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# Nutrient Limit Estimation for Eutrophication Modelling at Sengguruh Reservoir, Malang, Indonesia

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## ABSTRACT

Sengguruh Reservoir located in Malang Regency has important function as sediment barriers for Sutami Reservoir. The water contains many organic matters that will cause eutrophication. The effect of eutrophication can reduce the biodiversity in the reservoir. The purpose of this study is to identify the trophic status of Sengguruh Reservoir using TSI method and to estimate the nutrient limit (nitrate and phosphate) to predict the eutrophication using quantile regression approach. The results show that Sengguruh Reservoir is in heavy eutrophic state. On the other hand, the nutrient limit estimation to predict heavy eutrophication is at 0.853 mg/L for nitrate and 0.862 mg/L for phosphate.

## INTRODUCTION

Aquatic ecosystems can be divided into natural and artificial waters. The artificial waters were usually built for many purposes such as irrigation, power generation, navigation, flood control, water supply, and recreation. Reservoir is one example of artificial waters which is made by damming rivers, and has distinguished characteristics where it receives waters continuously from the rivers that are embodied with organic and inorganic matters. Moreover, they also contain fertilizer residues from agricultural activities and lead to nutrient (nitrogen and phosphorus) enrichment that is affecting phytoplankton community (Sugiura et al. 2004, Suryanto 2011).

Sengguruh reservoir is located in Malang regency, in the lower reaches of the Brantas River and Lesti River; also, at the end of the Sutami Reservoir inundation area. It is categorized as a multipurpose reservoir which aims to meet the availability of irrigation water, power plant, and the most important function as a sediment barrier that enters the Sutami Reservoir. Sedimentation in Sengguruh Reservoir increases every year. Since 2000, there is significant rise in population and industry around the reservoir area which result into the increasing of water use and pollution, especially by organic pollutants from domestic and industry wastes (Yetti 2007).

As an aquatic ecosystem, Sengguruh Reservoir contains high biodiversity because it is the habitation for aquatic organisms. The addition of organic matters in aquatic ecosystem can boost the nutrient (nitrogen and phosphorus) enrichment, and at any level results into eutrophication. The phenomenon of eutrophication brings negative effects for aquatic ecosystems such as mass mortalities of aquatic organisms and creating a dead zone where no organisms can survive. Thus, the biodiversity will reduce (Isnaini et al. 2014, Paiki & Kalor 2017, Putri et al. 2014, Rashidy et al. 2013, Widyastuti et al. 2015). Therefore, in order to prevent the eutrophication, it can be sought through making an observation to nutrient concentration in the waters. The estimation of nutrient limit that may cause eutrophication can be performed by use of quantile regression. The method has advantages to model the relationship between nutrient concentrations thoroughly, not only at mean level of response variable as in linear regression (Lusiana et al. 2019, Xu et al. 2015, Yu & Moyeed 2001).

The purpose of this study is to identify the eutrophication state of Sengguruh Reservoir by using Trophic State Index (TSI) and estimating the nutrient limit as the indicators to predict the eutrophication. Since this study concerns to the high abundance of phytoplankton which indicates eutrophication, then the relationship between nutrient and phytoplankton abundance will be modelled at upper quantile. The index was introduced by Carlson (1977) and has been widely used to assess the trophic status of many lakes and reservoirs (Bekteshi & Cupi 2014).

## MATERIALS AND METHODS

The research was conducted in Sengguruh Reservoir located in Kepanjen District, Malang. The sampling locations consist of four sites, they are (1) inlet from Brantas River; (2) inlet from Lesti River; (3) inner part of reservoir; (4) outlet or water exit which nears to residential area, power generating plant, and aquacultures. The study area can be seen in Fig. 1. The data were collected in January-February 2018.

The observed variables in this study are chlorophyll-*a* (mg/m$^3$), total phosphate (mg/L), visibility (m), phytoplankton abundance (ind/mL), orthophosphate (mg/L), and nitrate (mg/L). The first three variables were used to determine the trophic status of Sengguruh Reservoir using TSI method. Meanwhile, orthophosphate and nitrate, known as nutrients, in aquatic ecosystem become the predictors for phytoplankton abundance in order to estimate the nutrient limit for predicting eutrophication by modelling using quantile regression approach.

