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Developing An Integrated Model For Analyzing Andpredicting Deli River Water Quality Located In Medan City, Indonesia

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Abstract

Rivers are an essential component of the environment as many people depend on their sustainable use. Rivers, however, are strongly threat under many different pollutants which include conventional pollutants. This paper addresses a mathematical model to predict the water quality of the Deli River as raw water for clean water in Medan City; it is a simple dynamic water quality model.Predictions of the availability of clean water from Deli River water are made for the growing population of Medan to manage the Deli River water quantity. The disposal of waste due to human activities, the formation of sediment due to changes in land use that enter the Deli River, and the physical properties of the Deli River all contribute to changes in the Deli River's quality and quantity/discharge. The model can forecast changes in the Deli River's combined quality and quantity. This model can serve as a foundation for Deli River Management Planning.

Keywords: Modeling, Water Quality, Rivers, Prediction.

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1. Introduction

Rivers play an essential role in the natural environment. Rivers provide numerous benefits, including aesthetics (recreation), economics (fishery, power generation, transportation, and irrigation), ecology (biodiversity), and clean water sources (supply of water for domestic and industrial use)(Wu, Di, Wang, Wu, & He, 2019). Rivers are increasingly threatened by a variety of pollutants, including conventional pollutants (organic substances and inorganic nutrients) and hazardous substances (organic contaminants and heavy metals)(American Rivers, 2021). Anthropogenic activities, such as mining, agriculture, forestry, livestock, and urbanization, are the primary sources of pollution. The fact that, natural phenomena such as weather and geology can impact river water quality(Boorman, 2003; Othman & Elamin, 2014).

With a length of 74 kilometers, the Deli River is one of the sources of raw water for clean water for Medan residents. It is situated in the Belawan-Belumai-Ular River Basin Unit of Indonesia's North Sumatra Province(Pemerintah Provinsi Sumatera Utara, 2013). The Deli River provides 40% of the raw water for Medan residents, the Belawan River provides 40%, and springs in Sibolangit provide 20%.

People's anthropogenic activities along the Deli River are endangering the river's water quality and quantity.

New developments in water quality policies and future strategies based on integrated approaches necessitate the use of mathematical models as water quality management tools(Gu & Dong, 1998; Tyson, Guarino, Best, & Tanaka, 1993). Mathematical models are increasingly being used because they are more cost-effective and can predict water quality along river flows caused by pollution. Mathematical models can describe the complex relationship between pollutant content from various sources(Deksissa, Meirlaen, Ashton, & Vanrolleghem, 2004; Huang et al., 2018).

Several basic types of river water quality models, particularly those relating to nutrient and oxygen balance, have been published. From the simplest Streeter-Phelps model, the “oxygen sag” (Phelps & Streeter, 1958), to more advanced models like $QUAL_1$(Orlob, 1983), $QUAL_2$(Water Resource Engineers, 1973), $QUAL_2E$(Brown & Barnwell, 1987), $MIKE_{11}$(Danish Hydrologic Institute (DHI), 1992), DUFLOW-$EUTROF_1$(Aalderink, Klaver, & Noorman, 1995), ISIS(Wallingford Software, 1996), QUAL2K (Chapra, Pelletier, & Tao, 2003) the complexity and number of variables have increased.

This study's mathematical model is a new model that can be used to predict the water quality of the Deli River as raw water for clean water in Medan City; it is a simple dynamic water quality model(Anggraini & Mawengkang, 2013) that employs the Continuous Stirred Tank Reactor (CSTR) approach(Deksissa et al., 2004), mass balance, and dissolved oxygen (DO) balance diagram(Brown & Barnwell, 1987), where DO is an indicator of pollution in surface water(Hammer, 1981; Salmin, 2005).

Predictions of the availability of clean water from Deli River water are made for the growing population of Medan to manage the Deli River water quantity. The disposal of waste due to human activities, the formation of sediment due to changes in land use that enter the Deli River, and the physical properties of the Deli River all contribute to changes in the Deli River's quality and quantity/discharge. The model can forecast changes in the Deli River's combined quality and quantity. This model can serve as a foundation for Deli River Management Planning.

2. Environmental Model

2.1. River Water Quality Model

New developments in water quality management policies and strategies necessitate the use of mathematical models to forecast pollution and estimate its impact on water use. A mathematical model can more clearly express the complex relationship between each of the constituents found in river water(Deksissa et al., 2004).

