Relationship between land use and water quality in Pesanggrahan River

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Abstract. Pesanggrahan River watershed has several activities such as residential and commercial area in its catchment area. The purpose of this study was to analyse water quality related to spatial land use in Pesanggrahan River using GIS Analysis. River water quality in some locations, did not meet water quality standard of class III. From pollution load estimation it was revealed that segment 2 (Bogor City) has the highest BOD, COD, and TSS of 15,043 kg/day, 25,619 kg/day, and 18,104 kg/day respectively. On the other hand, the most developed area in Pesanggrahan Watershed is located in segment 7 (24.5%). Hence, it can be concluded that although an area has a fairly small developed area, high urban activity can cause high BOD, COD, and TSS.

1. Introduction

Pesanggrahan Watershed has an area of 55,141.84 ha with the river upstream in the city of Bogor which then flows into West Jakarta. Segmentation of Pesanggrahan Watershed area is divided based on administrative boundaries covering areas of Bogor City, Bogor District, Depok, South Tangerang, Tangerang City, South Jakarta and West Jakarta. The population within the Pesanggrahan Basin is different for each segmentation, in 2012 there are mostly in South Jakarta area of 710,406 population [1]. Based on the study of phytoplankton diversity in Pesanggrahan River both upstream and downstream showed moderate pollution, where the results of regression analysis showed that the nitrate content of waters significantly influenced the abundance of phytoplankton and zooplankton [2].

The contribution of pollutant source of Pesanggrahan River comes from household waste which is a waste from the tributaries obtained from spatial analysis. Previous studies have proven that the pollution load capacity in Pesanggrahan River needs to be reduced because it has exceeded the threshold [3]. It is important to set up the water class first in determining the pollution load capacity so that Pesanggrahan river can be utilized in accordance with its designation.

The importance of water for life such as supporting the economy, utilization as drinking water and washing make humans must be willing to preserve the environment [4]. The level of river water pollution of Pesanggrahan is crucial to be identified therefore it can be utilized in accordance with the designation of river class. The government regulates the classification of river classes into four classes in Government Regulation No. 82 of 2001, namely classes 1 (water use for drinking water), 2 (water use for tourism), 3 (water use for fisheries and livestock farming), and 4 (water use for crop irrigation).
Determination of water pollution level using the calculation method of storet index and pollution index, as done by [5,6,7,8,9].

Research on river water classes has been largely performed one of them is in Southern Iraq using water quality indexes [10]. Based on that study, the water quality index is able to classify water use. The purpose of this study was to analyze water quality related to spatial analysis of land use in Pesanggrahan River using GIS Analysis.

2. Methodology

2.1. Study area
The monitoring locations of Pesanggrahan watershed are located in seven regencies/cities (Bogor Regency, Bogor City, Depok, South Tangerang City, Tangerang City, South Jakarta, and West Jakarta) with total area of watershed is 55,141.84 ha. The upstream area is located in Bogor Regency and flows to West Jakarta through Depok, South Tangerang, Tangerang City, and South Jakarta. Pesanggrahan Watershed have been reported has several activities such as residential and commercial area. Land use of Pesanggrahan River can be seen in figure 1. While table 1 showed area percentage of every land use.

Figure 1. Land use map of Pesanggrahan Watershed in 2013.
Table 1. Land use and its percentage area in Pesanggrahan Watershed.

| No | Area             | Percentage Area (%) |
|----|------------------|---------------------|
|    |                  | Built area | Forest | Plantation | Agriculture | Shrub | Water Bodies |
| 1  | Bogor City       | 6.01       | 100.00 | 0.00       | 3.48        | 0.00  | 0.00         |
| 2  | Bogor Regency    | 1.27       | 0.00   | 0.00       | 29.21       | 0.00  | 10.17        |
| 3  | Depok            | 10.82      | 0.00   | 0.00       | 13.59       | 0.00  | 8.91         |
| 4  | South Tangerang  | 11.59      | 0.00   | 100.00     | 30.55       | 93.34 | 6.41         |
| 5  | Tangerang City   | 23.64      | 0.00   | 0.00       | 19.41       | 0.00  | 3.10         |
| 6  | South Jakarta    | 22.17      | 0.00   | 0.00       | 0.10        | 0.00  | 0.00         |
| 7  | West Jakarta     | 24.50      | 0.00   | 0.00       | 3.66        | 6.66  | 71.41        |
|    | Total            | 100.00     | 100.00 | 100.00     | 100.00      | 100.00| 100.00       |