### TSI Method

Trophic State Index (TSI) is the indicator of aquatic ecosystem fertility through algae biomass. The algae biomass estimates through chlorophyll-*a*, Secchi disc depth or visibility, and total phosphate. TSI ranged from 0 to 100. Trophic status classification using TSI is presented in Table 1 (Carlson 1977).

TSI score can be calculated using formula in equation (1)

$$TSI(SD) = 60 - 14.41 \ln (SD)$$

$$TSI(CHL) = 30.6 + 9.81 \ln (CHL)$$

$$TSI(TP) = 4.15 + 14.42 \ln (TP)$$

$$TSI = \frac{TSI(SD) + TSI(CHL) + TSI(TP)}{3} \quad \ldots(1)$$

Where,

SD = Secchi disc depth (m)

CHL = Chlorophyll-*a* (μg/L)

TP = Total phosphate (μg/L)

### Quantile Regression

Quantile regression is a method to analyse relationship between variables at various quantile of the response variable (Koenker & Hallock 2001). Equation (2) shows the general


Fig. 1: Sampling location in Sengguruh reservoir.

Table 1: TSI score classification.

| Score | Trophic State |
|---|---|
| <30 | Ultraoligotrophic |
| 30 – 40 | Oligotrophic |
| 40 – 50 | Meso-trophic |
| 50 – 60 | Light Eutrophic |
| 60 – 70 | Medium Eutrophic |
| 70 – 80 | Heavy Eutrophic |
| >80 | Hyper-eutrophic |

form of quantile regression model (Buhai 2005).

$$y_i = \mathbf{x}_\mathbf{i}^\mathbf{t}\beta(\mathtt{q}) + \mathtt{e}(\mathtt{q})_i \quad 0 < \mathtt{q} < 1 \qquad \ldots(2)$$

Where,

$y_i$ = response variable of the i$^{th}$ observation

$\mathbf{x}_i^t = \left(1, x_{1i}, x_{2i}, \ldots, x_{pi}\right)$

$\beta(\mathtt{q})$ = parameter regression at the $\theta^{th}$ quantile

$\mathtt{e}(\mathtt{q})_i$ = error/residual model of the $\theta^{th}$ quantile

i = 1, 2, ..., n

According to Koenker & Basset (1978), parameter estimation of equation (3) and (4) is the solution of minimization.

$$\min_{\beta \in \mathbb{R}^p}\left[\sum_{i \in \{i: y_i \geq \mathbf{x}_i{}'\beta\}} \mathtt{q}\left|y_i - f(\mathbf{x}_i)\right| + \sum_{i \in \{i: y_i < \mathbf{x}_i{}'\beta\}} (1-\mathtt{q})\left|y_i - f(\mathbf{x}_i)\right|\right] \qquad \ldots(3)$$

$$\min_{\beta \in \mathbb{R}^p}\left[\sum_{i \in \{i: y_i \geq \mathbf{x}_i{}'\beta\}} \mathtt{r}_\mathtt{q}\left(y_i - f(\mathbf{x}_i)\right)\right] \qquad \ldots(4)$$

$\mathtt{r}_\mathtt{q}(u) = (\mathtt{q} - 1_{\{u<0\}})u$ , is called as *check function* which is illustrated in Fig. 2.

According to Chen (2005), equation (4) does not have fixed derivative form, so that a common numerical iteration cannot be performed to obtain the parameter estimation. Thus, an alternative method of linear programming was considered namely simplex method.

## RESULTS AND DISCUSSION

### Trophic Status of Sengguruh Reservoir

The TSI scores of each sampling site in Sengguruh Reservoir are given in Table 2.

According to Table 2, it can be seen that the TSI scores of the four sampling sites in Sengguruh Reservoir are between 68.64 and 74.35. It means that the trophic status is categorized as medium eutrophic and heavy eutrophic, but mostly the status is heavy eutrophic. These results show that the TSI score for medium eutrophic almost reach the upper limit for this category. So, on the whole, the eutrophication status in Sengguruh Reservoir is heavy eutrophic.