Management problems are frequently expressed in mathematical models that optimize one of the objectives as mentioned earlier while constraining one or more of the others. This is a difficult task because the system's behavior is never completely predictable due to the uncertainty of the various inputs that enter the system. Uncertainty in pollutant movement models, reaction rates, and natural variations in the receiving system, such as variations in flow and temperature, all contribute to the difficulty of predicting the system's future behavior. Uncertainty in decision making is caused by input uncertainty(M Bruce Beck, 1987).

Because the main information on the parameter values is limited, it is determined by matching the model with observation data. Water quality models generally require a relatively large number of parameters to determine their functional relationship. The model can be used to simulate conditions that are within or near the calibrated or verified condition area. Parameter estimation is still predicted using a heuristic approach for this purpose (manually)(Deksissa et al., 2004).

This research(Romanowicz, Callies, & Young, 2004) to predict water quality without measuring catchment necessitates the development of a model capable of capturing the basic physical aspects of the process and relying only on variables that are easily obtained. In this regard, the model's requirements are similar to those of the model used in the analysis of future climate scenarios. For the purposes of climate change analysis, mechanistic water quality models only use climatic variables such as temperature, radiation, and release to predict time changes in algae concentrations. The development of a statistical analogy for this mechanistic model is introduced in this paper. The goal of this research is to derive a data-based model with the fewest parameters required to describe the data while also being able to represent the physical aspects of the process (Data-Based Mechanistic or DBM model). The mechanistic model is estimated using statistical analysis of the relationship between input and output model variables, as well as the linearity of the mechanistic algae equation, which leads to the development of a workable statistical model. The mechanistic algae model yielded a non-linear, Multi-Input Single Output (MISO) transfer function model as a result of this analysis. The model was used to calculate the chlorophyll-a concentration per day prior to 1990. The prediction uncertainty was assessed, and the results were validated against the monthly chlorophyll-a measurements that were available.

(Caviness, Fox, & Deliman, 2006)'s findings are as follows: the STREAM model (Steady Riverine Environmental Assessment Model) and the $QUAL_2E$ model produce different results for Big Black River conditions. The STREAM model predicts far above the daily average DO data, whereas the $QUAL_2E$ model predicts accurately with the daily DO average data.

$QUAL_2E$ is currently the most widely used water flow quality model on computers. Many water quality simulations use the same modeling approach as ISIS(Wallingford Software, 1996), DUFLOW(Aalderink et al., 1995) and $MIKE_{11}$(Danish Hydrologic Institute (DHI), 1992), SREAM(Park & Lee, 1996), DYRESM(D. P. Hamilton & Schladow, 1997), and $QUAL_2K$(Park & Lee, 2002). However, they do not include microbial biomass as a variable, despite the fact that microbial biomass influences the speed of the biotransformation process. Furthermore, the mass balance for carbon organic matter is based solely on biochemical oxygen demand (BOD). Because the BOD image only represents a portion of the biological transformation event, it is difficult to use BOD to calculate mass balance(Henze, Harremoes, Cour Jansen, & Arvin, 2010).

The $QUAL_2E$ model served as the foundation for the Deli River Water Quality Prediction Model in this study.

2.2. Deli River Water Quality

3.2.1. Deli River Water Quality Prediction Model

3.2.1.1. Formation of Deli River Water Quality Prediction Model

This study's model development can be divided into two major categories: hydraulic and water quality. The formation of a hydraulic submodel is presented first, followed by the expansion of this hydraulic model to include water quality.

A. Hydraulics

Essentially, the complex river hydrodynamic model of the St.Venant equation is simplified to a CSTR-based modeling approach(Brutsaert, 1971). The river is represented as a series of river compartments (tanks) in this approach, with each tank assumed to be perfectly mixed(M B Beck & Reda, 1994; Whitehead, Williams, & Lewis, 1997). The CSTR section of the conceptual model can be used for dynamic hydraulic modeling in rivers(Yuceer, Karadurmus, & Berber, 2003). Based on the mass balance expressed around the control volume, the incremental element of the flow volume per unit time $(\mathrm{dV}/\mathrm{dt})$ is the difference between the inflow rate Q_{in} and the outflow rate (Q_{out}), written as:

$$\frac{\mathrm{dV}}{\mathrm{dt}} = Q_{\mathrm{in}} - Q_{\mathrm{out}}$$

with:

V = tank volume (m^3)

Q_{in} = inflow rate (m^3/s)

Q_{out} = outflow rate (m^3/s)

Auxiliary flows or discharges can be connected around the control volume via stream boxes or tanks. In this case, the above equation can be expanded as follows:

$$\frac{\mathrm{dV}}{\mathrm{dt}} = Q_{\mathrm{in}} + Q_{\mathrm{d}} - Q_{\mathrm{out}}$$

with Q_d denotes the exhaust flow rate (m^3/s).