2.2. Tools and materials
The data used for analysis is water quality monitoring data from Balai Besar Wilayah Sungai Ciliwung-Cisadane (BBWS-CC) and Environmental Status Book (SLHD) from 2013 to 2014 (every year has different availability of monitoring data). Another data that used for analysis are number of population, administration map, Pesanggrahan watershed boundary map, water requirement every segment, planning official map and landuse landcover map. The tools used for research are ArcGIS 10.5 and microsoft excel.

2.3. Methods
Representative water quality data per year was concluded by averaging the data in that year. The parameters were total dissolved solids (TDS), total suspended solids (TSS), temperature, pH, biochemical oxygen demand (BOD), chemical oxygen demand (COD), and dissolved oxygen (DO) based on availability of data in every station. There were six monitoring stations for water quality observation, namely Jl. Ciputat Pasar Jum'at Lebak Bulus, Jl. H. Kelik, city park, Sawangan, Tanah Kusir, and Kebun Jeruk.

The potential polluted load in Pesanggrahan watershed was estimated by secondary data from SLHD report of Bogor City, Bogor Regency, Depok, South Tangerang, Tangerang City, South Jakarta, and West Jakarta. Because all of pollutant sources were non point source, it’s difficult to conduct direct measurement. Emission factor pollution load from industry, mining, residential area, agriculture, farms, fishing, hotel, hospital, and waste was estimated. The potential polluted load parameters was counted for BOD, COD, and TSS (kg/day). The formula for estimating potential polluted load can be seen in equation 1-10. While emission factor for each parameter can be seen in table 2, table 3, table 4, table 5, table 6, and table 7.

2.3.1. Pollutant estimation for industry

\[
P pollutant \left( \frac{Kg}{year} \right) = \frac{Ci \times V \times OpHrs}{1,000,000}
\]  

\( Ci = \) Concentration on wastewater (mg/L)  
\( V = \) Velocity of wastewater (L/hour)  
\( OpHrs = \) operational hours (hours/year)  
\( 1,000,000 = \) Conversion factor from mg to kg
2.3.2. Pollutant estimation for household

\[
\text{Pollutant (kg/day)} = \frac{\text{Population} \times \text{Emission factor} \times \text{equivalence ratio} \times \alpha}{1000}
\]

Emission factor:
1. BOD = 40 gr/person/day
2. COD = 55 gr/person/day
3. TSS = 38 gr/person/day

Urban equivalence ratio:
1. Urban area = 1
2. Suburb area = 0.8125
3. Countryside = 0.625

Alpha (\(\alpha\)): Load transfer coefficient (0.3 - 1)
\(\alpha = 1\) for location 0-100 meter from river
\(\alpha = 0.85\) for location 100-500 meter from river
\(\alpha = 0.3\) for location >500 meter from river

2.3.3. Pollutant estimation for livestock farming

\[
\text{Pollutant (kg/day)} = \frac{\text{number of livestock} \times \text{Emission factor} \times 0.2}{1000}
\]

Table 2. Livestock emission factor.

| Parameter | Unit | Buffalo | Cow | Horse | Pig | Sheep | Goat | Chicken | Swan | Duck |
|-----------|------|---------|-----|-------|-----|-------|------|---------|-------|-------|
| BOD       | gr/livestock | 207    | 292 | 226   | 128 | 55.7  | 34.1 | 2.36    | 2.46  | 0.88  |
| COD       | gr/livestock | 530    | 717 | 558   | 362 | 136   | 92.9 | 5.59    | 6.67  | 2.22  |
| N Total   | /day     | 2.6    | 0.93| 38.08 | 4.62| 0.278 | 1.62 | 0.002   | 0.061 | 0.001 |
| P Total   | /day     | 0.39   | 0.15| 0.31  | 0.31| 0.063 | 0.11 | 0.002   | 0.006 | 0.005 |

2.3.4. Pollutant estimation for agriculture

\[
\text{Pollutant (kg/day)} = \frac{\text{crop area} \times \text{emission factor} \times 0.1}{\text{number of days of planting season}}
\]

