|
| 1 | BOD | mg/l | 80,00 | 24,71 |
| 2 | COD | mg/l | 150,00 | 40,00 |
| 3 | TSS | mg/l | 60,00 | 15,00 |
| 4 | $NH_3$-N | mg/l | 5,00 | 2,03 |
| 5 | pH | - | 6-9 | 7,46 |

Company code L2.2

| No | Parameter | Unit | Standard | Results |
|---|---|---|---|---|
| 1 | BOD | mg/l | 100,00 | 96,11 |
| 2 | COD | mg/l | 200,00 | 178,00 |
| 3 | TSS | mg/l | 100,00 | 98,00 |
| 4 | Fat liquid | mg/l | 30,00 | 6,68 |
| 5 | pH | - | 6-9 | 7,72 |

Company code L2.3

| No | Parameter | Unit | Standard | Results |
|---|---|---|---|---|
| 1 | BOD | mg/l | 50,00 | 12,22 |
| 2 | COD | mg/l | 100,00 | 21,00 |
| 3 | TSS | mg/l | 30,00 | 6,00 |
| 4 | Fat liquid | mg/l | 6,00 | 0,00 |
| 5 | pH | - | 6-9 | 7,98 |

Company code L2.5

| No | Parameter | Unit | Standard | Results |
|---|---|---|---|---|
| 1 | BOD | mg/l | 70,00 | 67,00 |
| 2 | COD | mg/l | 150,00 | 112,20 |
| 3 | TSS | mg/l | 70,00 | 38,00 |
| 4 | Pb | mg/l | 0,10 | 0,00 |
| 5 | pH | - | 6-9 | 6,95 |

Company code L2.4

| No | Parameter | Unit | Standard | Results |
|---|---|---|---|---|
| 1 | COD | mg/l | - | 22,00 |
| 2 | BOD | mg/l | - | 38,00 |
| 3 | TSS | mg/l | 100,00 | 11,00 |
| 4 | Cr | mg/l | 1,00 | 0,19 |
| 5 | Ni | mg/l | 0,50 | 0,08 |
| 6 | Zn | mg/l | 15,00 | 0,09 |
| 7 | Mn | mg/l | 5,00 | 0,11 |
| 8 | Cd | mg/l | 0,10 | 0,00 |
| 9 | Pb | mg/l | 1,00 | 0,00 |
| 10 | pH | - | 6-9 | 7,5 |

Company code L2.6

| No | Parameter | Unit | Standard | Results |
|---|---|---|---|---|
| 1 | BOD | mg/l | 75,00 | 26,05 |
| 2 | COD | mg/l | 180,00 | 44,00 |
| 3 | TSS | mg/l | 60,00 | 7,00 |
| 4 | Fat liquid | mg/l | 15,00 | 1,99 |
| 5 | Phosphate ($P_2O_4$) | mg/l | 10,00 | 1,13 |
| 6 | Detergent (LAS) | mg/l | 30,00 | 3,26 |
| 7 | pH | - | 6-9 | 7,51 |

**Table 3.** Wastewater quality on Land Use Zone Group 03

Company code L3.1

| No | Parameter | Unit | Standard | Results |
|---|---|---|---|---|
| 1 | BOD | mg/l | 150,00 | 290,00 |
| 2 | COD | mg/l | 300,00 | 496,00 |
| 3 | TSS | mg/l | 100,00 | 215,00 |
| 4 | CN | mg/l | 0,20 | 0,00 |
| 5 | pH | - | 6-9 | 7,5 |

Company code L3.3

| No | Parameter | Unit | Standard | Results |
|---|---|---|---|---|
| 1 | BOD | mg/l | 100,00 | 50,00 |
| 2 | COD | mg/l | 350,00 | 88,00 |
| 3 | TSS | mg/l | 250,00 | 13,00 |
| 4 | Fat liquid | mg/l | 0,25 | 0,00 |
| 5 | Ammonia Total ($NH_3$-N) | mg/l | 20,00 | 0,12 |
| 6 | pH | - | 6-9 | 7,9 |

Company code L3.2

| No | Parameter | Unit | Standard | Results |
|---|---|---|---|---|
| 1 | BOD | mg/l | - | 21,00 |
| 2 | COD | mg/l | - | 36,00 |
| 3 | TSS | mg/l | 20,00 | 219,00 |
| 4 | CN | mg/l | 0,20 | 0,00 |
| 5 | $Cr^{+6}$ | mg/l | 0,10 | 1,16 |
| 6 | Cr total | mg/l | 0,50 | 1,56 |
| 7 | Cu | mg/l | 0,60 | 0,37 |
| 8 | Zn | mg/l | 1,00 | 0,37 |
| 9 | Ni | mg/l | 1,00 | 1,13 |
| 10 | Cd | mg/l | 0,05 | 0,08 |
| 11 | Pb | mg/l | 0,10 | 0,03 |
| 12 | pH | - | 6-9 | 7,63 |

Company code L3.4

| No | Parameter | Unit | Standard | Results |
|---|---|---|---|---|
| 1 | BOD | mg/l | 50.00 | 8750,00 |
| 2 | COD | mg/l | 150,00 | 14800,00 |
| 3 | TSS | mg/l | 50,00 | 224,00 |
| 4 | Phenol | mg/l | 1,00 | 0,69 |
| 5 | Crom | mg/l | 1,00 | 1,24 |
| 6 | Fat liquid | mg/l | 3,60 | 12,00 |
| 7 | Ammonia Total ($NH_3$-N) | mg/l | 8,00 | 4,77 |
| 8 | Sulfide ($H_3S$) | mg/l | 0,30 | 0,26 |
| 9 | pH | - | 6-9 | 4,65 |