Both equations are based on a simple mass balance, with the difference in the overall rate of entry and exit being the difference in the volume change with time. Using the power function method, the flow rate out of each tank can be calculated:

$$Q_{\mathrm{out}}(\mathrm{t}) = \gamma_1 \mathrm{h}(\mathrm{t})$$

And the flow velocity can be computed as follows:

$$Q_{\mathrm{out}}(\mathrm{t}) = \frac{\mathrm{v}(\mathrm{t})}{\mathrm{A}(\mathrm{t})}$$

Where:

$\mathrm{h}(\mathrm{t})$ = water depth at time t (m)

$\gamma_1 \gamma_2$ = parameters of the power function

A = flow cross-sectional area (m^2)

v = flow speed (m/s)

t = time

B. Water Quality

The hydraulic model described above can be easily extended to include submodels of river water quality. A one-dimensional river water quality model can be written in a differential equation model using the principle of mass balance:

$$\frac{\mathrm{d(VC)}}{\mathrm{dt}} = Q_{\mathrm{in}} C_{\mathrm{in}} - Q_{\mathrm{out}} C_{\mathrm{out}} + \mathrm{rV}$$

where:

C_{in} = inflow concentration (g/m^3)

C_{out} = outflow concentration (g/m^3)

r = overall reaction rate (g/m^3) per day

If waste is disposed of in the control volume (see figure 2), the differential equation above can be expanded to:

$$\frac{d(VC)}{dt} = Q_{in}C_{in} + Q_dC_d - Q_{out}C_{out} + rV$$

where:

C_d = concentration of additional or exhaust stream (g/m^3)

Q_d = exhaust flow rate

The flow behavior of the river is assumed to be shown by successively linked CSTRs in the dynamic model. Each reactor serves as a counter element and is connected in the same way that a river's counter elements are connected upstream and downstream(Deksissa et al., 2004). The following assumptions were used in the model's development: dendritic flow is perfectly mixed, river flow and river basin paths are constant, and chemical and biological reaction rates are constant in the calculations.

Physical, chemical, and biological reactions and interactions in river flows are all taken into account. The $QUA_{L2}E$ water quality model was used to develop the modeling strategy used in this study(Brown & Barnwell, 1987). Organic nitrogen, ammonia nitrogen, nitrite nitrogen, nitrate nitrogen, BOD, DO, organic phosphorus, dissolved phosphorus, coliform, chloride, algae phytoplankton are elements that represent water quality in terms of environmental pollution. The mass balances of substances are written down and combined with algebraic equations that describe the various phenomena.

3. Mathematical Modeling

3. 1. Model for the Nitrogen Cycle

River water naturally undergoes a gradual transformation from organic nitrogen to ammonia nitrogen, nitrogen nitrite, and finally nitrogen nitrate.

Ammonia nitrogen (N_1)

The following is the model for changing the concentration of Ammonia nitrogen (N_1) with respect to time (t):

$$\frac{dN_1}{dt} = \beta_3 \cdot N_4 - \beta_1 \cdot N_1 + \frac{\sigma_3}{d} - F_1 \cdot \alpha_1 \cdot \mu \cdot A + (N_1^0 - N_1)\frac{Q}{V}$$

Where:

A = algae biomass concentration (mg-A/L)

d = average flow depth (m)

N_1^0 = initial ammonia nitrogen concentration (mg-N/L)

N_1 = ammonia nitrogen concentration (mg-N/L)

N_4 = organic nitrogen concentration (mg-N/L)

F_1 = nitrogen fraction rate of algae from an ammonia nitrogen pond

β_1 = biological oxidation rate constant from NH_3 to NO_2 (1/day)

β_3 = hydrolysis rate constant from organic nitrogen to ammonia nitrogen (1/day)

