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The development of an action plan for the Jeneberang River pollution control based on the calculation of the total maximum daily load

B Kurniawan^{1,*}, M Komarudin² and Safrudin³

¹ Research Center for Environmental and Clean Technology, National Research and Innovation Agency (BRIN), Kawasan Puspiptek, Tangerang Selatan, Banten

² Faculty of Civil and Planning Engineering, National Science and Technology Institute, Jakarta, Indonesia

³ Directorate of Water Pollution Control, Ministry of Environment and Forestry, Kebon Nanas, East Jakarta, DKI Jakarta, Indonesia

*E-mail address: budi067@brin.go.id

Abstract. Jeneberang Watershed is one of the priority watersheds set by the Ministry of Environment and Forestry in the Sulawesi Island region and is the location of various important economic activities that contributes around 2% to the national gross domestic product (GDP). The results of water quality monitoring in 2018 and 2019 show that the average water quality status of the Jeneberang river was moderately polluted. This study aimed to develop an action plan for water pollution control derived from the calculation of the total maximum daily load (TMDL) to meet the river water quality standard. The method used in this study was the application of a numerical model of water quality combined with the spatial approach for calculating the TMDL. The calculation results indicated that the load of existing pollutants entering the Jeneberang river was 4,844.87 kg- BOD/day while the TMDL was 3,552.97 kg-BOD/day, therefore a load reduction of 1291.9 was required. Furthermore, it was necessary to reduce the water pollution load from domestic, industrial, and livestock activities by 871.37, 14.86, 337.28 kg-BOD/day, respectively, and from the combination of agriculture and built-up land by 68.39 kg-BOD/day. The action plan resulting from the development of TMDL is the construction of 122 units of communal sewage treatment plant with a budget of IDR 121.86 billion and 350 units of biodigester with a total budget of IDR 7.35 billion. Meanwhile, 46 inspectors and a budget of IDR10 billion per year are required to supervise industries. Thus, the study revealed that TMDL can be used as the basis for the development of an action plan.

Keywords: action plan; total maximum daily load; water pollution load; numerical model; spatial approach

1. Introduction

More than half of Indonesia's main rivers are classified as crucially polluted and two of the country's main river systems are known as the most polluted in the world. More than 70% of the national gross domestic product (GDP) is generated in river basins where most water samplings are considered as 'crucially polluted'. The Jeneberang Watershed is one of the priority watersheds of the Ministry of Environment and Forestry (MOEF) in Sulawesi Island and contributes around 2% to GDP [1]. It was reported as well that this area contributes around 2% to the GDP.



The results of water quality monitoring in 2018 and 2019 indicated that the average water quality status of the Jeneberang River was moderately polluted. Water quality monitoring is commonly conducted twice a year in the river using a manual monitoring system.

There are two types of river pollution sources, namely point sources and non-point sources [2,3]. If this condition is left uncontrolled, it will lead to an increase in the cost of environmental restoration. For comparison in China, from 2000 to 2015, the reduction of industrial wastewater by an average of 22.17 billion tons or 39% of the total average wastewater discharge of 56.978 billion tons resulted in a 60.41% increase in investment for wastewater treatment [4].

The latest Government Regulation on the Implementation of Environmental Protection [5] states that with regard to the Jeneberang River, the MOEF is obliged to develop total maximum daily loads (TMDL), which is defined as the highest value of water pollutant loads from polluting sources that are allowed to be discharged into the Jeneberang River.

The TMDL in the Jeneberang Watershed is needed for the formulation of programs and action plans for water quality protection and management as well as to establish the local effluent standard required in the effluent discharge permit. This study aimed to develop the TMDL and action plan for water pollution control to meet river water quality standards. TMDL in the Jeneberang River was developed for the entire river from upstream to downstream as well as for each segment.

2. Methodology

2.1. Study site

The study was carried out in the Jeneberang Watershed, which is one of the priority watersheds of the Ministry of Environment and Forestry. Jeneberang Watershed is geographically located at $5^{\circ} 9' 46.12''$ – $5^{\circ} 25' 0.67''$ South Latitude and $119^{\circ} 22' 45.13''$ – $119^{\circ} 55' 54.40''$ East Longitude. The watershed, which stretches an area of 788 km², is located on Sulawesi Island and passes through four districts namely Gowa Regency, Takalar Regency, Maros Regency, and Makassar City. The upstream watershed is in Gowa Regency and the downstream watershed is in the Makassar Strait. The main river in the Jeneberang Watershed is the Jeneberang River with approximately 80 km in length.

