Prediction of spatial pollution load using the PLOAD Model

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Abstract The rapidly growing population density has decreased water quality due to waste from human activities originating from industrial, agricultural, and household activities that produce waste. Non Point Sources pollutants are difficult to control because their formation is very complicated. The BASINS-PLOAD model is used to predict the amount of pollutant load and non-point sources based on spatial data. The pollution loading model using BASIN PLOAD shows good results. The estimated pollution load of Nitrate and Phosphate parameters in the Garang watershed from 2006 to 2012 and 2012 to 2017 increased. It was related by a massive increase in residential land area. Settlements produce domestic waste, which contains nitrate and phosphate parameters.

1. Introduction

Currently, watersheds around the world are having problems caused by excessive human activity [1], [2]. One of the issues that arise is the pollutant load in rivers, increasing the human population, thus changing land use due to housing, food, and infrastructure development for transportation that encourages urbanization and agricultural activities [3-5]. The rapidly growing population density has decreased water quality due to waste from human activities originating from industrial, agricultural, and household activities that produce waste[6].

Pollutants originating from runoff from various types of land use and human activities are called non-point source (NPS) pollutants. The release of NPS pollutants has a significant impact on river water quality in a watershed [7]. However, NPS pollutants are difficult to control because their formation is very complicated, so a tool or tool that can predict the NPS pollutants produced in a watershed is needed. One of the tools that can estimate this is by using a simulation model. The advantage of using a simulation model is that it is cost-effective, and the hydrological data can be easily analyzed. However, the main limitation is the inability to calibrate and verify model parameters in applications if the inputted data is insufficient, especially in watersheds of developing countries, such as Indonesia[8]. BASINS integrates the data in a Geographic Information System (GIS) environment. BASINS has a variety of models, one of which is the Pollutant Loading Estimator (PLOAD), which is a simplified GIS-based model for calculating the pollution load for river basins (DAS). The BASINS-PLOAD model is used to predict the amount of pollutant load and non-point sources based on spatial data [9-11].
Research on the estimation of non-point source (NPS) pollution load in the Fujiang River Basin, China using the PLOAD model shows that land-use changes affect the non-point source pollution load. Land use is the leading cause of NP pollutants, while human and livestock disposal is the leading cause of TP pollutants. Therefore, PLOAD can be used to support non-point source pollution management [12]. Another study used PLOAD to model pollutants in the Mulberry and Catoma watersheds, Alabama, United States, where the model results were compared with the results obtained from field sampling followed by laboratory analysis. The results obtained from the PLOAD model are following the analysis results. So that PLOAD is a valid model for determining pollutants in the watershed.

Like the city of Semarang and its surroundings, population growth has led to urbanization events that have led to land changes. It can impact the hydrological process in a watershed (DAS), including in the Garang Watershed. The Garang River has an essential role as the primary source of raw water for the City of Semarang, processed at the Sampangan and Jatibarang Drinking Water Treatment Plants. Changes in land use and precipitation, soil type, and topography can affect runoff, erosion, and the process of contaminant flow to water bodies [13,14]. In Indonesia, research is still rare to calculate the pollutant load of rivers using modeling. Rivers in Indonesia have different characteristics due to socioeconomic factors, climate, and geological conditions that are different from developed countries. This study aims to determine the estimated pollutant load due to land-use changes in the Garang watershed using the PLOAD model.

