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Regional Case Study

Pollution Load Analysis of Wonokromo River with Program System Dynamics (STELLA)

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Abstract

Population growth, the increase in the industrial sector and the presence of waste from activities that haven't been treated properly can make a water river being contaimined high pollutants. The pollutant parameters identified is Total Suspended Solid (TSS), Biological Oxygen Demand (BOD), Chemical Oxygen Demand (COD), Dissolved Oxygen (DO) and E.Coli. One of the polluted rivers is Wonokromo River which is located in Surabaya City, according from monitoring results Balai Besar Wilayah Sungai (BBWS) Brantas in 2021 the pollutant value in river with TSS is 484 mg/L, BOD is 15.96 mg/L, COD 23.91 mg/L, DO 3.67 mg/L, and E.coli 4.283 MPN/100 ml from the monitoring data included polluted category. Depectin model of water river conditions using the STELLA program. The results indicate that the water quality of the Wonokromo River is polluted with the parameters TSS, BOD and E. Coli, determination refers to Goverment Regulations number 22 in 2021 about "Implementation of Environmental Protection and Management" in clasification II for raw water. So Wonokromo River is not suitable as a source of raw water in that year and a policy scenario is needed to reduce water river pollution.

Keywords: River water quality; wonokromo River; dynamic system; STELLA

1. Introduction

Wonokromo River is one of the raw water sources used for Surabaya people as a drinking water and the river flow supports the activities of residents around the river. Water river the potential to contain high pollutants caused by domestic, non-domestic and industrial activities. The condition of water river based on the results of Yudo and Said's research in 2019, describes the condition of the river water in poor condition, the results of the study state that the Wonokromo River has two parameters that do not meet the standards is BOD and COD parameters. According to Karnaningroem (2018), the pollutant parameters identified is Total Suspended Solid (TSS), Biological Oxygen Demand (BOD), Chemical Oxygen Demand (COD), Dissolved Oxygen (DO) and E.Coli. This assumption is reinforced by the results of the monitoring of the Balai Besar Wilayah Sungai (BBWS) Brantas in 2021 that the pollutant value of the Wonokromo River with TSS is 484 mg/L, BOD is 15.96 mg/L, COD is 23.91 mg/L, DO is 3.67 mg/L, and parameter E.oli is 4.283 MPN/100 ml, this shows that water river has been polluted. Wonokromo River also used as raw water in filling PDAM Surya Sembada Surabaya City, that's why this river included in the category of class II raw water quality standards based on Government Regulations number 22 in 2021 about "Implementation of Environmental Protection and Management" The main impact of pollutants in water river to environmental damage for the example can triggers high temperatures which is can make the oxygen content in the water to decrease, can make increasing the sedimentation process at the bottom of the river, increasing organic waste in water river and also health problems for people who use water river (Arisandi, 2004).

In general condition of the river in the results from previous studies, it's necessary to assess the quality of water river in the current condition. In this case pollution of water river is complex and dynamic because the elements in it experience symptoms of transport and transformation, inputs that enter to the river can vary in each time according Qin et al., in 2007. The Dynamic System method will be used in this study because according to Muhammadi in 2001, the dynamic system can understanding the complex problems of variables that are interrelated and changing with time or dynamically. The dynamic system will be a analysis method that uses basis calculating pollutant load of waste in water river, with the output a water river behavior in current conditions for few years. The purpose this article is to analyzing the water of Wonokromo River with pollutant parameters, namely TSS, BOD, COD, DO and E.Coli, then processed water river quality data using the Dynamic System method to obtain an assessment of water river quality for the feasibility of raw water sources.

2. Methods

2.1. Research Sites

The research will be conducted in the Wonokromo River located in the Surabaya City. This river flows for approximately 3 km from upstream (Jagir Wonokromo Street) to downstream (Nginden Bridge). The following in **Figure 1**. is a map of the river.