α_1 = nitrogen found in the algae biomass fraction (mg-N/mg-Ǻ)

σ_3 = benthic source rate for ammonia nitrogen (mg-N/m^2-day)

μ = local specific growth rate of algae (1/day)

V = volume of water in each CSTR section (m^3)

Q = flow rate (m^3/sec)

F_1, which is a nitrogen algae component that is taken up by ammonia nitrogen, can be expressed as:

$$F_1 = \frac{P_N \cdot N_1}{P_N \cdot N_1 + (1 - P_N)N_1}$$

P_N = ammonia nitrogen selection factors

Using the above-mentioned formation concept, nitrite nitrogen, nitrate nitrogen, organic nitrogen, BOD, DO, organic phosphorus, dissolved phosphorus, coliform, chloride, and phytoplankton algae can be obtained.

Nitrite nitrogen (N_2)

$$\frac{dN_2}{dt} = \beta_1 \cdot N_1 - \beta_2 \cdot N_2 + (N_2^0 - N_2)\frac{Q}{V}$$

N_2^0 = initial concentration of nitrite nitrogen (mg-N/L)

N_2 = nitrite nitrogen concentration (mg-N/L)

β_2 = biological oxidation rate constant from NO_2 to NO_3, (1/day)

Nitrate nitrogen (N_3)

$$\frac{dN_3}{dt} = \beta_2 \cdot N_2 - (1 - F_1)\alpha_1 \cdot \mu \cdot A + (N_3^0 - N_3)\frac{Q}{V}$$

N_3^0 = initial concentration of nitrate nitrogen (mg-N/L)

N_3 = nitrate nitrogen concentration (mg-N/L)

Organic nitrogen (N_4)

$$\frac{dN_4}{dt} = \alpha_1 \cdot \rho \cdot A - \beta_3 \cdot N_4 - \sigma_4 \cdot N_4 + (N_4^0 - N_4)\frac{Q}{V}$$

Nitrite nitrogen: $(\beta_2)_{\text{inhibition}} = C_{\text{ORDO}} \cdot (\beta_2)_{\text{input}}$

ρ = local respiration rate of algae (1/day)

σ_4 = precipitation rate of organic nitrogen (1/day)

N_4^0 = initial concentration of organic nitrogen (mg-N/L)

N_4 = organic nitrogen concentration (mg-N/L)

3.2. Model for the Phosphorus cycle

The phosphorus cycle works similarly to the nitrogen cycle. The organic form of phosphorus is formed when algae die, and it is then converted to dissolved inorganics, where it is available for primary production by the algae. Phosphorus discharged from factories is generally in the form of dissolved inorganic phosphorus, which is immediately absorbed by algae. The model that depicts the phosphorus change is shown below.

Organic phosphorus

$$\frac{dP_1}{dt} = \alpha_2 \cdot \rho \cdot A - \beta_4 \cdot P_1 - \alpha_5 \cdot P_1 + (P_1^0 - P_1)\frac{Q}{V}$$

α_2 = phosphorus found in the algae biomass fraction (mg-P/mg-A)

α_5 = O_2 production rate per unit of NH_3 oxidation (mg-O/mg-N)

P_1 = local concentration of organic phosphorus (mg-P/L)

P_1^0 = local organic concentration of phosphorus (mg-P/L)

β_4 = the rate constant for converting organic phosphorus to dissolved phosphorus (1/day)

Dissolved phosphorus

$$\frac{dP_2}{dt} = \beta_4 \cdot P_1 + \frac{\sigma_2}{d} - \alpha_2 \cdot \mu \cdot A + (P_2^0 - P_2)\frac{Q}{V}$$

P_2^0 = initial local concentration of dissolved phosphorus (mg-P/L)

P_2 = local concentration of dissolved phosphorus (mg-P/L)

σ_2 = benthos source rate for dissolved phosphorus (mg-P/ m^2-day)

μ = local specific growth rate of algae (1/day)

3.3. Dissolved Oxygen (DO) Model

The oxygen balance in the flow system is determined by the stream's ability to exchange oxygen between air and water (reaeration). This capacity is determined by the advection and diffusion processes that occur within the system, as well as internal resources and oxygen loss. Apart from atmospheric reaeration, the oxygen produced by photosynthesis and the oxygen contained in the inlet stream are the primary sources of oxygen. Biochemical oxidation of organic carbon and nitrogen, benthic oxygen demand, and oxygen used by algae respiration all contribute to dissolved oxygen loss(Bowie et al., 1985).

