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Mathematics Modelling of Nitrogen Mass Balance at the Rembangan River with Plug flow System Approach Using Finite Difference Methods

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ABSTRACT

Fertilization of nitrogen for the crop has purpose to optimized of crop farm and minimized damage of environment, actually most additions of nitrogen caused releasing of nitrate. Nitrate from nitrogen compound able to release passing the ground water. Contaminated of nitrate at the river water made the river water became very underprivileged of oxygen (hypoxic) and depressed life of biota river water at the downstream area. Aim the research was to know mass balance of nitrogen at the Rembangan river affected from input run off which entered into the river that contained waste from nitrogen fertilization. This research was built nitrogen mass balance model using Plug Flow System equation with Streeter-Phelps equation approach. This equation was finished by mathematics modelling finite difference method with Leapfrog schema. Result this research was value of output model for nitrate concentration equal to 0,728 mg/litre, but actually in the case average concentration of nitrate was equal to 0,6723 mg/litre for before fertilization and 0,8307 mg/litre for after fertilization . Value of plug flow system mass balance modelling was equal to 1,66 mg/sec of nitrate that dissolved at the Rembangan river. This result was shown that contribution of nitrate compound at Rembangan river still could be categorized as good based on the Indonesian Government Regulation number 20 Year 1990 with a maximum standard parameter of nitrate was 5 mg/liter.
Keyword: mathematics modelling, finite difference, plug flow system, nitrogen, river

INTRODUCTION

At the agriculture area, nitrogen fertilizer was a main source of groundwater pollution wich used as drinking water. At the area where nitrogen fertilizer was widely used, certainly residential wells were contaminated by nitrate. A study by the United States Geological Survey showed that more than 8200 wells at the U.S. were contaminated by nitrates exceed the drinking water standard by Environmental Protection Agency (EPA), which was 10 ppm. Other sources of nitrate contamination of well water were organic animal waste and seepage from septic tanks as biofertilizer which can be given directly into the soil, included in organic fertilizer or lining at the seeds to be planted. (Anonymous, 2009).

The addition of fertilizer in the soil can also released nutrition and contaminated water supply. Recent studies by researchers at the University of Minnesota showed that agriculture activity contributed an increase nitrate levels in surface and groundwater caused by modern or conventional fertilization (Anonymous, 2007). Nitrate contamination at the river water can caused river water became deficiency of oxygen (hypoxic) and can depressed life of the river biota (Anonymous, 2009)

Research on the effect of fertilization activity to water quality degradation in the watershed had been done in various countries, including Indonesia (Rest et al, 1983; Pujiyanto and Wibawa, 1999,2001; Korsaeth, 2000; Wahyuningsih, 2001; Affandi et al, 2002; Lee, Anne and Lee, G, 2002, 2005, 2006, 2008; Lee, G and Lee, Anne, 2002.2008; Kim et al, 2003; Le, 2005; Salo and Turtola, 2006; Karnaningroem, 2006; Graeff et all, 2008; Purwanto, 2009; Wahyuningsih et al, 2011). But until now still not many research done concern on the pollutant load mass balance model at the river from fertilization activities on the plantation.

To keep the river water quality did not degradation then required effort to manage river water quality monitoring, one of them is by using water quality modeling that was the nitrogen mass balance model. The basic concept of mass balance model was calculated using mathematical modeling with the finite difference method to the nitrogen mass balance approach plugflow system. This concept to calculate how many amount of fertilizer for the crop, how many loads that will enter through surface runoff caused by the fertilization of activity?

The spesific objectives of this research was the nitrogen mass balance model can applicable to predict the load of pollutant which contained in runoff water from fertilization activity in plantation area.

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MATERIALS AND METHODS

Study design

This research was executed in area plantation of coffee Afdeling Renteng Rayap PTPN XII Jember with model concept showing at **Figure 1.**