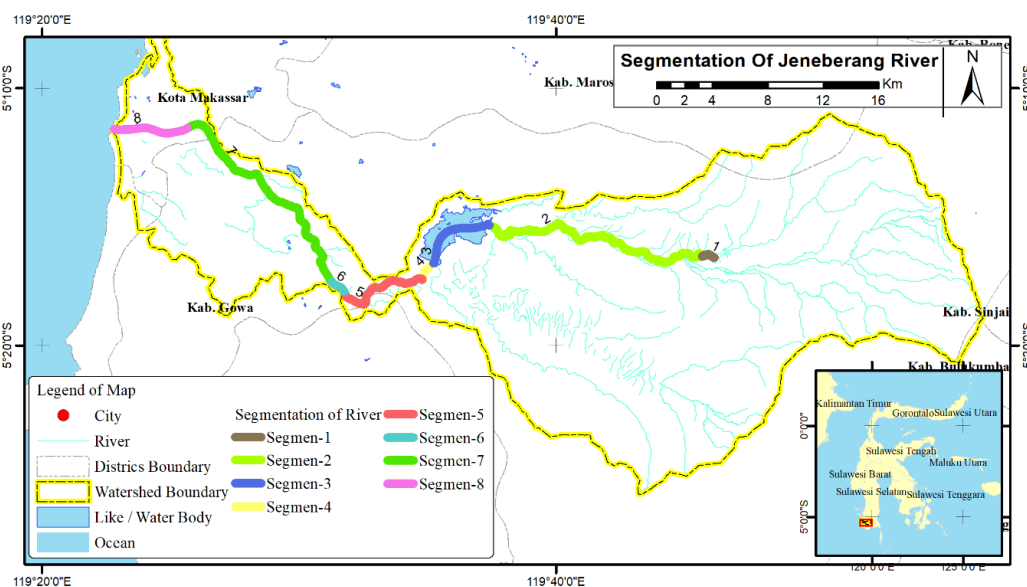


Figure 1. Map of study location.

A map of the location and segmentation of the study site can be seen in Figure 1. The determination of river segmentation in this study was mainly made based on hydrological boundaries (sub-watersheds), which also considered the homogeneity of polluting sources, both point and non-point pollutant sources,

the location of water quality monitoring points, and administrative boundaries. It was done by applying the geographical information system (GIS), which resulted in the division of the Jeneberang River into eight segments.

2.2. Total maximum daily load (TMDL)

The TMDL term was first introduced by the United State of America Environmental Protection Agency (USEPA) under the Clean Water Act for enhancing the quality of water bodies nationwide. The term TMDL served as indicating the maximum quantity of a pollutant that a water body can assimilate and still meet water quality standards [6]. This program has been applied by several countries including Indonesia.

The developed TMDL is intended to restore water quality in rivers, lakes, and estuaries and to reduce the pollution load from point and non-point sources. Countries namely Korea, China, Taiwan, and Thailand have formulated TMDL implementation plans. Presently, TMDL is one of the best approaches for river protection and management in Malaysia [7]. A TMDL implementation plan supports the stakeholders and regulators to maintain and enhance the water quality of the rivers, lakes, and estuaries. The TMDL can be expressed mathematically in Equation 1 as follows [8]:

$$\text{TMDL} = \Sigma\text{WLA} + \Sigma\text{LA} + \text{MOS} \quad (1)$$

where WLA is the waste load allocation for accounting point sources, LA is the load allocation for quantifying non-point sources and water quality background, and MOS is the margin of safety for compensating the uncertainties of calculation.

The MOEF guidelines [9] mention that to correctly determine the load allocation for each sector, watershed hydrological information is vital. Hydrological data should at least include geographical maps of the concerned watershed that includes length, depth, width, and surrounding topographic of the watershed; hydraulic data of the water body (depth, width); climate conditions (temperature, wind velocity, precipitation rate); present and future (plan) of water utilization; and water quality and flow rate. The content of the guidelines [9] also refers to the technical guidelines developed by USEPA as shown in Figure 2.