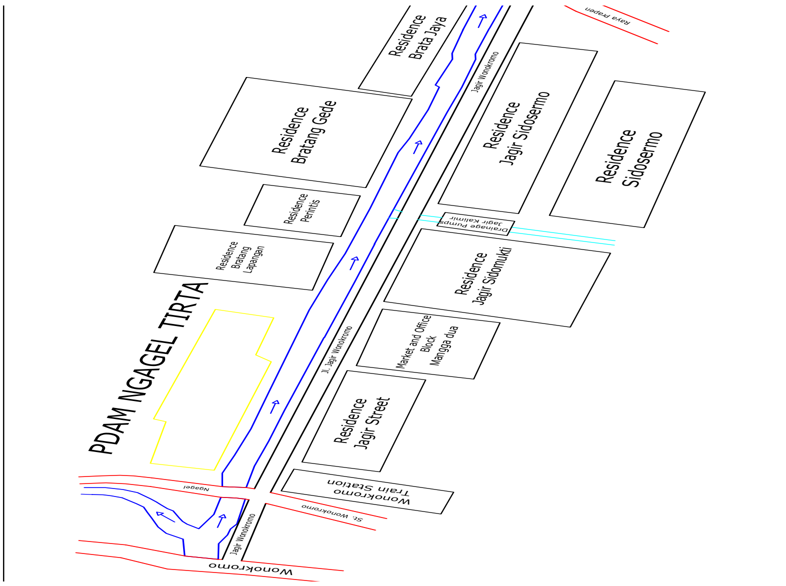

Figure. 1 Wonokromo river flow map

River water analysis research will be divided into 3 segments for sampling step. Determination of sampling points make that's more easier for sampling step of river water. The distribution of location points according from Regulation Minister of Environment and Forestry number No. 01 in 2007 about "Guidelines Technical Assessment for Class Water", research sampling points is determined by clusteration of pollution-producing areas (waste) or point sources. The purpose of taking water samples as a material analyzing river water quality, the sample will be tested for pollutant levels in accordance with predetermined parameters.

1. Segment 1

Segment 1 is located at the Water Gate Jagir to the Wonokromo River (Jagir Wonokromo Street) before the PDAM Ngagel Tirto drain outlet. Located at latitude 7°18'2.21"S and longitude 112°44'28.18"S. The length of the segment is 725 meters, has an average river width of 56 meters and the depth of the river reaches 2.90 m. The river flow has a speed in 0.14 m/s and an average flow rate in 16.30 L/s. This segment is the upstream of the Wonokromo River.

2. Segment 2

Segment 2 is located after the PDAM Ngagel Tirto drain outlet to the Jagir Kalimir drainage outlet. Located at latitude 7°18'7.14"S and longitude 112°44'50.71"S. The length of the segment is 765 meters, has an average river width of 63 meters and the depth of the river reaches 2.70 m. The river flow has a speed in 0.12 m/s and an average flow rate in 16.10 L/s.

3. Segment 3

Segment 3 is located after the Jagir Kalimir drainage outlet to the Prapen Bridge. Located at latitude 7°18'13.49"S and longitude 112°45'10.23"S. The length of the segment is 1,360 meters, has an average river width of 60 meters and the depth of the river reaches 2.50 m. The river flow has a speed in 0.11 m/s and an average flow rate in 15.94 L/s.

2.2. Data Collection

The research was conducted in several stages, have two data there is primary data and secondary data. Primary data from river water quality tests, meanwhile secondary data is supporting research data that's the Wonokromo River map, river hydraulics data, previous river water quality data and population growth data. The purpose of this data collection is as material for analysis of river water models that cover all variables from a technical and technical point of view.

1. Primary data

In this study, primary data is the existing data of the Wonokromo River, which includes the existing condition of the river environment, the hydraulics of the river water and the cross-sectional size of the river. The purpose of collecting primary data is to obtain data on the current condition of river water which can describe the physical, chemical and biological properties as the basis of research.