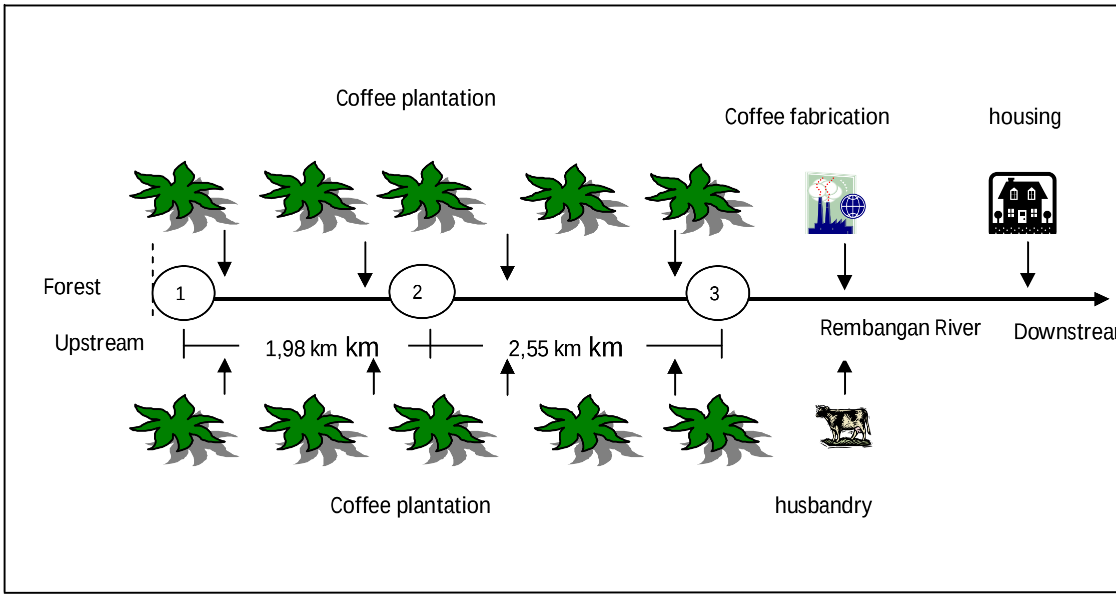


Figure 1: Schema Modelling Location Research

Data Collection

This research was used by the primary data and secondary data. Primary data taken directly in field. Test of water quality done in laboratory of Environmental Engineering Department, Civil Engineering Faculty of ITS Surabaya and laboratory of Soil Department , Agricultural Faculty of Jember University. The Primary data is nitrogen concentration data, dissolved oxygen concentration, velocity and discharge. Secondary data is the rainfall data in station of Dam Arjasa Jember, soil type, and slope of farm and also erosion value data in plantation of coffee Jember and obtained from related institution that was Watering Department of east Java Province, office of water river management Sampean Baru Bondowoso, PTPN XII Jember and Institute of Coffee and Cacao Research Indonesia (ICCRI). Research procedure showing at the flowchart research at **Figure 2.**

Formulation of Model

After processing and analyzing primary and secondary data, further more was formulated of nitrogen mass balance structure model that enter and leave of system. Building of model done by using of mathematics model finite different method with solution of mathematical equation using by the numeric analysis with Leap Frog scheme. Mass balance model for nitrogen pollutant in river done by using Plug Flow System method. The nitrogen mass balance model in the river was modelling wich combination for hydrology model and water quality model. Hydrology Model was built with approach of rainfall-discharge model using equation of discharge calculation with Rational method (Chin,2006; Suripin,2004) showing at **Figure 3**.

This model was modelling the condition of nitrogen fertilization at the plantation. That was when the rain fall so some of nitrogen will leaching by surface runoff hence have potency to add amount of the nitrogen concentrations in the river. Mathematics model structure finished by numeric method finite difference with leap frog schema. Compilation of algorithm model using the Visual basic 6 program. Built of this model was needed compilation of the mathematics structure base on continuity equation , Momentum equation, Pollutant Transport equation and mass balance Plug Flow System equation.