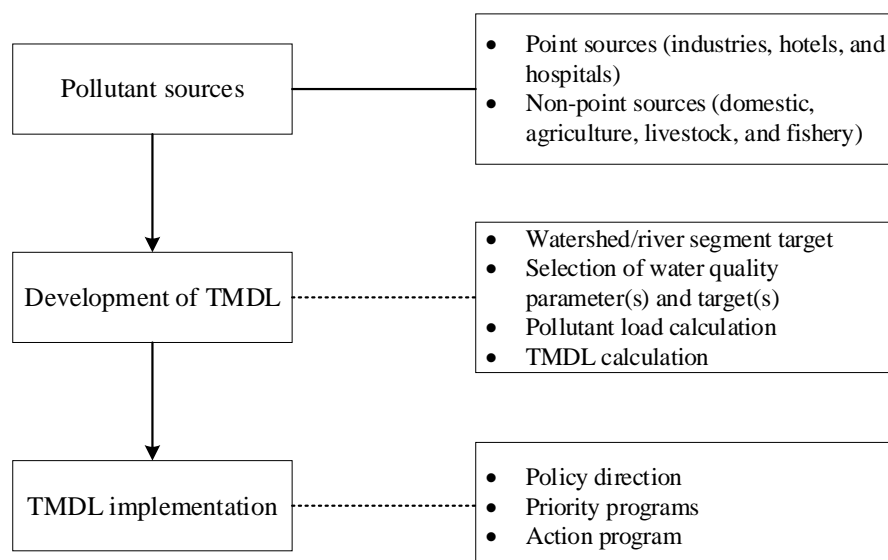


Figure 2. Structure of TMDL in Indonesia.

Based on the Government Regulation No. 22 of 2021, TMDL in Indonesia is based on the watershed, which is similar to that in the USA. The terms point sources and non-point sources include activities that contribute to pollution sources such as industry, domestic, mining, oil and gas, agriculture and plantations, fisheries, animal husbandry, and others [5].

2.3. Water quality data

The water pollutant parameter used in the TMDL of this study was the biochemical oxygen demand (BOD), considering the characteristics of wastewater from all pollutant sources in the Jeneberang Watershed. In addition, Mulla *et al* [2] stated that the BOD parameter is one of the key parameters in simulating interactions between components to simulate and analyze river water quality. Furthermore, Desbureaux *et al* [10] also mentioned overcoming the curse of dimensionality needs the use of BOD, which is frequently considered an ‘umbrella pollutant’ because of its ability to surrogate many different water quality parameters.

The BOD data used in this study were obtained from monitoring results in the Jeneberang River conducted in 2019 as shown in Table 1.

Table 1. BOD concentration in the Jeneberang River.

Segment	BOD (mg/l)	Distance (km)
1	2.24	0.00
2	0.46	11.61
3a	0.43	14.95
3b	5.97	15.29
3c	5.97	15.86
4	5.32	21.38
5	3.13	25.21
6a	3.13	32.02
6b	3.43	33.61
6c	3.43	34.66
7	2.84	36.37
8	2.84	40.10

The Indonesian Government has not yet stipulated a water quality standard for the Jeneberang River, thus based on Government Regulation No.22/2021, it was established as class 2 with a threshold value for BOD set at 3 mg/L [5].

2.4. Water quality modeling

The calculation of TMDL mostly applies water quality modeling as the water quality planning tool during the enhancement process. It is one of the foremost methods to simulate the changes in water bodies including physical, chemical, and biological changes, and reflect the relationship between pollution load changes from pollution sources and water quality, while also creating scenarios simulation and analysis for decision-making process by using a mathematical technique [2, 11]. The modeling results can support government agencies in the management and decision-making process [12]. The application of water quality modeling has played important role in TMDL development in order to attain the stipulated water quality standard and support the decision-making process [2].