The oxygen rate of change model is shown below, with each term representing a primary source of oxygen or a loss of oxygen.

$$\frac{dO}{dt} = K_2(O^* - O) + (\alpha_3 \cdot \mu - \alpha_4 \cdot \rho)A - K_1 L - \frac{K_4}{d} - \alpha_5 \cdot \beta_1 \cdot N_1 - \alpha_6 \cdot \beta_2 \cdot N_2 + (O^0 - O)\frac{Q}{V}$$

α_3	= O_2 production per unit algae growth (mg-O/mg-A)
α_4	= O_2 rate per unit from algae respiration (mg-O/mg-A)
α_5	= O_2 production rate per unit of NH_3 oxidation (mg-O/mg-N)
α_6	= O_2 production rate per unit of NO_2 oxidation (mg-O/mg-N)
β_1	= rate constant for biological oxidation from NH_3 to NO_2 (1/day)
β_2	= biological oxidation rate constant from NO_2 to NO_3 (1/day)
K_1	= deoxygeneration rate constant (1/day)
K_2	= reaeration rate constant (1/day)
K_4	= benthosic oxygen uptake (mg-O/m^2-day)
L	= main concentration of carbon BOD (mg/L)
O^*	= saturated concentration of DO at local temperature and pressure (mg/L)
O	= DO concentration (mg/L)
O^0	= DO initial concentration (mg/L)

3.4. Model Biological Oxygen Demand (BOD)

The amount of oxygen required by microorganisms to break down organic substances is known as Biological Oxygen Demand (BOD). BOD is proportional to the concentration of decomposed organic carbon and is denoted by the letter L. The decrease in BOD is caused by precipitation following decomposition, which varies depending on the rate of deposition and the rate of decomposition.

Under constant conditions, the pure advection model is as follows:

$$\frac{dL}{dt} = K_1 \cdot L - K_3 \cdot L + (L^0 - L)\frac{Q}{V}$$

Or

$$L(t) = L^0 e - \frac{K_r t}{V}$$

K_1	= deoxygeneration rate constant (1/day)
K_3	= decrease speed due to deposition (1/day)
L	= main concentration of carbon BOD (mg/L)
L^0	= main initial concentration of carbon BOD (mg/L)

Coliforms

$$\frac{dE}{dt} = -K_5 \cdot E + (E^0 - E)\frac{Q}{V}$$

K_5 = coliform death rate (1/hari)

E = coliform concentration (MPN)

E^0 = initial concentration of coliform (MPN)

Variable non-conservative substances, such as chlorides

$$\frac{dR}{dt} = -K_6 \cdot R - \sigma_6 \cdot R + \frac{\sigma_7}{d}(R^0 - R)\frac{Q}{V}$$

K_6 = non-conservative loss coefficient variable (1/day)

σ_6 = variable non-conservative deposition rate (1/day)

σ_7 = benthal source rate for variable non-conservative deposition rates (mg-ANC/m^2-day)

R = variable concentrations of non-conservative substances (mg/L)

R^0 = variable initial concentration of a non-conservative substance (mg/L)

It should be noted that the shape of this initial C_o concentration model is determined by the variables of current population and drainage area, which are two basic terms with no uncertainty.

4. Execution Model

Numerical methods are used to solve all of the previously stated differential equations, beginning with the differential equation for changes in the concentration of ammonia nitrogen (N_1) and ending with the differential equation for chlorophyll a. A computer program is used to carry out the completion process (source code).

The following data are used in the program:

1. The values stated in the notation can be used to obtain data for constants (Table 1)

2. Data for the depth, flow velocity, and water discharge of the Deli River are taken from Table 2 and averaged for Sembahe Village, Sibolangit.

