Total maximum daily load of bod in urbanized Belik River, Yogyakarta

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Abstract. The Upper Belik watershed is a river that flows in Special Region of Yogyakarta. Land use in this watershed is dominated by settlements. The development activities by the human can cause river pollution if there are no maintenance and monitoring related to their waste. The study aims to determine the waste load and capacity of the BOD. The descriptive quantitative with spatial analysis is used. The determination of the sample is by dividing the study area into five segments based on variations in pollutant sources and drainage flow directions. Water sampling and river morphological measurements were carried out purposively, water quality taken by grab sampling. Data are processed using the Water Quality Analysis Simulation Program (WASP). The results showed that Belik River could not accommodate waste loads. Segment one has to reduce 22,41 kg/day BOD, while the second segment does not need to reduce the load. Segment three must reduce as much as 5,73 kg/day, segment four by 35,81 kg/day and segment five by 61,16 kg/day. Reducing the waste load can be done by reducing the pollution load that flowing to the river.

1. Introduction

Water is a basic need for humans. People use water to drink, bathe, and wash, agricultural irrigation, fishpond, sanitation, and transportation both in rivers or sea. Also, water is useful for industrial and technological activities [1]. Water quality can decline due to the influence of human activities such as urbanization, population growth, industrial production, climate change, and other factors [2]. Disposing of untreated waste leads to deviations from normal water conditions to polluted. Waste from human activities is often discharged directly into the river system without any treatment so that it can become a pollutant burden for a river. According to Republik Indonesia Government Policy Number 82 of 2001, the pollutant load is the amount of a pollutant entering the water while the capacity of the pollutant load is the ability of the water to accept the pollutant load without pollution. The capacity of water capacity for pollution needs to be maintained to minimize the occurrence of river water pollution [3].

Waste generated by human activities in the Belik watershed is in the form of domestic waste, small industrial waste, livestock waste, and hospitality waste. The Belik river is classified as heavily polluted river water [4]. Therefore, it is necessary to know the amount of pollutant load that has the potential to enter the Belik River without river water pollution. Calculation of pollutant load capacity in a river is very complex, and the processes that occur in the river tend to be complicated because there are chemical, physical, and biological phenomena.

Simplification of the calculation of the capacity of the pollution load can be done using the Water Quality Analysis Simulation Program (WASP) modeling. WASP is a model that interprets and predicts
the response of water quality to natural phenomena and pollution in surface water [5]. This modeling uses the calculation of the mass balance method. The water quality parameters used in the calculation of the load capacity of pollutants are Biological Oxygen Demand (BOD). BOD is oxygen needed by microbiologists to decompose organic substances in the water [6]. River water will be increasingly polluted when the BOD is high [7]. BOD is one of the best indicators that the river has been polluted.

This research was conducted at the Upper Belik watershed located in the Special Region of Yogyakarta. The main river of the watershed is the Belik River which passes through Sleman Regency, Yogyakarta City, and Bantul Regency. Upper Belik watershed is one of the watersheds in urban areas whose land use is dominated by settlements so that human activity is more intensive which affects the water quality of Belik River. Figure 1 shows a map of landuse in Upper Belik Watershed. According to the Yogyakarta Special Region Governor Policy Number 22 of 2007, Belik River is based on its designation as a second-class river starting from Klebengan, Caturtunggal, Depok, Sleman downstream until meeting with the Opak River in Blawong, Trimulyo, Jetis, Bantul.

Figure 1. The Landuse in Upper Belik Watershed

2. Methods

The study was conducted at the Belik Upstream Watershed, cut-offs in Sleman Regency and Yogyakarta City (Fig. 2).
The study area is divided into five segments which were determined based on river morphology, variations in pollutant load, and open channel flow direction. Samples are taken from each segment of water quality as well as the river water discharge. Figure 3 shows a map of river water sampling and point sources sample. Water samples are taken to represent each segment. In total, nine water samples were taken, six primary river water samples, one water channel input sample to the main river, and two wastewater samples. Water sampling is to grab sampling to describe the condition at that time. In addition to water quality, river water discharge measurements and river morphology measurements are taken at each sample point.