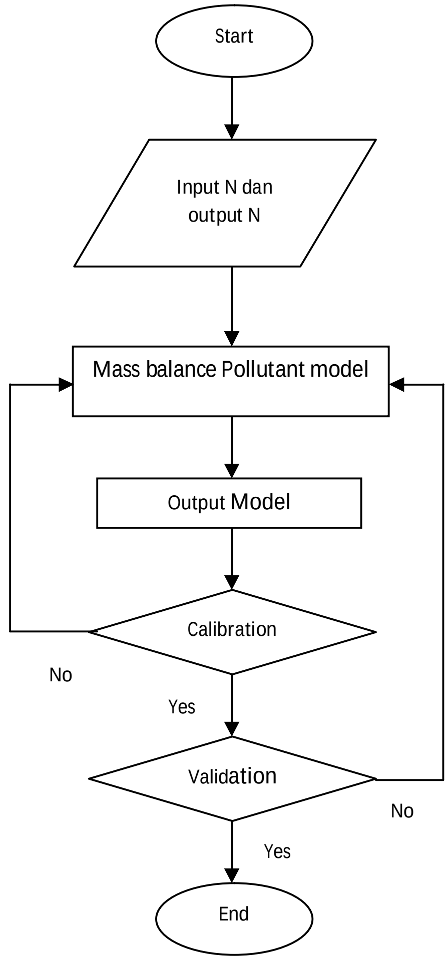


Figure 2: Flowchart Research

1. Continuity equation .

This modelling assumed that there were addition of discharge, so that the equation was as follow:

$$\frac{\partial \rho}{\partial t}+\frac{\partial \rho u}{\partial x}+\frac{\partial \rho v}{\partial y}=q \tag{1}$$

2 Momentum Equation

This modeling assumed that the river was straight with laminar flow and turbulent flow condition

a. Momentum equation for laminar flow condition was as follow:

$$\left[\frac{\partial \rho U}{\partial t}+\frac{\partial \rho u U}{\partial x}+\frac{\partial \rho v U}{\partial y}\right]-\left[Po+\rho g h\right]-\mu\frac{U\Delta}{\Delta x\Delta y}=0 \tag{2}$$

b. Momentum equation for turbulent flow condition was as follow:

$$\left[\frac{\partial \rho U}{\partial t}+\frac{\partial \rho u U}{\partial x}+\frac{\partial \rho v U}{\partial y}\right]-\left[Po+\rho g h\right]-\mu\frac{U\Delta}{\Delta x\Delta y}+E\frac{\partial \Phi}{\partial x_i}=0 \tag{3}$$

(Anggrahini, 2007)