Primary data is collecting from field survey activities and water river sampling. Sampling of water river carried out from upstream to downstream of the river. Determination of sampling points based on waste water point sources, the results from field survey determined 3 sampling points. Technically, sampling is taken simultaneously in the two peak hours of wastewater discharge in the morning and evening. Sampling is ideally carried out in the dry season and the rainy season. However, in this study the sampling was taken only in the dry season, while in the rainy season using secondary data. Sampling of river water is in accordance with the standard of SNI 6989.57:2008 about "Water and Waste Water" regarding the method of sampling surface water. The method used is Grab Sampling, samples taken directly from river water bodies.

Furthermore, the sample will be analyzed for water quality on a laboratory scale. The purpose of this analysis is to determine the levels of pollutants in river water. The parameters used as research indicators were TSS, BOD, COD, DO and E.Coli.

2. Secondary Data

In this study, secondary data is data supporting research in the form of technical and non-technical data. Technical data are river water quality data and river water hydraulics in the dry season and rainy season, while non-technical data are river maps, Master Plans Spatial City and population growth data around rivers. The purpose of adding this secondary data as data related variables that support research analysis.

2.3. Data Analysis

The data analysis step was carried out to compare the test results with the designated water river standards. An analysis approach was carried out with manual calculations and simulation of the water river model at 3 predetermined points. Manual calculation analysis is calculation of wastewater pollutant that enters river water, while a water river model simulation is in the form of dynamic system analysis to determine river water behavior.

1. Determination of Waste Pollutant Load

River water that has indicated pollution, requires a calculation step to determine the condition of river water. Calculation analysis uses data that has been collected, then processed in calculating the pollutant load of wastewater. Calculation of the pollution load using the direct calculation method (Rapid Assessment), data using on wastewater discharge and pollutant levels. The following is the formula for calculating the pollutant load based on Mitsch & Goesselink (1993) in Appendix II of the Regulation Minister of Environment and Forestry number 1 in 2010 about "Water Pollution Control".

$$BP = Qi \times C \times f$$

Information:

BP = Pollution load originating from the source (kg/day)

Q = discharge of waste water or river water (m^3 / second)

ci = concentration of the parameter (mg/Liter)

f = conversion factor (86.4)

2. Dynamic System

Problem solving in the research will be analyzed using the dynamic system method. In the analysis, a model for depicting river water will be made by including a pollutant reduction scenario. Here are the steps for modeling.

1. Big Picture Mapping
   At the beginning of the research, it is necessary to limit the problem. In the dynamic analysis method, the problem limitation is carried out by drawing a frame of mind, namely Big Picture Mapping. The Big Picture Mapping on model water river which illustrates the focus of this research is pollutants load. Pollutants generated by the activities of residents both from the domestic, economic, industrial and office sectors in the area around the river basin, cause that's an impact on the quality of water river. Improving quality of water river will be carried out by creating people behavior scenarios and government policy scenarios.
2. Cause and Effect Diagram (Casual Loop Diagram)
   Casual Loop diagram will show the relationship between variables in the study. The Casual Loop diagram in this research illustrates the existing condition of the Wonokromo River which has been adjusted to its flow value, the diagram depicts the input variables (+) and output variables (-). In the river water dynamic system model the input variable (+) is an uncontrolled variable, originating from an increase in the population whose activities cause a decrease in river water quality and for the output variable (-) is the desired variable, namely a decrease in river water pollutant load resulting in good quality.
3. Dynamic System Diagram (Stock and Flow Diagram)
   This diagram will describe the flow in a problem model, consists of two systems namely "Stock" is river water and flow is contains pollutants. Dynamic system diagrams or Stock and Flow Diagrams consist of technical aspects and non-technical aspects. Technical aspects will be included in the simulation model, consisting of variables that affect river water quality. Variables of water quality are pollutant parameters, namely parameters of TSS, BOD, COD, DO, and E. Coli substances. Variables of river water quantity and continuity are river water hydraulics, deoxygenation and re-aeration
4. Model Verification and Validation
   The verification and validation steps of the model are needed to ensure that the model is in accordance with the existing conditions. The model validation test in this research uses the calculation of the Pollutant Index (IP) value, where this calculation will compare the simulation model with the existing conditions of river water. The difference in the deviation value is set at a maximum of 10%.