2. Methodology
The Garang watershed consists of 3 districts, namely Semarang Regency, Kendal Regency, and Semarang City. The data needed, namely secondary data, includes GIS data on land use data for 2006, 2012, and 2017 from digitization and rainfall data for that year. This research estimates or estimates the amount of non-point source pollution load using the PLOAD model in BASINS 4.1 software. The PLOAD model for calculating the pollutant load is categorized into two, namely the Expert Coefficient (simple method) and also the simple method (EMC) [15]. This study uses a simple method that requires data on EMC values and impervious factors for each land use. This EMC (Event Mean Concentration) value is an approach to each land use category [16,17]. EMC data and impervious factors specific to the study area were not available, so this study uses data from the literature recommended by PLOAD.

| Landuse        | Impervious (%) | EMC Nitrate | EMC Phosphate |
|----------------|---------------|-------------|---------------|
| Forest         | 2             | 0.4         | 0.2           |
| Settlement     | 36            | 0.8         | 0.3           |
| Shrubs         | 2             | 0.4         | 0.2           |
| Moor           | 5             | 0.4         | 0.2           |
| Plantation     | 5             | 0.4         | 0.2           |
| Mixed Plantation| 5            | 0.4         | 0.2           |
| Industry       | 91            | 1           | 0.4           |
| Open Field     | 2             | 0.4         | 0.2           |
| Recreation     | 75            | 0.9         | 0.4           |
| Watershed      | 0             | 0.4         | 0.2           |
| Rice Fields    | 5             | 0.4         | 0.2           |
| Farm           | 5             | 0.4         | 0.2           |
| Grave          | 2             | 0.4         | 0.2           |
| Pond           | 0             | 0.4         | 0.2           |
The calculation method "Simple Method" on PLOAD was chosen to calculate the Garang watershed's estimated pollution load because the calculation is more accurate. After all, the simple method considers the effect of rainfall in calculating the pollutant load. The following equations are used in the PLOAD model. Pollution load using the PLOAD Model produces pollution load in units of lbs/year; the results are converted into tons/year units.

\[ RVU = 0.05 + (0.009 \times IU) \]  
\[ RVU = \text{Runoff coefficient for land use type } u, \text{ runoff in inches/rainfall in inches} \]  
\[ IU = \text{Percent imperviousness} \]

\[ LP = \sum U (P \times PJ \times RVU \times CU \times AU \times 2.72/12) \]

\[ LP = \text{Pollutant load, lbs;} \]
\[ P = \text{Precipitation, inches/year;} \]
\[ PJ = \text{Rainfall ratio resulting in runoff (default } = 0.9; \]
\[ RVU = \text{Runoff coefficient for land use type } u, \text{ runoff in inches/rainfall in inches;} \]
\[ CU = \text{Event Mean Concentration for land use type } u, \text{ milligram/liter} [17]. \]

3. Results and discussion

Urban land change is marked by the broader area of built-up lands such as settlements and industry, followed by an increase in population and an increase in economic activity in Semarang and its surroundings, as shown in figure 1. From 2006 to 2017 was an increase in the area of built-up land, but the location of forest land was also increasing. This increase in forest land is suitable for watersheds because forests have an essential role in holding back surface runoff to reduce flooding and landslides, in addition to forests' presence, less sediment and nutrients dissolved in the flow [14].

![Figure 1. Graph of land changes in Garang watershed 2006-2017.](image)

The Garang watershed has an area of 21,277.36 hectares which includes the administrative areas of Semarang City, Semarang Regency and Kendal Regency. Of the three districts / cities, the district that has the most dominant area is Semarang City with an area of 11,451.90 hectares or about 53.82% of the total area. So far, the main water source of PDAM is from the Garang River and a small part of the spring. The increase in forest land area in the Garang watershed follows the Spatial Planning of Semarang Regency 2011-2031 and the Spatial Planning of Kendal Regency in 2011-2031. The direction for forest land maintenance efforts in the Spatial Planning Semarang Regency is one way to limit the conversion of production forest functions. Simultaneously, in the Spatial Planning, Kendal Regency provides directions for intensifying production forest land and optimizing community forest management. Table 2 is an example of 6 sub-districts from 17 sub-districts in the Garang watershed that
experienced significant changes from 2006 to 2012 and 2012 to 2017. On the other hand, rice fields in the Garang watershed sub-districts from 2006 to 2017 continue to decrease. The area of mixed gardens in several sub-districts in the Garang watershed has reduced the size of land. Meanwhile, residential land has continued to increase in land area. It is supported by BPS data that there has been an increase in population in the sub-districts in the Garang watershed area.