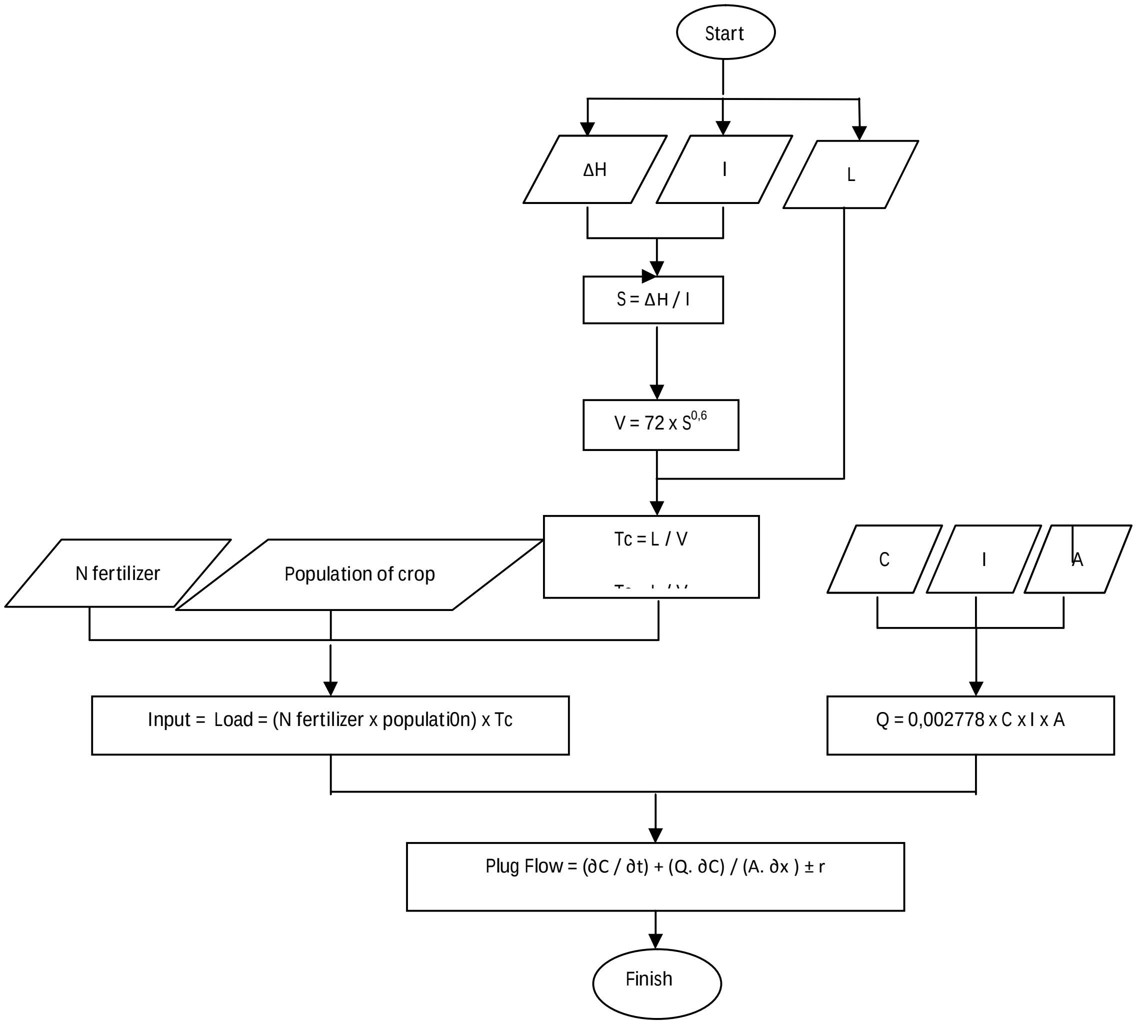


Figure 3: Flowchart Nitrogen Mass Balance Model

3.a. Transport equation for laminar flow condition was as follow:

$$\frac{\partial C}{\partial t} = -u\frac{\partial C}{\partial x} - v\frac{\partial C}{\partial y} - R \qquad (4)$$

If pollutant that enter in to the river was conservative pollutant , hence R = 0, so that equation (4) became as follow: $\frac{\partial C}{\partial t} = -u\frac{\partial C}{\partial x} - v\frac{\partial C}{\partial y}$ (5)

While if pollutant that enter in to the river was non conservative pollutant, hence there will be reaction with oxygen was $R = \frac{dL}{dt} = -K_1 L$ and transport equation became as follow:

$$\frac{\partial C}{\partial t} = -u\frac{\partial C}{\partial x} - v\frac{\partial C}{\partial y} - K_1 L \qquad (6)$$

b. Transport equation for turbulent flow condition was as follow:

$$\frac{\partial C}{\partial t} = -u_i\frac{\partial C}{\partial x_i} + \frac{\partial}{\partial x_i}E_i\frac{\partial C}{\partial x_i} - R \qquad (7)$$

If pollutant that enter in to the river was conservative pollutant , hence R = 0, so that equation (7) became as follow:

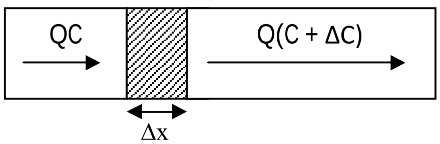
$$\frac{\partial C}{\partial t} = -u \ \frac{\partial C}{\partial x} - v\frac{\partial C}{\partial y} + E_x \frac{\partial^2 C}{\partial x^2} + E_y \frac{\partial^2 C}{\partial y^2} \qquad (8)$$

While if pollutant that enter in to the river was non conservative pollutant, hence there will be reaction with oxygen was $R = \frac{dL}{dt} = -K_1 L$ and transport equation transport became as follow:

$$\frac{\partial C}{\partial t} = -u \ \frac{\partial C}{\partial x} - v\frac{\partial C}{\partial y} + E_x \frac{\partial^2 C}{\partial x^2} + E_y \frac{\partial^2 C}{\partial y^2} + K_1 L \qquad (9)$$

(Karnaningroem, 2006)

4. Mass balance Plug Flow System equation using of Streeter-Phelps equation approach:



Accumulation = input - output ± R xns

$$\frac{d(VC)}{dt} = QC - Q(C + \Delta C) \pm rV \qquad (10)$$

$$\frac{dc}{dt} = \frac{QC}{A.\Delta x} - \frac{QC}{A\Delta x} - \frac{Q\Delta C}{A\Delta x} \pm r \qquad (11)$$

$\Delta x \longrightarrow 0$

$$\frac{\partial C}{\partial t} = -\frac{Q\partial C}{A\partial x} \pm r \qquad (12)$$

With $\frac{Q}{A} = \bar{u}$ hence equation (12) became: $\frac{\partial C}{\partial t} = -\bar{u}\frac{\partial C}{\partial x} \pm r$ (13)

(Schnoor,1996)

This equations were finihed by Leap Frog Scheme method, This method can used to finished finite difference mathematics equation for space and time.