The data is simulated into a dynamic system model using the STELLA 9.1.3 program. The simulation model will include policy scenarios for reducing river water pollution substances, in the form of technical, non-technical and regulatory policies that are expected to improve river water quality. The river water model that has been simulated is then processed with an analysis of river water quality assessment based on the calculation of the pollutant index as a validation step.

3. Results and Discussion

Wonokromo River was chosen as the research location based on the results of field analysis where the condition of water river is not feasible as a source of raw water and the needs of the surrounding community. River water quality is the biggest highlight in this study where it's the main parameter in the use of river water as raw water. The research will process the data that has been collected from primary and secondary data.

The results of the field research show that the river water of the Wonokromo River is not suitable to be used as source of raw water. Based on the parameters that have been determined as pollution indicators, there are parameters that exceed the quality standard values. The following in **Table 1**. are the results of the existing water quality of the Wonokromo River

Table 1. Wonokromo river water quality (existing)

No	River Segment	TSS	BOD	COD	DO	E. Coli
		mg/L	mg/L	mg/L	mg/L	MPN/100ml
1	Segment 1	685	17.5	37.5	1.76	900
2	Segment 2	504	33.5	74.5	4.76	1500
3	Segment 3	481	40	87.5	1.4	2000

Source: Field survey results

The calculation of waste water that enters the river is calculated using the value of the average consumption of drinking water community around the river flow. From the secondary data, the people of Surabaya City uses water as much as 252.6 Liters/person/day where that amount will be multiplied by 80% as waste water, then amount of waste discharged into the river is 283,58 m^3/day. This amount will then multiplied by the pollutant parameter values and entered into the model simulation.

The water quality data and other supporting data are then processed using the dynamic system analysis method. This method was chosen in this study because it can provide a conceptual description of the river water system model. Preparation of simulation model is made on the basis of two main techniques, the first using a mathematical and statistic approach, secondly using a quantitative approach with time series models and dynamic models (casual method) according from Gilad (2003)

According to Satria (1994) the simulation model can be separated into two prediction times, namely short term predictions and long-term predictions. predictions in the short term are used as guidelines for future planning, while predictions in the long term are used for detailed handling and strategy formulation. This research has limited scope to make a water river simulation model that only describes the existing or just in one day. then all units used will be calculated in a special unit that directs to the results for one day.

The method is applied with model restrictions in the form of Big Picture Mapping (BPM), then proceed with making Casual Loop diagrams and making Stock and Flow diagrams. The limitation of the model is done so that the research does not get out of the discussion and becomes the focus of the research.

a. Big Picture Mapping

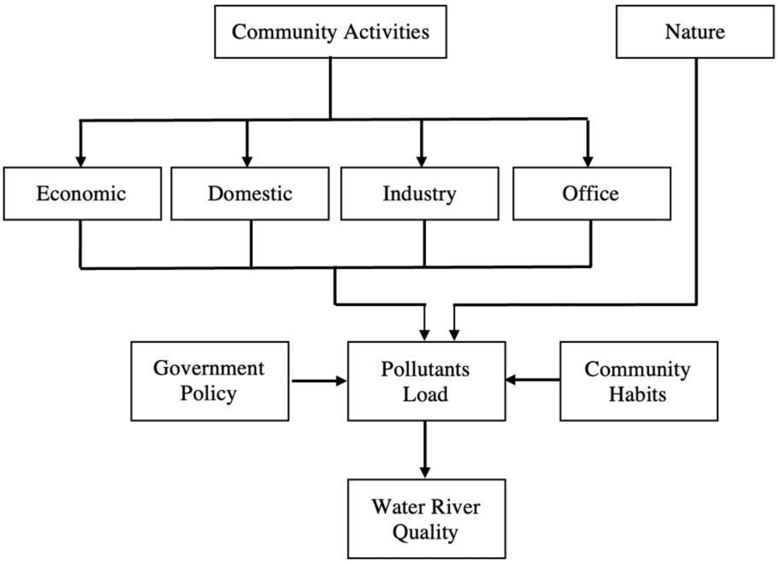

Figure 2. Big picture mapping

The picture above is a Big Picture Mapping model of river water which illustrates the focus of this research. The focus leads on waste disposal generated by residents' activities from the domestic, economic, industrial and office sectors in the area around the river, causing an increase in pollutant loads and impacting on water quality descending river. Improvement of river water quality will be carried out by making scenarios of population behavior and government policy scenarios.