Pollutant load can be obtained by estimating point source and non-point sources. The non-point source is estimating domestic pollutants, livestock, fisheries, land built up, laundry, and hotels. Boarding houses are estimated at the expense of domestic polluters. Calculating the population and the livestock in average weight estimates the burden of domestic pollutants and livestock. The number of laundry and hotels obtained through field surveys. The point source obtained by taking data on water quality, which discharge into the river. Flows measurement using slope area method and velocity area method. The formula of slope area method as follows

$$Q = \frac{1}{n} \cdot A \cdot R^2 \cdot S^2$$  \hspace{1cm} (1)

Where n is manning, A is area, R is the hydraulic radius of the cross-section, and S is slope. The formula of velocity area method as follows

$$Q = A \times K \times U$$  \hspace{1cm} (2)

Where is Q as flows, A as area, K as float coefficient, and U is velocity

Data processing using WASP simulation models. Input data for the model are flows, river morphology, pollutant load, and water quality. Model simulations are carried out to obtain the combination of flows and concentration pairs that best fits the observed data. The simulation is carried out in two stages. The first step is to simulate the model of the observational data for pollution loads, and the second step simulate the model towards quality standards to calculate the capacity of the pollution load.

Adjustment of model results with observational data is obtained by conducting trial and error on pollutant load values. The results of the model, following with the observation data, were tested for
reliability with relative bias and mean relative error method. The formula of the relative bias method as follows.

\[ r_B = \frac{(R_m - R_o)}{S_o} \]  

(3)

\[ F = \frac{S_m^2}{S_o^2} \]  

(4)

Where \( r_B \) is relative bias, \( R_m \) is the average of the model value, \( R_o \) is the average of the observation model, \( S_m \) is the standard deviation of the model value, \( S_o \) is standard deviation of the observation model, and \( F \) is the ratio of model and observation. The calculation result of the \( r_B \) method has a requirement that the model results can be accepted. If \(-0.5 < r_B < 0.5 \) and \( 0.5 < F < 1.5 \) then the model is accepted and if \( r_B < -0.5 \) or \( r_B > 0.5 \) and \( F < 0.5 \) or \( F > 1.5 \) then the model rejected [8]. The MRE method has the following formula

\[ MRE = \sum_{i=0}^{n} \frac{RE}{n} \]  

(5)

Where MRE is mean relative error. The MRE method also has a requirement that the model results are accepted. Calculations with the MRE method are considered acceptable if the MRE value < 10% and rejected if the MRE value > 10% [9].

3. Results and Discussion

Pollution load of a river can be identified based on BOD levels in water [7]. BOD can determine the burden of pollution due to the community or industrial wastewater, and to design biological treatment systems for polluted water [10]. Organic matter that has not been processed and thrown into the body of water, the bacteria will use oxygen dissolved in water for the decay process. River water quality can be measured but very dynamic. This is because water quality sampling is “grab” sampling, which is only one-time sampling to determine the current water quality conditions. BOD values of laboratory test results are presented in Figure 3.

![Figure 3. BOD values of laboratory test results](image)

Figure 4. The BOD values along the second class quality standard

Based on laboratory tests, the value of BOD in the study area has fluctuated and is above the quality standard. The BOD value is based on the second-class quality standard of 3 mg/l and the second class was chosen because according to the Yogyakarta Special Region Governor Policy Number 22 of 2007, Belik River according to its designation belongs to the second-class. According to Yogyakarta Special Region Governor Policy Number 20 of 2008, second-class water is designated as water recreation facilities or infrastructure, to irrigate crops and to similar to these uses.

Sample point one has a BOD value of 4.2 mg/l, the BOD value exceeds this quality standard because water from the Mataram Canal has received quite a lot of pollutant input, especially from domestic activities and it is not uncommon for human activities to dump trash directly into river bodies. The BOD
value at the second point increased to 5.1 mg/l. The increase in the value of BOD can be caused by organic materials originating from domestic and other wastes [11]. There is an input in the form of a channel that originates from Mataram Canal. This channel gets through the UGM Faculty of Animal Science which transfer animal waste or livestock food residues to the river.