Prediction of non-point source pollution load estimation resulted from settlement using the PLOAD model based on land-use change. The estimated pollution load from the PLOAD model is divided into five categories based on the Natural Breaks (Jenks) classification in ArcGIS 10 with the same intervals for each year.

![Figure 2](image)

**Figure 2.** The Year nitrate pollution load estimation (Lbs/Year) (a) 2006, (b) 2012, (c) 2017.

In figure 2, the estimation of nitrate pollution load from 2006 to 2017 shows that the category of pollution load is very high, indicated by a dark purple color in the sub-districts/villages in the Garang watershed, the number of distribution increases. The estimated value of nitrate pollution load from the PLOAD model has increased from 2012 to 2017, amounting to 15.02 tons/year and rising from 2006 to 2012 of 65.80 tons/year. Meanwhile, the estimated map of phosphate pollution load from 2006 to 2017 shows that the category of pollution load is very high, indicated by a dark red color in the sub-districts/villages in the Garang watershed of distribution increases. According to figure 3 of the PLOAD model, the estimated value of phosphate pollution load has increased from 2006 to 2012 by 1476.94 tons/year and increased from 2012 to 2017 by 110.52 tons/year. The increase in nitrate pollution load can be seen spatially in area that have experienced a significant increase in residential areas such as Sekaran, Patemon, and Kalisegoro sub district due to the development of the UNNES campus area. Meanwhile, an increase in the upstream watershed occurred significantly in Ungaran district in Ungaran, Lerep, and Bandarharjo villages.

According to figure 4, Nitrate and Phosphate in the Garang watershed, the total estimated pollution load parameters from 2006 to 2012 and 2012 to 2017 have increased. Nitrate parameters experienced an increase in pollutant load from 2006 to 2012 by 23% and increased again from 2012 to 2017 by 4%. Phosphate parameters experienced an increase in pollutant load from 2006 to 2012 by 23% and increased from 2012 to 2017 by 1%. The change in phosphate pollutant load has a slightly different change trend with nitrate. The increase in phosphate is significantly more distributed in the areas along city roads where there is a change from agricultural land to developed land. The increasing pollution load in the Garang watershed from 2006 to 2017 was supported by a massive increase in residential land area. The
growth in residential land in the Garang watershed is supported by BPS data, namely the population's expansion in the Garang watershed area's sub-districts.

Figure 3. The year phosphate pollution load estimation (Lbs/Year) (a) 2006, (b) 2012, (c) 2017.

Figure 4. Graph of estimation of the total change in pollution load for all parameters (Tonnes/year) 2006-2017.

The estimated pollution load from PLOAD of nitrate and phosphate parameters from 2006 to 2017 has increased because increased settlements influence it, colonies produce domestic waste. Others research explained that anthropogenic sources (unnatural sources of pollution that arise due to human intervention or their activities) of phosphorus and nitrogen are domestic and industrial waste [1,18].

4. Conclusion
The pollution loading model using BASIN PLOAD shows good results. The estimated pollution load of Nitrate and Phosphate parameters in the Garang watershed from 2006 to 2012 and 2012 to 2017 increased. Nitrate parameters experienced increased pollutant load from 2006 to 2012 by 23%, and there was an increase again from 2012 to 2017 by 4%. Phosphate parameters experienced an increase in pollutant load from 2006 to 2012 by 23%, and there was an increase from 2012 to 2017 by 1%. The increasing pollution load in the Garang watershed from 2006 to 2017 was supported by a massive increase in residential land area. The expanding population supports the growth in residential land in the Garang watershed in the Garang watershed area. Settlements produce domestic waste, which contains
nitrate and phosphate parameters. Further research needs to be studied more deeply related to the validation of values by testing the quality of water in the Garang river. Environmental quality data in time series to provide a more detailed description of trends that occur for model correction.

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