b. Casual Loop Diagram

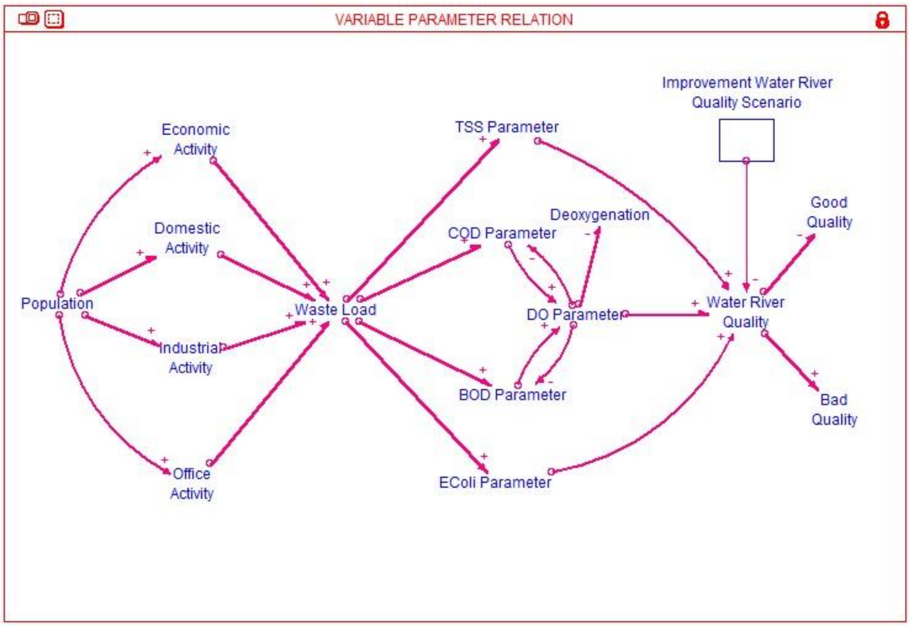

Figure 3. Casual loop diagram

The Casual Loop diagram in this study describes the existing condition of the Wonokromo River which has been adjusted to its flow value, the diagram describes the input variable (+) and the output variable (-). In the dynamic system model of river water, the input variable (+) is an uncontrollable variable, originating from the increase in the number of people whose activities cause a decrease in river water quality and for the output variable (-) is the desired variable, namely a decrease in the pollutant load of river water which results in better water quality good.

c. Stock and Flow Diagrams

Dynamic system diagrams or Stock and Flow Diagrams consist of technical aspects and non-technical aspects. Technical aspects will be included in the model simulation, consisting of variables that affect river water quality. Variables of water quality are parameters of pollutant substances, namely parameters of TSS, BOD, COD, DO, and E. Coli substances. The variables of river water quantity and continuity are river water hydraulics, deoxygenation, reaeration and natural effect. From the simulation of a dynamic system model based on technical variables, it will produce a behavior of river water pollutants and river water quality. The following in **Figure 4**. to **Figure 6**. are simulations of the dynamic system model of the Wonokromo River.