Point three experienced a decrease in BOD value of 3.8 mg/l. This decrease can be caused by the existence of self-purification because between points two and point three there is a waterfall resulting in turbulence which causes the process of reaeration of air into the water to be reduced so that the ability of river self-purification is optimal [12]. Also, the potential pollutant load entering this point affects the decline in the value of the BOD. Pollutant sources only come from built-up land and pollutant loads from the drinking water industry. Therefore, the load entering this point is lower than the second point.

The BOD value at the fourth point is stagnant. The BOD value is similar to the second point BOD value, which is 3.7 mg/l. A decrease of 01 mg/l can be caused by a fall resulting in turbulence which affects water reacts with air and can increase oxygen content. BOD value increased at the fifth point, which is 5.. mg/l, then at the sixth point, it also increased to 6.5 mg/l. This increase was caused by the presence of pollutants which mainly came from domestic waste through the discharge pipes, which were directly discharged into river bodies. The settlement at this point is very close to the river body, and quite a lot of pipes go directly into the river body.

3.1 Potential Pollutants

Pollutants load will be estimated based on every segment of the river. Pollutants load input is conducted by estimating its inventory result. Hence, segment division is needed. The division is based on open channel flow direction in the research area and type of pollutants burden. Every segment has each pollutants burden. Segment 1 is regarded as the highest river with pollutants burden, which reaches 1067.59 kg/day, while the lowest burden is the second segment with 7.92 kg/day (see Table 1).

| Segment | Domestic (kg/day) | Livestock (kg/day) | Laundry (kg/day) | Hotel (kg/day) | Fishpond (kg/day) | land built up (kg/day) | Point Source (kg/day) | Total (kg/day) |
|---------|------------------|--------------------|-----------------|---------------|-------------------|-----------------------|----------------------|---------------|
| 1       | 1012.61          | 2.20               | 0.65            | 3.17          | 13.32             | 2.39                  | 33.26                | 1067.59       |
| 2       | 3.10             | 3.53               | 1.29            | 7.80          | 2.33              | 315.58                |                      | 7.92          |
| 3       | 294.9            | 0.01               | 0.27            | 9.49          | 7.80              | 2.33                  | 116.36              |               |
| 4       | 116.27           | 0.01               | 0.08            | 19.04         |                   |                       |                      |               |
| 5       | 568.66           | 0.05               | 0.17            | 19.04         |                   |                       |                      | 587.92        |

This condition is influenced by the segment’s wide, which also affect the pollutants burden’s wide and type of pollutants burden. The contribution of PS is contained in the first, second, and third segment. PS that is contained in the first segment is channel type PS, which comes from Mataram Canal, PS in the second segment is a pipe from the mineral water industry, while PS in the third segment is wastewater management installation pipe.

All segments are dominated by domestic pollutants burden. The settlement land use is the most dominating land use in the urban area. Domestic pollutants burden in the first, second to five segments are more than 90%. The second segment is dominated by pollutants burden of the land build as much as 44.5%. PS and NPS contribution percentage is provided in Figure 3. The first segment has potential pollutants burden more varied than other segments.

3.2 Pollutant Load Capacity

Capacity value estimation of pollutant load is by measuring existing pollutant load value. After the capacity value is measured, then the must reduce the amount of following pollutant load value is known. Hence, existing pollutant load value input to the body of the river is important to know. Existing capacity value estimation is conducted with pollutants load simulation continuously with trials and error system.
until it results in a proportional BOD observation concentrate combination. Pollutant load capacity value model is started by stimulating flows with BOD valuation.

### 3.3 Flows Calibration

The flows increase and decrease are caused by the existence of water input and output. Flows calibration in WASP is done so that simulation can be close with the condition in the field. Flows simulation result can be seen in Figure 4, which shows flows value test result close to the observation results in the field.