Tabel 1 Constant Data

Constant	Description	Value Range
A	Algae biomass constant	$0.1 - 0.3$
α_1	Algae biomass fraction is nitrogen	$0.07 - 0.08$
α_2	Algae biomass fraction is phosphorus	$0.01 - 0.02$
α_3	O_2 production per unit algae growth	$1.4 - 1.8$
α_4	Algae growth produces O_2 per unit of time	$1.6 - 2.3$
α_5	O_2 production rate per unit of NH_3 oxidation	$3.0 - 4.0$
α_6	Oxidation rate of O_2 per unit of NO_2	$1.0 - 1.14$
μ_{max}	Maximum rate of algae specific growth	$1.0 - 3.0$

ρ	Local respiration rate of algae	$0.05 - 0.5$
K_L	Half saturation coefficient for light	$0.02 - 0.1$
K_N	The Michaelis Menten half-saturation constant for nitrogen	$0.01 - 0.03$
K_P	The Michaelis Menten half-saturation constant for phosphorus	$0.001 - 0.05$
λ_0	The non-algae portion of the light-extinguishing coefficient	0.3
λ_1	Algae linear shading coefficient	$0.002 - 0.02$
λ_2	Algae non-linear shading coefficient	0.0165
P_N	Ammonia nitrogen selection factors	$0.0 - 1.0$
σ_1	Algae deposition rate	$0.5 - 6.0$
σ_2	Benthos source rate for dissolved phosphorus	1.074
σ_3	Benthos source rate for Ammonia nitrogen	1.074
σ_4	Precipitation rate of organic nitrogen	$0.001 - 0.1$
σ_5	Phosphorous organic deposition rate	$0.001 - 0.1$
σ_6	Variable non-conservative deposition rate	1.026
σ_7	Benthal source rate for variable non-conservative deposition rates	1.0
K_1	Deoxygeneration rate constant	$0.02 - 3.4$
K_2	Reaeration rate constant	$0.0 - 100$
K_3	The rate of decline due to deposition	$-0.36 - 0.36$
K_4	Benthosic oxygen uptake	1.06
K_5	Coliform death rate	$0.05 - 4.0$
K_6	Variable non-conservative loss coefficient	1.0
β_1	Biological oxidation rate constant from NH_3 to NO_2	$0.1 - 1.0$
β_2	Biological oxidation rate constant from NO_2 to NO_3	$0.2 - 2.0$
β_3	Hydrolysis rate constant from organic N to Ammonia nitrogen	$0.02 - 0.4$
β_4	The rate constant for decreasing from organic phosphorus to dissolved phosphorus	$0.01 - 0.7$

Tabel 2. Water depth, flow velocity, and discharge in the Deli River, Sembahe Village, Sibolangit (May – December 2020)

	No Sample	**May**	**June**	**July**	**Aug**	**Sept**	**Oct**	**Nov**	**Dec**

Depth (cm)	11	54.00	54.00	85.00	63.00	66.00	85.00	78.00	85.00
	12	63.00	69.00	58.00	80.00	74.00	56.00	70.00	56.00
	13	66.30	53.00	65.00	70.00	67.00	61.00	60.00	63.00
	14	64.00	74.00	68.00	75.00	115.00	68.00	78.00	65.00
	15	64.00	42.00	82.00	70.00	79.00	82.00	68.00	80.00
Flow Speed (m/sec)	11	1.15	1.25	1.05	1.15	1.50	1.56	1.50	1.62
	12	1.50	1.32	1.14	1.30	1.35	1.52	1.04	1.72
	13	0.65	1.02	1.05	1.29	1.35	1.05	1.02	1.02
	14	0.80	1.25	0.93	1.13	0.95	0.92	1.02	0.85
	15	0.90	1.02	0.99	1.05	1.35	1.27	0.95	0.90
Debit (m^3/sec)	11	13.04	13.84	19.99	14.27	21.78	26.12	25.74	28.97
	12	18.90	17.40	12.70	20.07	20.80	17.62	15.57	19.18
	13	7.75	9.62	11.33	12.82	18.09	11.02	12.24	10.28
	14	10.24	18.13	12.33	14.49	19.67	9.70	14.89	10.38
	15	11.52	8.31	6.58	12.27	18.06	19.68	11.56	12.96

Other information required includes Deli River water temperature ranges of 10°C – 30°C and solar radiation ranges of 250–500 Ly/day.

Because the starting point of measurement for each concentration data was carried out at Sembahe Village, Sibolangit District, that location was chosen as the data for the initial concentration. Figure 1 depicts a DO concentration profile derived from the above-mentioned program processing of the data.