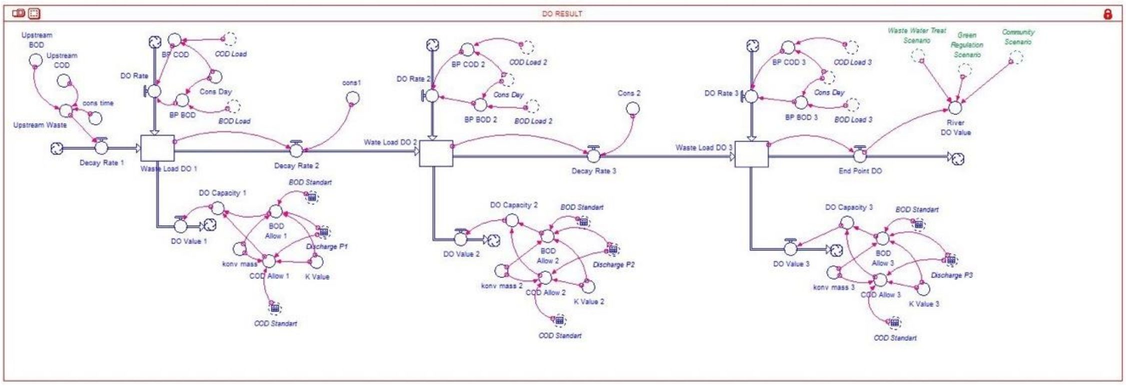

Figure 4. BOD, COD and DO dynamic system model simulation

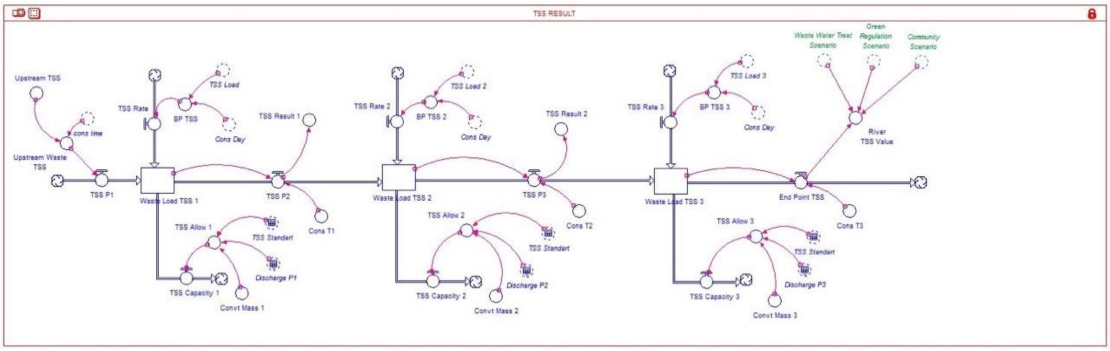

Figure 5. TSS dynamic system model simulation

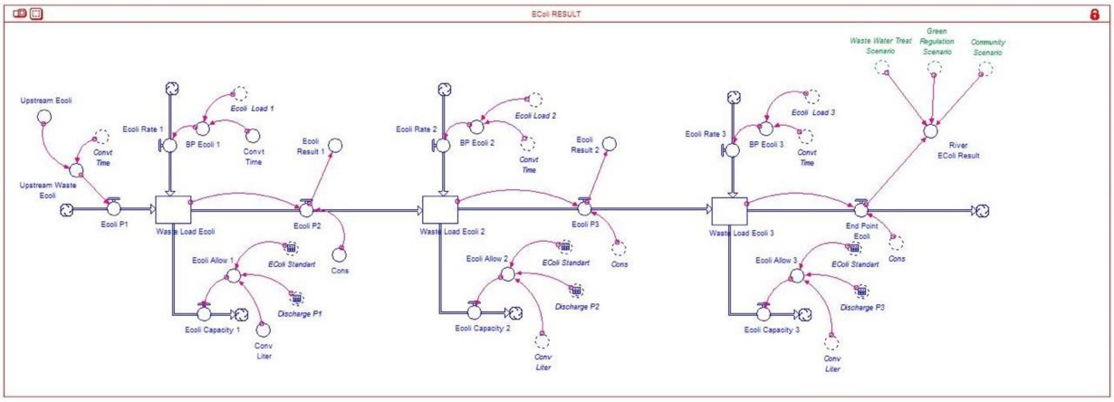

Figure 6. E. Coli . system dynamics model simulation

The dynamic system model that has been created is used to predict the value of the water quality of the Wonokromo River in the existing condition. The model is an existing description the behavior of river water pollutants, namely the parameters TSS, BOD, COD, DO and E.Coli whose formulation has been adjusted to the calculation of the pollutant load of river water. The following is a table of model simulation results listed in **Table 2**.