![Figure 5. The discharge of Belik River during the study.](image)

Flows calibration is done through trial and error parameter which sensitive in WASP, that is flow function input to the segment. Flows adjustment result model with flows measurement result are conducted because flows do influence water quality. There many aspects of water quality and flow, which interconnected each other, pollutants in the flow will be varied depends on flows and how much dilution occurs [13]. Pollutants which contained in low flow can disturb water condition, while pollutants which contained in high flow also can disturb water condition but more likely influenced by dilution.

### 3.4 BOD Simulation

A simulation model to measure capacity after flows calibrated is by simulating BOD value. The BOD value result model will be influenced by pollutants burden income of each segment. Pollutants burden estimation, which comes inside the river has not yet supported by accurate data availability, so that modeling is needed to know pollutants water input by watching respond of water quality result in the water. BOD value model will be calibrated with trial and error pollutants burden inventory result in order to be similar to laboratory test result from taken samples in the field. The BOD value result model is displayed in Figure 5.

![Figure 6. The concentration of BOD Observation and BOD Model along the river](image)

### 3.5 Existing Pollutant Load

Pollutant load result of trial and error shows that existing pollutant load which comes inside the river’s
body. Pollutants load value is provided in kg/day unit. Analysis BOD pollutants burden value is done based on segment division which is divided into five segments. The pollutant load value for each segment is the sum of PS and NPS input in each segment.

Pollutant load value of inventory result a more significant value compare to pollutant load modeling result. The difference is provided in Table 2. This is caused by not all pollutants load which potential to pollute Belik River’s body come inside the river’s body. Pollutants load modeling result does not go inside the river is because of distant settlement which affect the ease level of waste to the river. In addition, it can also be affected by the estimation of the calculation of the weighted mean for the population, number of boarders, and the number of livestock.

| Segment | Inventory Pollution Loads (Kg/day) | Existing Pollutant Load (Kg/day) |
|---------|-----------------------------------|---------------------------------|
| 1       | 1070.55                           | 25.71                           |
| 2       | 7.92                              | 2.10                            |
| 3       | 332.48                            | 26.53                           |
| 4       | 116.36                            | 52.61                           |
| 5       | 568.88                            | 104.76                          |
| Total   | 2096.18                           | 211.71                          |

Based on pollutants load estimation result, both inventory and existing, the value of one to five segment fluctuates. Total pollutant burden in Upper Belik watershed is 211.71 kg/day. The first segment has pollutant load value as much as 25.71 kg/day with BOD value 5.1 mg/l. This segment has a source of pollutant in the form of PS from Mataram Canal and NPS of fishponds, apartment settlements and built land. Pollutant load experiences decrease in the second segment. The pollutant load in this second segment is the lowest among others. Pollutant load value in the second segment is 2.71 kg/day so that the BOD value is reducing to be 3.82 mg/l. The low value of BOD is influenced by pollutant load contribution, which is not spacious, and its type is not varied.

The third river has pollutant load 26.53 kg/day. In this segment, the number is increasing. This condition is caused by the existence of domestic and hotel pollutant load contribution. Domestic waste in this segment is getting outnumbered because people throw it through the pipe and directly comes inside the river. Pollutant load which number increased is not along with increasing BOD value, and it is more likely to be stagnant in number 3.72 mg/l. This is affected by the water’s ability to restore. The fourth segment has increasing pollutant load to be 52.61 kg/day with BOD value 5.1 mg/l. the increasing number of pollutant load in this place is caused by the bigger non-point source contribution from the third segment and other pollutant loads such as laundry, which has the lowest contribution.

Pollutant load in the fifth segment occur, increasing up to 104.76 kg/day. The highest BOD value proves the pollutant load amount inside segment compares to other segments, namely 6.5 mg/l. Pollutant load increase in the fifth segment is influenced by domestic pollutant load and hotel. The number of hotels in the fifth which reach ten hotel units, its segment is countable compared to other segments.