Figure 1 shows that the model's initial DO concentration is 7.56, that at a distance of 10 km, the DO concentration is 6.98, that at a distance of 20 km, the DO concentration is 6.75, and that at a distance of 30 km, the DO concentration is 6.6. The concentration increases again at distances greater than 50 km due to the transfer of oxygen between the water and the atmosphere.

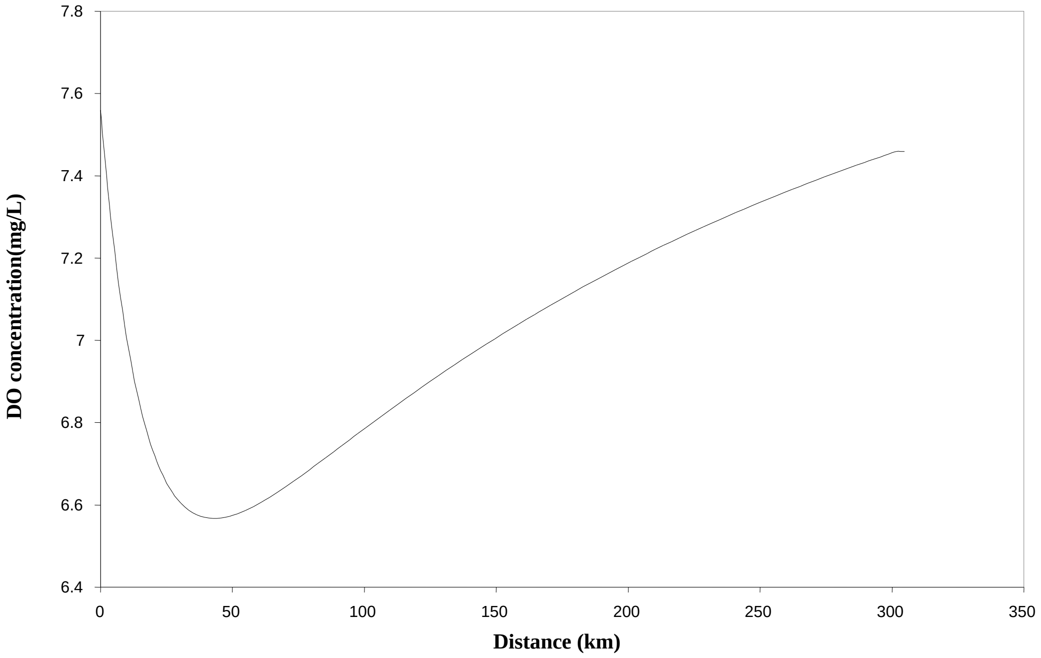

Figure 1. DO Concentration Profile from Model

5. Discussion

Deli River Water Quality Prediction Model

5.1. Sensitivity Analysis of Deli River Water Quality Prediction Model

To put the model to the test, a sensitivity analysis of dissolved oxygen (DO) concentration was performed. A sensitivity analysis test on the concentration of Dissolved Oxygen (DO) was performed in this study. This is illustrated by the DO balance diagram, which shows that the concentration of other constituents, namely ammonia nitrogen, nitrogen nitrate, nitrogen nitrite, SOD, BOD, organic phosphorus, dissolved phosphorus, chlorophyll, and solar radiation, influences the concentration of DO(Brown & Barnwell, 1987). Because dissolved oxygen (DO) plays a role in the oxidation and reduction of organic and inorganic materials, oxygen is an important indicator of water quality(Hammer, 1981; Salmin, 2005).

DO, BOD, ammonia nitrogen, nitrate nitrogen, and nitrite nitrogen were all measured in this study. If data is not collected, the program will issue data automatically due to the DO balance. Physical changes in the river, such as flow velocity, SOD, BOD, radiation, chlorophyll, river depth, and temperature, also influence the DO concentration in river water. The sensitivity analysis results show that the DO concentration changes in response to changes in the variables mentioned above, as shown below.