Finite difference mathematics equation for space was as follow:

$$\left.\frac{\partial f}{\partial x}\right|_i = \frac{f_{i+1}^n - f_{i-1}^n}{2\Delta x} \qquad (2.68)$$

Finite difference mathematics equation for time was as follow:

$$\left.\frac{\partial f}{\partial t}\right|_i = \frac{f_i^{n+1} - f_i^{n-1}}{2\Delta t} \qquad (2.69)$$

(Luknanto, 2003)

Running Model

After building the structure model, furthermore done the running model. Running model done to the steady flow condition.

RESULTS AND DISCUSSION

Based on the analysis of water quality data before and after fertilization it was known that organic nitrogen content in the Rembangan river water Jember was not detected and nitrate compound while successfully detected. This suggests that the types of nitrogen pollutant that potentially get into the river Rembangan Jember was nitrate compound.

Base on the result of running model showed that calculation value of output model about to all of parameters indicate that the value of discharge from output model was equal to 20,5467 m^3/sec , whereas value of average discharge measurement in field before fertilization was equal to 0,145 m^3/sec and after fertilization was equal to 0,194 m^3/sec. Difference of this value caused by using discharge as input model was peakdischarge two annual period. Selection peak discharge for two annual period based on the use factor of discharge as input model to calculate concentration pollutant which was very reactive to change of climatology and river morphology factor. Layout of model showed at **Figure 4.**