Table 3. Agriculture emission factor.

| Pollutant (Kg/Ha/Planting Season) | Paddy | Secondary crop | Plantation |
|-----------------------------------|-------|----------------|-----------|
| BOD                               | 225   | 125            | 32.5      |
| N                                 | 20    | 10             | 3         |
| P                                 | 10    | 5              | 1.5       |
| TSS                               | 0.46  | 2.4            | 1.6       |
| Pesticide                         | 0.16  | 0.08           | 0.025     |
2.3.5. Pollutant estimation for hotel and hospital

\[
Pollutant \ (kg/\text{day}) = \frac{\text{number of room} \times \text{emission factor} \times \% \text{ occupancy} \times \text{equivalence ratio} \times \text{Runoff Ratio}}{1000}
\]  
(5)

\[
Pollutant \ (kg/\text{day}) = \frac{\text{number of bed} \times \text{emission factor} \times \% \text{ occupancy} \times \text{equivalence ratio} \times \text{Runoff Ratio}}{1000}
\]  
(6)

Table 4. Emission factor of hotel and hospital.

| Type of Pollutant Source | Emission factor (gr/day) |  |  |
|-------------------------|--------------------------|---|---|
|                         | BOD                      | COD | TSS |
| Hospital (per bed)      | 123                      | 169.125 | 116.85 |
| Hotel (per room)        | 55                       | 75.625 | 52.25 |

2.3.6. Pollutant estimation for fisheries

\[
Pollutant \ (kg/\text{day}) = \frac{\text{fisheries production} \ (kg/\text{year}) \times \text{Emission factor}}{365}
\]  
(7)

Table 5. Quantity of pollutant load per 1 kg of aquaculture production (kg/year).

| BOD          | COD          | Nitrogen Total | Phosphor Total |
|--------------|--------------|----------------|----------------|
| 0.0966       | 0.1449       | 0.0572         | 0.0131         |

2.3.7. Pollutant estimation for domestic waste

\[
Pollutant \ (kg/\text{day}) = \text{unhandled domestic waste} \ (kg/hari) \times \text{Emission factor}
\]  
(8)

Table 6. Domestic waste emission factor.

| Emission factor | Emission (Kg/day) |
|-----------------|-------------------|
| BOD             | 0.00282           |
| COD             | 0.003878          |
| TSS             | 0.002679          |

2.3.8. Pollutant estimation for small enterprise

\[
Pollutant \ (kg/\text{day}) = \frac{\text{Production} \ (kg/\text{day}) \times \text{Emission factor} \times 0.3}{1000}
\]  
(9)
Table 7. Small enterprise emission factor.

| No | Type of Small Enterprise | Parameter (Kg/day) |  |
|----|--------------------------|--------------------|---|
| 1  | Soybean processing       | BOD: 50            | COD: 110 | TSS: 80 |
| 2  | Tapioca processing       | BOD: 3.34          | COD: 10.30 | TSS: 4.67 |

2.3.9. Total pollutant estimation

Total Water Pollution Load

\[ = \text{Industry pollutant} + \text{Household pollutant} + \text{Livestock pollutant} \\
+ \text{Agriculture pollutant} + \text{Hospital pollutant} + \text{Hotel pollutant} \\
+ \text{Fisheries pollutant} + \text{Domestic waste pollutant} + \text{Small enterprise pollutant} \] (10)

The landuse map was generated from planology agency of Indonesia. The classification of landuse was grouped into eleven classes such as airport, planting forest, farm/plantation, residential area, dry land agriculture, dry land agriculture with shrubs, paddy field, shrubs, shrubs swamp, ponds, and water body. The watershed boundary was generated from Indonesian watershed data. Quality standards of TDS, TSS, temperature, pH, BOD, COD, and DO based on government regulation No. 82 year 2001 can be seen in table 8.