Table 2. Wonokromo river model simulation results

No	Parameter	Quality standards	Result Value	Unit	Information
1	TSS	50	252.7	mg/L	Exceed
2	BOD	3	4.08	mg/L	Exceed
3	COD	25	10.32	mg/L	Sufficient
4	DO	>4	4.79	mg/L	Sufficient
5	E. Coli	5000	6.023	MPN/100ml	Exceed

Source: research analysis results

From the analysis of the dynamic system model as in the table above, it is stated that the water quality of the Wonokromo River has been polluted, there are several water quality parameters that exceed the class II quality standards from regulation Government Regulations number 22 in 2021 about "Implementation of Environmental Protection and Management" in classification II for raw water, there are is TSS, BOD and E.Coli parameters.

The TSS parameter is high value which can be caused by the large amount of organic waste was entering to the water river from domestic waste and can also be estimated to be high soil erosion because they using a drainage pumps around the river. The high value of BOD parameter indicates that organic waste dominates pollution which can be caused by domestic waste discharged into river water, it can also be caused by the slow speed of river water, which causes the ability of river water to degrade to be small. The E.coli parameter has a high value because of the habit of the people disposing of domestic waste, especially black water and gray water directly into the river without any prior treatment, this is a bad habit for the community.

Verification on this model will be carried to ensure that the model was created is accordance with the intended model. This step is checking any formulation model (calculation formulas) and variable units (units) in the model. Verification model in this article is automatically use model simulation with the STELLA program, where this program will be able to run when all the formulations and units are correct.

Model validation step in analyzing the quality status of river water quality, it is necessary to calculate with Pollutant Index (IP) formulation as a proof of the model. The pollution index method will compare the pollutant parameter value with the quality standard used. The results of the calculation of the pollutant index in the Wonokromo River are presented in **Table 3**. The result it shows that along the Wonokromo River are different, here is the equation for the calculation of the pollution index formula

Table 3. IP Value of Wonokromo river dynamic system model

No	Parameter	Score IP	Information
1	TSS	5.24	Medium Polluted
2	BOD	1.67	Lightly Polluted
3	COD	0.41	Meet Quality Standard
4	DO	0.95	Meet Quality Standard
5	E. Coli	4.50	Medium Polluted
Average IP		2.55	Lightly Polluted
Maximum IP		5.24	Medium Polluted

Source: Research analysis results

Referring to the results, status of water river is currently lightly polluted to medium polluted. There needs to improvement quality of water river. There are various options or scenarios in order to reduce the pollution, both from a technical and non-technical perspective.

a. Technical Scenario
   This scenario is very efficient; we can create environmental buildings such as Waste Water Treatment Plants (WWTP) which can manage waste pollutants from community activities, domestic and non-domestic.
   From the estimation of the types of waste and the calculation of removal efficiency, wastewater treatment can use technology in the form of biological treatment in the form of anaerobic treatment, because waste is dominated by domestic products.
b. Non-Technical Scenario

Non-technical steps can be carried out in a variety of activities such as community education and community empowerment at the community level around the river basin. There are also steps to work with the government or related stake holders to make a regulation or policy in the management of Wonokromo River.

4. Research Conclusion

Based on the discussion result of the research above, the conclusions in this study are the parameter values of Kali Wonokromo river that exceed the quality standard class II refrers from *Goverment Regulations number 22 in 2021 about "Implementation of Environmental Protection and Management"* there are TSS, BOD and E.Coli parameters. The simulation results are assessed by calculating the Pollution Index (IP) showing that the Wonokromo River is in the status of lightly polluted to medium polluted water river. Controlling of water river quality in Wonokromo River to reduce polluting waste to water river is very necessary. Controling can be solve by built waste water treatment plant (WWTP) and social regulation.

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