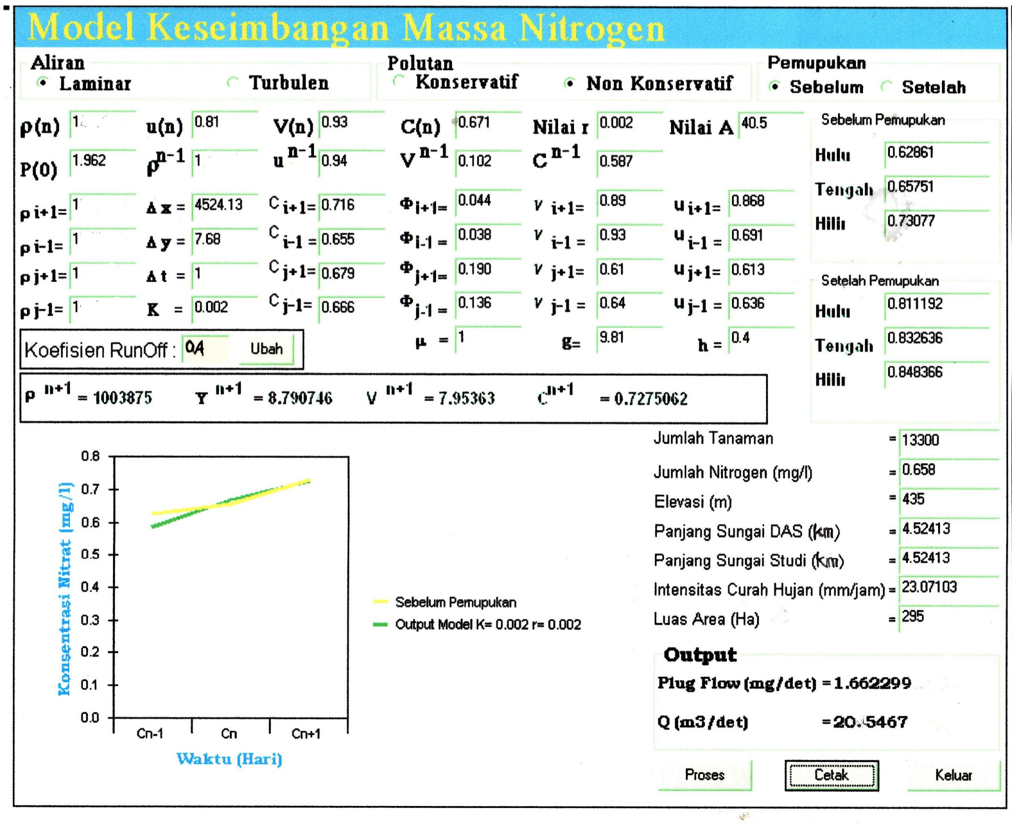


Figure 4: **Layout Nitrogen Mass Balance Model**

Result of the calibration for reaction coefficient r value was 0,002 and K value was 0,002. Nitrate concentration value of output model was equal to 0,728 mg/litre, whereas value of measurement in spacious that was average nitrate concentration before fertilization was equal to 0,6723 mg/litre and after fertilization was equal to 0,8307 mg/litre. The result calculation of plug flow system mass balance model was equal to 1,66 mg/sec of nitrat that dissolve in the Rembangan river. Comparison between nitrate concentrations from measurement in spacious with nitrate concentration from the result of output model presented at T**able 1** and **Figure 5** following.

Table 1. Comparison between Nitrate Concentrations from Measurement in Spacious with Nitrate Concentration from Output Model at The Running Model

Node	Measurement of nitrate concentration (mg/litre)	Modeling of nitrat concentration (mg/litre)
Upstream	0.6287	0,587
Middle	0.6575	0,671
Downstream	0.7307	0,728

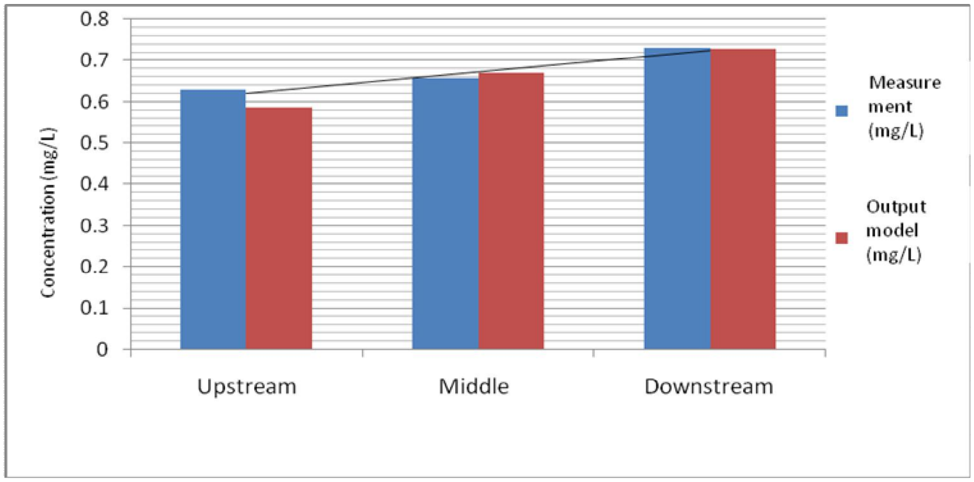


Figure 5: Comparison between Nitrate Concentrations from Measurement in Spacious with Nitrate Concentration from Output Model at the Running Model

From above result hence can in explained that the use of nitrogen fertilizer at the coffee crop in plantation of coffee Afdeling Renteng Rayap Jember giving the fertilizer with dose of 100 gram/crop for amount of 133.000 tree in plantation area and wide garden was 186,16 hectare will give the nitrate concentration was equal to 0,728 mg/litre with mass balance Plug Flow System was equal to 1,66 mg/sec.

Pursuant to this research result hence concluded that contribution of nitrate compound at Rembangan river still can be categorized as good base on the Indonesian Government Regulation number 20 Year 1990 with a maximum standard parameter of nitrate at 5 mg/litre. The nitrate concentration at the river water of Rembangan Rayap Jember was still can be categorized as good because it belongs to class A in water quality, that was as water that can be used as direct drinking water without any treatment.

CONCLUSION

Base on the result of running model got the value discharge of output model is equal to 20,5467 m^3/sec and nitrate concentration equal to 0,728 mg/litre with mass balance Plug flow system equal to 1,66 mg/sec. Contribution of nitrate compound at Rembangan river still can be categorized as good base on the Indonesian Government Regulation number 20 Year 1990 with a maximum standard parameter of nitrate at 5 mg/litre. The nitrate concentration at the river water of Rembangan Rayap Jember is still can be categorize as good because it belongs to class A in water quality, that is as water that can be used as direct drinking water without any treatment.

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