The US EPA Water Quality Analysis Simulation Program (WASP, version 7.52), which is a generalized framework for modeling contaminant fate and transport in surface waters, was applied in this study. WASP is a dynamic generalized modeling framework using the finite-volume method to quantify the fate and transport of water quality variables in surface waters in 1-D, 2-D, or 3-D [13]. It has been successfully applied in the fate and transport modeling for several water quality parameters in

ivers, estuaries, and lakes. The time-varying processes of advection, dispersion, point and diffuse mass loading, and boundary exchange are represented in the basic program. The equations solved by WASP are based on the mass conservation key principle. The general mass balance equation around an infinitesimally small fluid volume is given by the governing equation [14,15,16]:

$$\frac{\partial C}{\partial t} = -\frac{\partial}{\partial x}(U_x C) - \frac{\partial}{\partial y}(U_y C) - \frac{\partial}{\partial z}(U_z C) + \frac{\partial}{\partial x}(E_x \frac{\partial C}{\partial x}) + \frac{\partial}{\partial y}(E_y \frac{\partial C}{\partial y}) + \frac{\partial}{\partial z}(E_z \frac{\partial C}{\partial z}) + SL + SB + SK \quad (2)$$

where C is the concentration of the water quality parameter in mg/L or g/m^3 ; t is time in days; U_x, U_y, U_z are longitudinal, lateral, and vertical advective velocities in m/day obtained from the results of HEC-HMS simulation; E_x, E_y, E_z are longitudinal, lateral, and vertical diffusion coefficients in m^2/day ; SL is the total direct and diffuse loading rate in $\text{g/m}^3 \cdot \text{day}$; SB is the total boundary loading rate (including upstream, downstream, benthic, and atmospheric) in $\text{g/m}^3 \cdot \text{day}$; and SK is the total kinetic transformation rate in $\text{g/m}^3 \cdot \text{day}$.

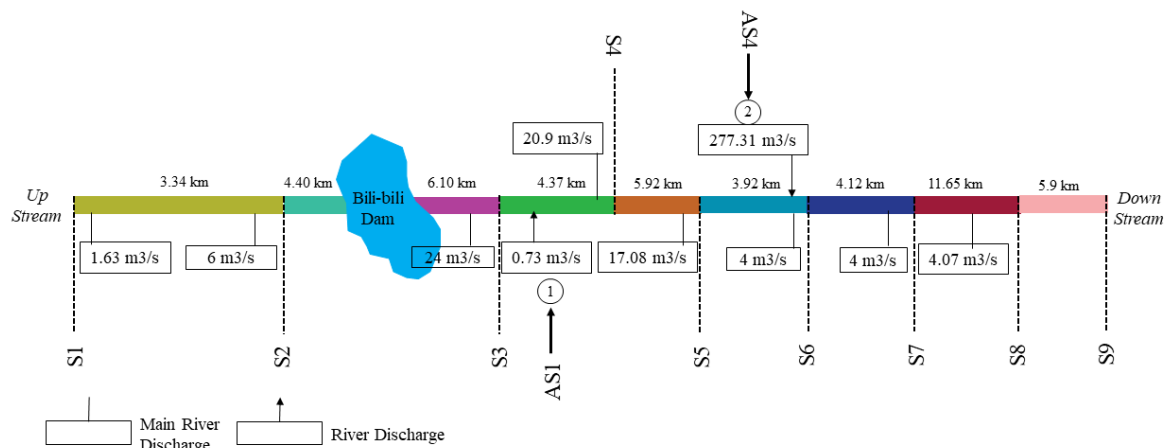


Figure 3. The schematic of the Jeneberang River segments.

Table 2. Morphometry of each segment of the Jeneberang River.