The status indicates that Sengguruh Reservoir has high fertility and this condition can reduce fishery production and biodiversity. The increase of fertility in aquatic ecosystem due to nutrient enrichment by the addition of organic matters into waters. According to Firdaus (2015), there is a tendency of land use changes and use of natural resources that do not consider aspects of soil and water conservation around the upstream Brantas River (Site 1) and Lesti River (Site 2) which cause the decline in watershed function, specifically

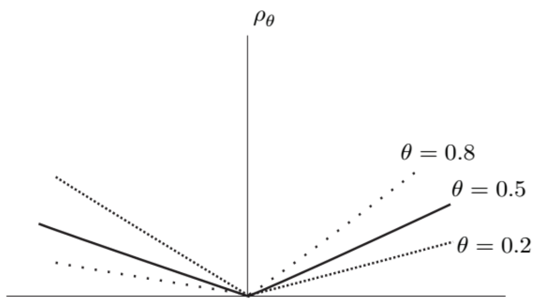



Fig. 2: Check function.

Table 2: Result of TSI Scores in Sengguruh Reservoir.

| Site | Week | TSI Scores | Remarks |
|---|---|---|---|
| 1 | 1 | 71.1025 | Heavy eutrophic |
| | 2 | 73.2234 | Heavy eutrophic |
| | 3 | 72.269 | Heavy eutrophic |
| 2 | 1 | 69.805 | Medium eutrophic |
| | 2 | 74.0642 | Heavy eutrophic |
| | 3 | 72.0439 | Heavy eutrophic |
| 3 | 1 | 68.6458 | Medium eutrophic |
| | 2 | 74.2981 | Heavy eutrophic |
| | 3 | 73.8333 | Heavy eutrophic |
| 4 | 1 | 70.5054 | Heavy eutrophic |
| | 2 | 74.3593 | Heavy eutrophic |
| | 3 | 73.864 | Heavy eutrophic |

to hold sediment materials.

As the consequence, the water entry of Brantas River and Lesti River into Sengguruh Reservoir embodied by a lot of sediments and organic matters as the result of domestic and agricultural wastes. Moreover, the residential areas and aquaculture activities (Site 4) around the Sengguruh Reservoir also contribute to the accumulation of sediment and organic matter in the waters. Especially, the use of fertilizer in agricultural activities and fish feed residues in aquaculture activities that contain nitrogen and phosphate may result in nutrient enrichment in the reservoir ecosystem.

## Eutrophication Model

Eutrophication predictive model through nitrate and phosphate concentration in Sengguruh Reservoir as the predictors conducted using quantile regression. The scatterplot to describe the relationship between nutrients and phytoplankton abundance is shown in Fig. 3.