3.6 Pollutant Load Capacity and Pollutant Load which Needs to be Reduced
Capacity valuation of pollutant load based on the standard quality value has been determined. According to Yogyakarta’s Governor Policy No 22 in 2007 about the class determination of water river in Special Region Yogyakarta. Belik river is shortlisted in second class quality standard. Classification of quality standard water river was regulated in the Yogyakarta’s Governor Policy No. 20 in 2008 about water standard quality in Yogyakarta’s province, the BOD second class of quality standard is 3 mg/l.

The process of capacity valuation is done through trial and error system towards the BOD value model until concentration value obtained close to BOD standard capacity, but its value should be excessive over standard quality value. Figure 6 shows the comparison between BOD value model with BOD standard quality so that the BOD value model obtained is closer to the real the BOD standard.
quality value.

![Figure 7. The BOD model and compared with standard quality](image)

According to the simulation of BOD which the number is close to the standard quality, the total amount of pollutant load that can be contained in the segment of River Belik without causing any pollution is obtained. The maximum pollutant load that can endure in River Belik is elaborated in Table 3.

Based on the calculation of the pollutant load capacity, the total amount of pollutant load that has to be reduced is different in every segment. It can be caused by the morphological condition of the river and also the total amount of pollutant load received. The endurance capacity of segment one is 3.3 kg/day with existing pollutant load 25.71 kg/day. The difference between pollutant load and endurance capacity is 22.40 kg/day, which 87% have to be reduced from it. PS causes the small number of pollutant load endurance capacity and also the significant amount of domestic pollutant load received. Besides, It can also be affected by a morphological condition such as river length that is 0.22 km. The first segment is the shortest one. The shorter the segment, it will decrease the river’s capability to recover itself from pollution. The longer the segment, the river’s capability to restore is better as long as there is no low-quality input [14].

### Table 3. Calculation Result of Total Maximum Daily Load

| Segment | Length Segment (Km) | Flow (m³/s) | BOD (mg/l) | Existing Pollutant Load (Kg/day) | Total Maximum Daily Load (Kg/day) | Difference (Kg/day) | Information |
|---------|---------------------|-------------|------------|---------------------------------|----------------------------------|---------------------|-------------|
| 1       | 0.22                | 0.13        | 5.12       | 25.71                           | 3.30                             | 22.41               | Pollutant must be reduced by 87% |
| 2       | 0.46                | 0.17        | 3.82       | 2.10                            | 2.10                             | 0.00                | Able to Accept Pollutant must be reduced by 22% |
| 3       | 0.56                | 0.20        | 3.72       | 26.53                           | 20.80                            | 5.73                | Pollutant must be reduced by 68% |
| 4       | 0.36                | 0.21        | 5.11       | 52.61                           | 16.80                            | 35.81               | Pollutant must be reduced by 68% |
| 5       | 0.65                | 0.24        | 6.50       | 104.76                          | 43.60                            | 61.16               | Pollutant must be reduced by 60% |
| Total   | 211.71              | 86.60       | 125.11     |                                 |                                  |                     |                          |

Segment two has a significant number of pollutant load endurance capacity which number is as significant as existing pollutant load, 2.1 kg/day. Consequently, segment two does not need to reduce
the pollutant load, but neither it means that segment two can endure a greater amount of it. The pollutant
load of segment two is affected by the pollutant load of segment one. If the pollutant load in segment
two is more prolonged than segment one and also the water of segment two has a more significant volume
than segment one. This bigger water volume is because segment two receives water from UGM Reservoir while segment two has a waterway out to UGM Reservoir. The increase in water volume can help the process of water dilution. Thus pollution can be decreased.

The pollutant load in segment three need to be reduced 5.73 kg/day because the endurance capacity
is only 20.80 kg/day, and the existing pollutant load is 26.53 kg/day. In segment three, 22% of existing
pollutant load has to be reduced. The increase of pollutant load has to be orderly reduced from segment
two to three because the pollutant load in segment three is getting higher. Most of the pollutant load are
domestic and hotel.

The reduction of pollutant load in segment four is higher than the former segments, 35.81 kg/day. The pollutant load endurance capacity of segment four is 16.8 kg/day, and the existing pollutant load is 52.61 kg/day. The rise of pollutant load potency is enabled by the increase of domestic pollutant load in this segment. The contributors to pollutant load in this segment are mostly livestock, laundry, and domestics. If it is being compared to segment three, the domestic land used in segment four is broader.