Table 8. Quality standards based on government regulation No. 82 year 2001 for each water use class.

| Parameters | Unit | Quality standards |
|------------|------|-------------------|
|            |      | Class I | Class II | Class III | Class IV |
| TDS        | mg/l | 1000     | 1000     | 1000      | 2000     |
| TSS        | mg/l | 50       | 50       | 400       | 400      |
| Temperature| °C   | -        | -        | -         | -        |
| pH         | -    | 6 – 9    | 6 – 9    | 6 – 9     | 5 – 9    |
| BOD        | mg/l | 2        | 3        | 6         | 12       |
| COD        | mg/l | 10       | 25       | 50        | 100      |
| DO         | mg/l | 6        | 4        | 3         | 0        |

3. Results and discussion

All monitoring locations were located in downstream area which water use is for freshwater fish farming and husbandry (Class III). The averaged water quality data in 2014 is shown in table 9. The values in grey shading means that they didn’t meet the quality standards of Class III. The high value of BOD usually indicates high residential and commercial lands [11]. According to Li’s research [12] the sampling time also affects the water quality. BOD and COD concentrations tend to be higher during the dry season.

Table 9. Averaged water quality in 2014.

| Parameter | Jl. Ciputat Pasar Jum'at Lebak Bulus | Jl. H. Kelik | Taman Kota | Sawangan | Tanah Kusir | Kebun Jeruk |
|-----------|--------------------------------------|--------------|------------|----------|-------------|-------------|
| TDS       | 107.7                                | 133.2        | 143.3      | 99.0     | 140.0       | 194.0       |
| TSS       | 28.3                                 | 57.0         | 42.5       | 112.0    | 71.0        | 43.0        |
| Temperature| 27.6                                 | 29.2         | 28.6       | 27.5     | 28.0        | 28.0        |
| pH        | 7.4                                  | 7.4          | 7.4        | 7.5      | 7.7         | 7.7         |
| BOD       | 3.8                                  | 9.6          | 8.6        | 2.7      | 2.5         | 3.5         |
| COD       | 40.0                                 | 34.7         | 40.0       | 48.8     | 60.6        | 68.8        |
Parameter | Jl. Ciputat Pasar Jum'at Lebak Bulus | Jl. H. Kelik | Taman Kota | Sawangan | Tanah Kusir | Kebun Jeruk
---|---|---|---|---|---|---
DO | 4.6 | 1.1 | 3.0 | 4.4 | 2.0 | 1.1

Figure 2. Estimation of potential polluted load of BOD, COD and TSS in Pesanggrahan river from 2012 – 2014 (kg/day).

Figure 2 illustrated the estimation of potential pollution load in Pesanggrahan river from 2012 to 2014. Segmentation division based on administrations boundary mentioned in table 1. The highest potential pollution load of BOD, COD, and TSS is in segment 2. Based on analysis, residential area contributed highest source of pollution load of BOD. Meanwhile, small and medium enterprise contributed highest source of COD and TSS in Pesanggrahan River.

Land use in the Pesanggrahan watershed is divided into eleven kinds of land utilization comprising airports, crops, plantations, residential area, dryland farming, dryland farming with shrubs, paddy fields, shrubs, swamps, mines, water bodies. Residential area has an area of almost 90% of the entire Pesanggrahan River Watershed. The contribution of this residential area to changes water quality is household waste. According to Downing et al [13], land conversion from forest to developed area or plantations is more common in tropical countries. The land cover in the built area is dominated by pavement, allowing sediment deposits to water bodies [14-16].

The highest developed area is located in segment 7 (24.5%). However, area with the highest BOD, COD, and TSS values is located in segment 2. The concept of BOD came after cities started dumping their waste water into the water bodies and this led to depletion of oxygen. Thus, although an area has a fairly small developed area but high urban activity, it may cause the BOD value to increase. Urbanization increases the high value of pollutants such as ammonia, chloride, and coliform [17]. On the other hand,
in areas with urban land cover and accompanied by high agricultural activity tend to have high nitrate concentration. This is related to the use of fertilizers and pesticides [18]

4. Conclusion
The high concentration of BOD, COD, and DO that have been obtained from the sampling result shows high urban activity in some segments. It may cause water sample can not meet water quality standard of Class III. Based on the estimation of potential pollutant load, the highest BOD, COD and TSS values are located in segment 2. However, the percentage of developed area is located in segment 7. It shows that in segment 2 there is high urban activity and produce BOD, COD and TSS that exceed other segments. Although land cover has influence on water quality, land cover is not the only one factor that affected water quality. Domestic wastes are generally main cause of river water pollution in almost developing countries. Therefore, further research needed to ensure that land cover has important impact on water quality.

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