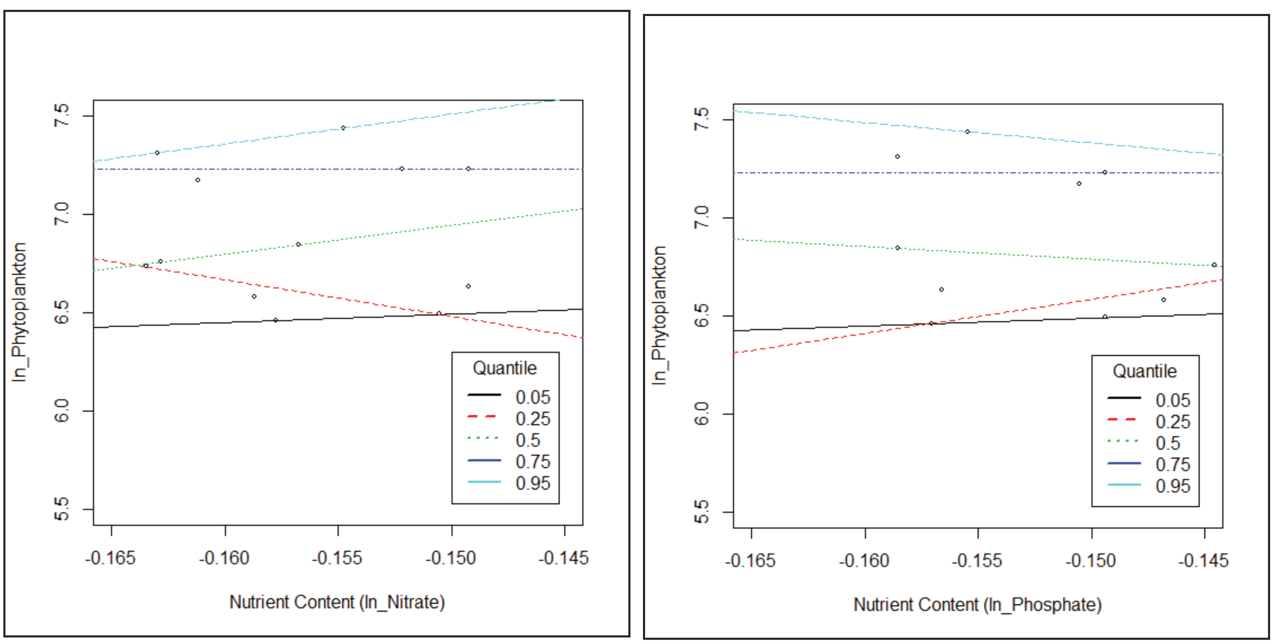
Fig. 3(a) reveals that the relationship between nitrate and phytoplankton abundance is not uniform of each quantile. Negative relationship was found in quantile 0.25 and 0.75, and the rest quantiles showed positive relationship. Meanwhile in Fig. 3b, the positive relationship carried out on quantile 0.25 and 0.75, but the remaining quantiles have negative relationship. The positive relationships of the variables explain that the increasing of nutrient content will result in the higher abundance of phytoplankton. This finding is relevant to the eutrophication theory due to nutrient enrichment. However, in some quantiles, the relationship is negative or in other words the increase of nutrient will cause the phytoplankton abundance to decrease instead.

According to Table 2, current Sengguruh Reservoir is in heavy eutrophic state. It means that the eutrophication modelling at high quantile (θ = 0.95) level will be used to predict heavy eutrophication. The parameter estimates of quantile regression are presented in Table 3.

Based on Table 3, nitrate and phosphate concentration of 0.853 mg/L and 0.862 mg/L respectively will cause medium eutrophication in Sengguruh Reservoir. If the results compared are to Wetzel (2001), then such concentration of nitrate and phosphate indicate the that the water is oligotrophic. These findings indicate that the classification cannot be used to identify the eutrophication in Sengguruh Reservoir since the sedimentation has been too high, and moreover a bit increase of nutrients will boost the abundance of phytoplankton.

## CONCLUSION

Trophic status of Sengguruh Reservoir is classified as heavily eutrophic. The level of nitrate concentration to predict the heavy eutrophication is 0.853 mg/L, and phosphate is 0.862 mg/L. This result indicates that when the measurement of




(a) (b)

Fig. 3: Scatterplot of phytoplankton abundance with quantile lines (a) nitrate; (b) phosphate.

Table 3: Parameter estimates of quantile regression.

| Quantile | Phytoplankton-abundance (ind/mL) | Parameter estimates | | | |
|---|---|---|---|---|---|
| | | Nitrate | | Phosphate | |
| | | Intercept | Slope | Intercept | Slope |
| 0.05 | 650.92 | 7.137 | 4.282 | 7.092 | 4.012 |
| 0.25 | 749.80 | 3.687 | -18.637 | 9.199 | 17.428 |
| 0.50 | 899.11 | 9.140 | 14.636 | 5.839 | -6.349 |
| 0.75 | 1380.00 | 7.230 | 0.000 | 7.230 | 0.000 |
| 0.95 | 1586.91 | 9.799 | 15.254 | 5.849 | -10.224 |

nitrate and phosphate almost reach such concentrations, then handling action must be carried out in order to prevent heavy eutrophication.

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