Segment	Velocity (m/s)	Depth (m)	Length of segment (m)	Width (m)	Minimum depth (m)	Manning coefficient	Volume	Flow rate (m^3/s)
1	0.39	0.18	11605.33	16.40	0.2	0.30	34258.93	1.14
2	0.27	0.17	3342.74	127.48	0.2	0.31	74283.11	6.00
3a	0.32	0.43	337.42	30.00	0.03	0.45	4352.72	4.13
3b	0.54	0.60	572.82	65.81	0.25	0.39	22618.37	21.32
3c	0.61	1.23	5517.6	65.81	0.2856	0.33	446629.30	49.38
4	0.38	2.00	3829.8	73.30	0.26	0.30	561448.68	55.71
5	0.40	1.70	6810.41	98.40	0.31	0.30	1139245.38	66.91
6a	0.40	1.70	1594.19	123.00	0.33	0.30	333345.13	83.64
6b	0.42	1.60	1051.89	118.00	0.3257	0.35	198596.83	79.30
6c	0.30	1.52	1710.63	190.00	0.3	0.42	494029.94	86.64
7	0.30	1.52	3726.01	217.00	0.3	0.48	1228987.14	98.95
8	0.96	0.40	5941.62	277.00	0.23	0.45	658331.50	106.37

In this TMDL study, GIS was used for managing data on the presence of polluting sources both quantitatively and qualitatively with overlay techniques. In addition, GIS was also used to compile a base map of the research area, analysis and preparation of watershed/sub-watershed boundary maps, analysis and determination of river segmentation, and presentation of other thematic maps [17].

The data used to develop TMDL by employing WASP in this study was the distance of river reach based on the division of the segmentation of the river and the scheme development of the river reach as shown in Figure 3. In addition, the program needed the hydrological and morphometry data including river width, river depth, river slope, riverbed material, riverside slope, and flow rate as well as climatological data including air temperature as presented in Table 2. Furthermore, water quality data and potential pollution load from all related sectors were inputted into the model.

The simulation was carried out using two scenarios, namely: Scenario 1, which was designed to simulate the load of existing pollution entering Jeneberang River that produced the actual water quality according to the sampling results, and Scenario 2, which was applied to simulate such a pollution load that the water quality met the stipulated water quality standard. In this case, the water quality standard for BOD was set at 3 mg/L.

It was essential to calibrate the model during the development of TMDL using water quality modeling [11]. Calibration is the adjusting of parameters aiming to demonstrate that the model is capable of producing output that matches the value of measured data [18]. The calibration process determines the relative validity and reliability of model development by comparing the simulated data against the observed data. The model is considered well-calibrated if the simulated water quality concentration fits the observed concentration adequately [19]. This process is performed to ensure the model can reproduce the observed water quality patterns in the river by means of comparing the simulated water quality with the observed data and key kinetic parameters are simultaneously adjusted until a reasonable match between model results and data is fulfilled [20]. The calibration method used in this study was the percentage bias (PBIAS), which was calculated with Equation 3 [21]:

$$PBIAS = \frac{\sum_{i=1}^N (P_i - O_i) \times (100)}{\sum_{i=1}^N (O_i)} \% \quad (3)$$

where PBIAS is the deviation of data being evaluated, expressed as a percentage, O_i and P_i are, respectively, the observed and predicted values.

2.5. Implementation of TMDL

The waste load allocations, which are derived from point sources, are generally implemented through the discharge permit system under US EPA's national pollutant discharge elimination system (NPDES). Meanwhile, load reduction actions for non-point sources are conducted through a wide variety of programs at the federal, state, and local levels. Besides, US EPA provides grant money to the states to fund specific projects aimed at reducing pollution from non-point sources [8].

The basic principles of the total pollutant load control system (TPLCS) in Japan are to quantitatively measure all pollution load that is being discharged into the water bodies, analyze its effects on the water quality, develop quantitative reduction targets, formulate control plans, and gradually implement the planned measures. The total pollutant load control plan should incorporate additional reduction measures, such as water quality monitoring, supervisory monitoring of industrial effluents, supportive measures for installing wastewater treatment facilities at industries, and the development of the framework for promoting the reduction of pollutant load [22].

The development of an action plan for the protection and management of TMDL-based water quality in this study focused on reducing the pollution load from sectors that contributed to the pollution of the Jeneberang River. The amount of targeted pollution load reduction from each sector was determined based on the allocation of pollution load from the TMDL calculation. These activities can take the form of infrastructure and non-infrastructure development.

The TMDL result and action plan would be incorporated into the water quality protection and management planning (WQPMP) of Jeneberang River and other priority rivers legalized by the Ministry of Environment and Forestry decree. It should be used for the related ministries and other central government institutions as well as the provincial government and four local governments for improving the water quality. The WQPMP procedure is applied for all watersheds nationwide based on the new government regulation.