Segment five has the highest number of pollutant load reduction, which is 61.16 kg/day. The existing
pollutant load in segment five is 43.60 kg/day. The endurance capacity that is getting higher can be
influenced by the river morphological condition such as river length and also the rise of the water
volume. The high amount of pollutant load that has to be reduced is caused by the more pollutant load
contaminating the river. The increase of pollutant load reduction in segment five is the result of the rise
of domestic pollutant load and also the contribution of hotel pollutant load.

The total of pollutant load endurance capacity in upstream Belik watershed is 86.60 kg/day. According to the difference between endurance capacity and pollutant load, upstream Belik Watershed needs to reduce 125 kg/day pollutant load. The reducible is domestic pollutant load because it has a greater contribution than any other sectors. In order to decrease domestic pollutant load, a communal Wastewater Management Installation can be built. A monitoring and evaluation process also accompany the establishment of communal wastewater management installation. Thus the pollutant that is released from communal Wastewater Management Installation will not exceed the quality standard and will not be harmful to the river.

3.7 Validation Test
The concentration value of BOD model is being validated in order to figure out the compatibility
between the value of BOD model and BOD observation. Validation test uses a chi-square test. Based on
calculations, the calculated $x$ value (0.000236) is smaller than $x$ table (1.145), so the model can be
accepted.

3.8 Model Reliability
Reliability test is a consistency test of a series of measurement or consistency of a measuring instrument
which can be used to describe a test result [15]. In this research, the reliability test is conducted in order
to value the expediency of model. Reliability test is done statistically by applying relative bias ($rB$)
method and mean relative error (MRE).

The calculation result of the relative bias method has a requirement in order to be accepted or denied.
If the result is $-0.5 < rB < 0.5$ and $0.5 < F < 1.5$, then model is acceptable. The calculation results of
BOD based on observation and BOD based on the model are $rB 0.01$ and $F 0.99$, which mean that the
model is acceptable.

Mean relative error method also has a requirement in order to decide whether the model is accepted
or denied. If the total value of MRE <10%, the model is acceptable. Based on the calculation, BOD
based on observation and BOD based on the model has MRE value 0.304%, which means the model is
acceptable because it is <10%.
4. Conclusion

The total amount of existing pollutant load in Upper Belik watershed are 211.71 kg/day. The value of the pollutant load in each segment is different from one another. Segment one has 25.71 kg/day pollutant load, segment two has 2.1 kg/day pollutant load, segment three has 26.53 kg/day pollutant load, segment four has 52.61 kg/day pollutant load, and segment five has 104.76 kg/day pollutant load. The pollutant load, the tested area, is gained from the calibration result of WASP model. The difference value of the pollutant load in each segment is caused by the wide, and the diverse pollutant load received.

The total amount of pollutant load in Upper Belik watershed are 86.60 kg/day. The endurance capacity of BOD pollutant load in segment one to segment five are successively 3.3 kg/day; 2.1 kg/day; 20.80 kg/day; 16.80 kg/and; and 43.60 kg/day. The endurance capacity of pollutant in each segment is affected by the river morphological condition such as the length and volume of the river, which will influence the water ability to restore.

Generally, some segments in Belik river are incapable of enduring pollutant load. The pollutant load that has to be reduced is different in every segment. The Upper Belik watershed needs to reduce 125.11 kg/day of pollutant load. Segment one has to reduce 22.41 kg/day of pollutant load or 87% of the existing pollutant load. Segment two does not need to reduce the pollutant load as long as segment one can reduce the existing pollutant load received. Segment three has to reduce 5.73 kg/day or 22% of the pollutant load received. Segment four has to reduce 68% of the pollutant load received or 35.81 kg/day. Segment five has to reduce 61.16 kg/day or 58% of the pollutant load received. Domestic pollutant has to be reduced because of its greater contribution to pollution than other sectors. The reduction of a domestic pollutant can be made by building a communal wastewater treatment installation.

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