3. Result and discussion

The simulation result of Scenario 1 (Figure 4) shows that the modeled BOD was adjacent to the observed BOD. This result was also strengthened by calibration results that gave a $|PBIAS|$ value of 7.5%. According to Moriassi *et al* [21], the simulation result can be judged as “very good” if $|PBIAS| \leq 25\%$, “good” if $25\% \leq |PBIAS| < 40\%$, “satisfactory” if $40\% \leq |PBIAS| < 70\%$, and “unsatisfactory” if $|PBIAS| \geq 70\%$. Meanwhile, the discharge calibration was carried out by calibrating the hydraulic model on the WASP, by means of trial and error for the speed, depth, and slope of the segment.

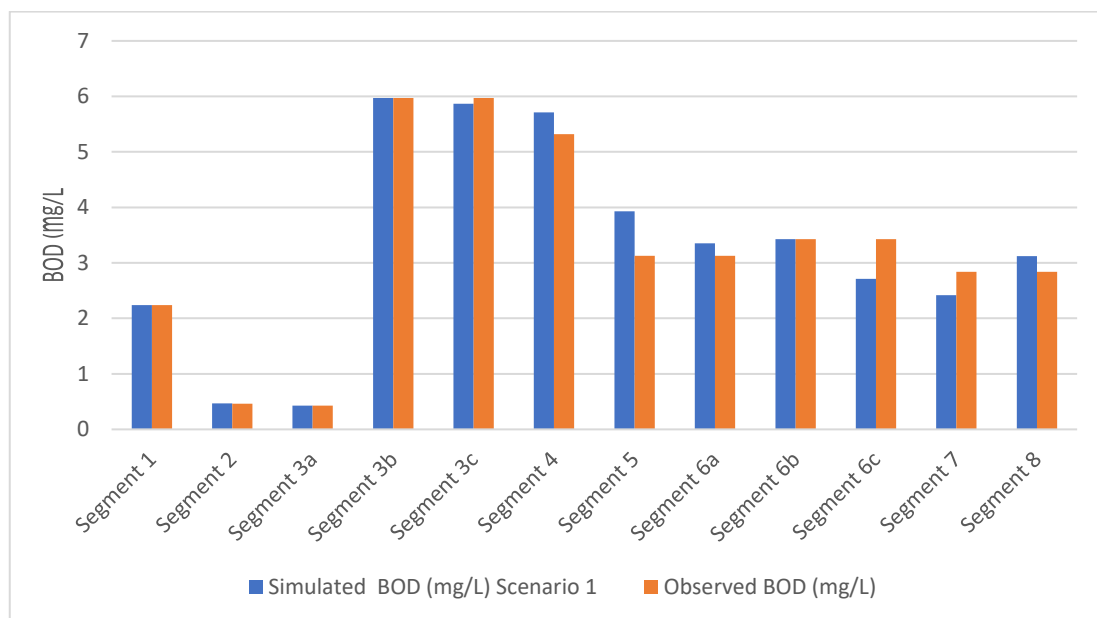


Figure 4. Simulation result of Scenario 1.

Figure 4 indicates that the actual BOD concentration in the Jeneberang River mostly exceeded the class 2 BOD concentration in the river with a threshold value set at 3 mg/L. The pollutant load resulting from the simulation of Scenario 1 applying the WASP model was 4844.87 kg-BOD/day which is an estimate of the actual pollution load entering the Jeneberang River from segment 1 to segment 8. The total pollution load was contributed by the sectors of domestic at 67.97%, livestock at 26.31%, agriculture and built-up land at 5.34%, and point sources such as industries, hotels, and hospitals at 0.38%.

Meanwhile, the simulation of Scenario 2 was used to obtain the maximum pollution load (TMDL) that is allowed to be discharged into the Jeneberang River to meet the class 2 BOD concentration in the river. The simulation result of Scenario 2 is depicted in Figure 5. The calibration of the simulation results of Scenario 2 with class 2 BOD concentration gave a PBIAS value of 2.55%, which was categorized as very good [21].

Based on the simulation result of Scenario 2, the allowed total pollution load to be discharged (TMDL) into the Jeneberang river was 3552.97 kg-BOD/day. Therefore, the total load reduction of 1291.9 kg-BOD/day is required for the Jeneberang river to fulfill class 2 for the BOD parameter.

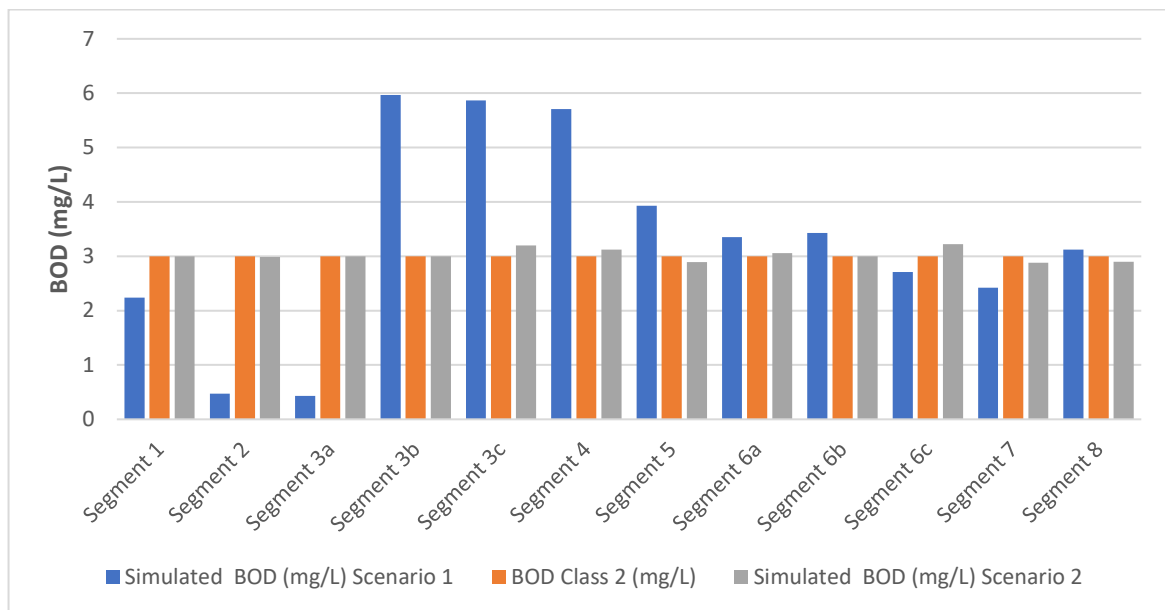


Figure 5. Simulation result of Scenario 2.

Strategies, programs, and action plans are needed in order to reduce the pollution load by 1291.9 kg-BOD/day. The result of the study also shows that the action plan to reduce the pollution load must be carried out according to the percentage of contribution of each sector as follows: 871.37 kg-BOD/day from the domestic sector, 337.28 kg-BOD/day from livestock activities, 68.39 kg-BOD/day from agriculture and built-up land, and 4.86 kg-BOD/day from point sources such as industries, hotels, and hospitals.

Since the contribution of domestic pollutants was very dominant, the improvement of the quality of the Jeneberang River depends on the achievement of the pollution load reduction from domestic sources. It was noted as well that the domestic wastewater generally was generated from community settlement, thus a legal approach such as inspection or supervision would not be appropriate. Public service approaches such as infrastructure development and mentoring would be more suitable. Furthermore, comprehensive strategy, program, and action plan are needed that include policy, institutional, physical infrastructure, and sociocultural aspects of the community.

The cost of one unit of communal sewerage treatment plant (STP) for 100 households, which equals 40 m³/day, is estimated to be around IDR 1 billion including the piping cost. However, it is excluding the land acquisition costs. The load decrease per one unit of STP with a capacity of 100 households was estimated at 12.8 kg-BOD/day. Thus, the total number of STP needed to reduce the pollution load from domestic wastewater in the entire Jeneberang Watershed is 122 units with a budget of IDR 121.86 billion. Table 3 shows the estimated number of communal STP required and the budget per segment.

Table 3. Estimated number of communal STP and required budget per segment.

Segment	District/City	Pollution load reduction (kg-BOD/day)	Number of STP (unit)	Budget (IDR)
3	Gowa, Takalar	1261.11	99	98,524,218,750
6	Gowa	30.76	2	2,403,125,000
8	Makasar	267.91	21	20,930,468,750
Total		1559.78	122	121,857,812,500

The pollution load from livestock activities was caused by the fact that animal manure was discharged directly into the Jeneberang River without processing. One unit of biodigester worth IDR 21 million was designed for processing manure from four cattle and was estimated to be able to reduce the pollution load by 0.58 kg-BOD/day. Based on the results of the TMDL calculation in the Jeneberang River related to animal husbandry, it is estimated that to reduce the pollution load from the livestock sector, a total amount of 350 biodigesters spread across three segments is needed requiring a total budget of IDR 7.35 billion. The estimation of numbers and budget for the construction of the biodigesters can be seen in Table 4.

Table 4. Estimation number and budget for biodigester construction.

Segment	District/City	Pollution load reduction (kg-BOD/day)	Number of biodigesters (unit)	Budget (IDR)
3	Gowa, Takalar	488.13	283	5,945,423,400
6	Gowa	11.9	7	144,942,000
8	Makasar	103.7	60	1,263,066,000
Total		603.73	350	7,353,431,400

The action plan to reduce the pollution load from agriculture is associated with the use of fertilizers and pesticides that are environmentally friendly and effective and efficient. This is done by providing counseling as well as incentives and disincentives for farmers. Meanwhile, the action plan to reduce the pollution load of built-up land, especially in urban areas, focuses on controlling the level of non-construction rainwater runoff, managing the volume of rainwater runoff, and reducing the burden of pollutants sourced from rainwater runoff which can eventually control and reduce the negative impacts of land development and zero-point polluting sources. This can be done by applying urban runoff water treatment technology such as stormwater ponds, constructed wetlands, infiltration basins, retention/detention ponds, green roofs, and others.

Supervision is an absolute requirement that must be implemented so that industries, hotels, and hospitals can comply with government regulations and finally can reduce the pollution load from this sector. An adequate number of inspectors and a budget related to inspection activities are needed, as shown in Table 5. However, gradually, the surveillance can be assisted by the application of an online wastewater monitoring system.

Table 5. Estimation of inspector numbers and inspection activity budget.

Point sources	Number	Inspection frequency (1 year)	Inspector numbers	Budget (IDR)
Industry	326	12	33	7,828,890,000
Hotel	64	12	6	1,536,960,000
Hospital	25	12	3	600,375,000
Total			42	9,966,225,000

4. Conclusion

The application of a combination of WASP water quality and GIS spatial model in the study was able to predict the observed water quality patterns in the Jeneberang River. The modeling results indicated that the total load of existing pollutants entering the Jeneberang river from upstream to downstream was 4,844.87 kg-BOD/day while the TMDL was 3,552.97 kg-BOD/day. Therefore, a load reduction of 1291.9 kg-BOD/day is required although, there were several segments on the river where the TMDL was greater than the existing load. Furthermore, the study results also show that it is required to reduce

the water pollution load from the domestic, industries, livestock activities, and the combination of agriculture and built-up land by 871.37, 14.86, 337.28, and 68,39 kg-BOD/day, respectively. The calculation results reveal as well that the total number of communal sewerage treatment plants needed to reduce the pollution load from the domestic sector in the entire Jeneberang Watershed is 122 units with a budget of IDR 121.86 billion. To reduce the pollution load from the livestock sector, a total of 350 units of biodigester with a total budget of IDR 7.35 billion is necessary. Meanwhile, 46 inspectors and a budget of IDR 10 billion per year are required to supervise industries. The final Jeneberang watershed pollution reduction action plan will be made after discussions with stakeholders using the results of the study.

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Author contributions

B. Kurniawan and Safrudin planned the study and conducted the sampling result analysis. B. Kurniawan, M. Komarudin, and Safrudin performed modeling, modeling result analysis, and development of programs and action plans. M. Komarudin performed GIS and spatial analysis. All authors are the main contributors to this article and contributed equally to the data interpretation, manuscript preparation, and approval.

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