5.1.1 DO Concentration Sensitivity Analysis with Changes in Flow Rate

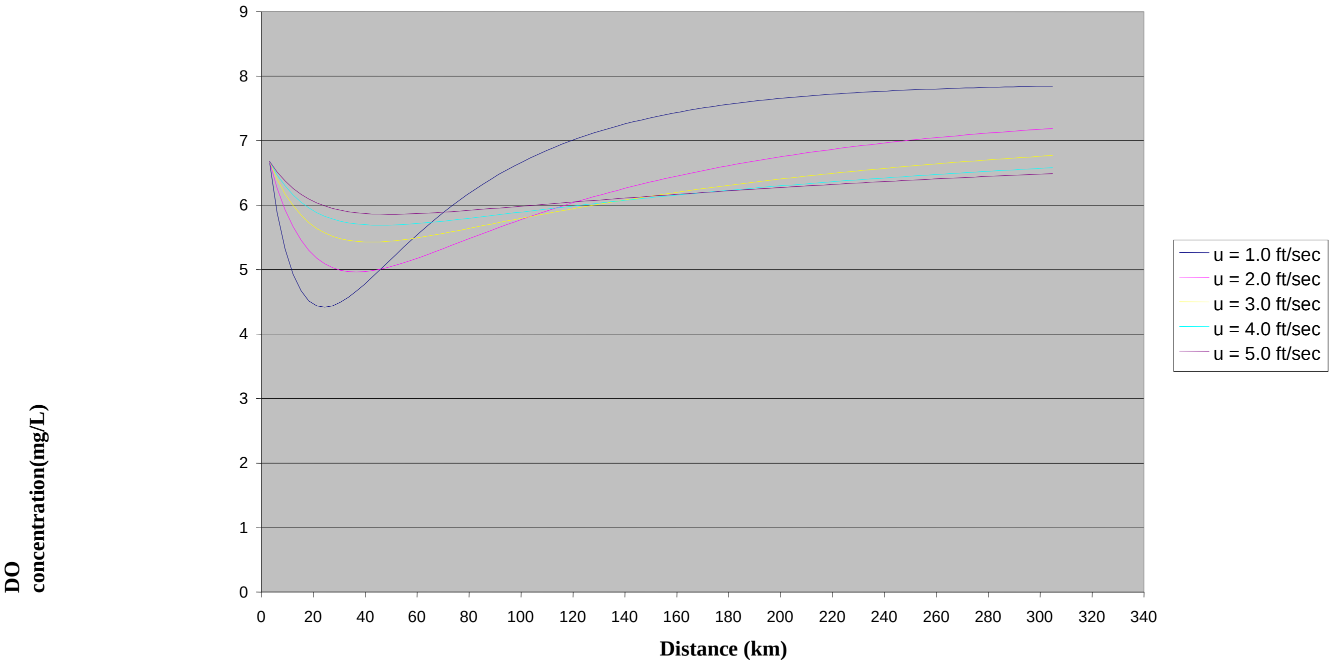

Figure 2. DO concentration with change in flow velocity

The DO concentration is between 4.5 and 7.5 at a flow velocity of 1 ft/s and a distance of more than 25 km. The DO concentration is 6.0 – 6.2 at a speed of 5 ft/s and a distance of more than 25 km. This means that at higher flow rates, the initial DO concentration is higher and the change in DO concentration is smaller, whereas at lower flow rates, the DO concentration change is greater.

The sensitivity analysis or simulation results show that the river water quality prediction model is consistent with the theory of (Manahan, 1994; Salmin, 2000), which states that average flow velocity is an important factor in reaeration coefficient and flow travel time. According to the model, as the velocity increases, so does the reaeration coefficient, resulting in an increase in the rate of oxygen transfer between the water and the atmosphere. Because an increase in velocity results in a decrease in travel time, the flow velocity influences the DO distribution as well. As a result of the combined effect of these two relationships, the overall oxygen deficit is reduced due to an increase in the reaeration coefficient, which has a larger effect than the DO deficit due to reduced travel time. If the speed increases, the oxygen produced by phytoplankton is released into the atmosphere at a faster rate, resulting in a smaller decrease than the DO concentration(Manahan, 1994; Salmin, 2000).

Dredging the sediment load at a speed of 5 ft / sec is required to keep the flow velocity high and the DO concentration of Deli River water in the range of 6.0.

5.1.2 DO Concentration Sensitivity Analysis to Changes in SOD

The DO concentration was higher in the stream with 0.05 SOD concentration than in the stream with 5.0 SOD concentration. The DO concentration was between 5.8 and 6.2 at a SOD concentration of 0.05 at a distance of more than 50 km. At a distance of more than 50 km, the SOD concentration is 5.0, and the DO concentration is between 5.0 and 6.0. The higher the concentration of SOD, the lower the concentration of DO. DO concentration changes were greater at higher SOD concentrations.

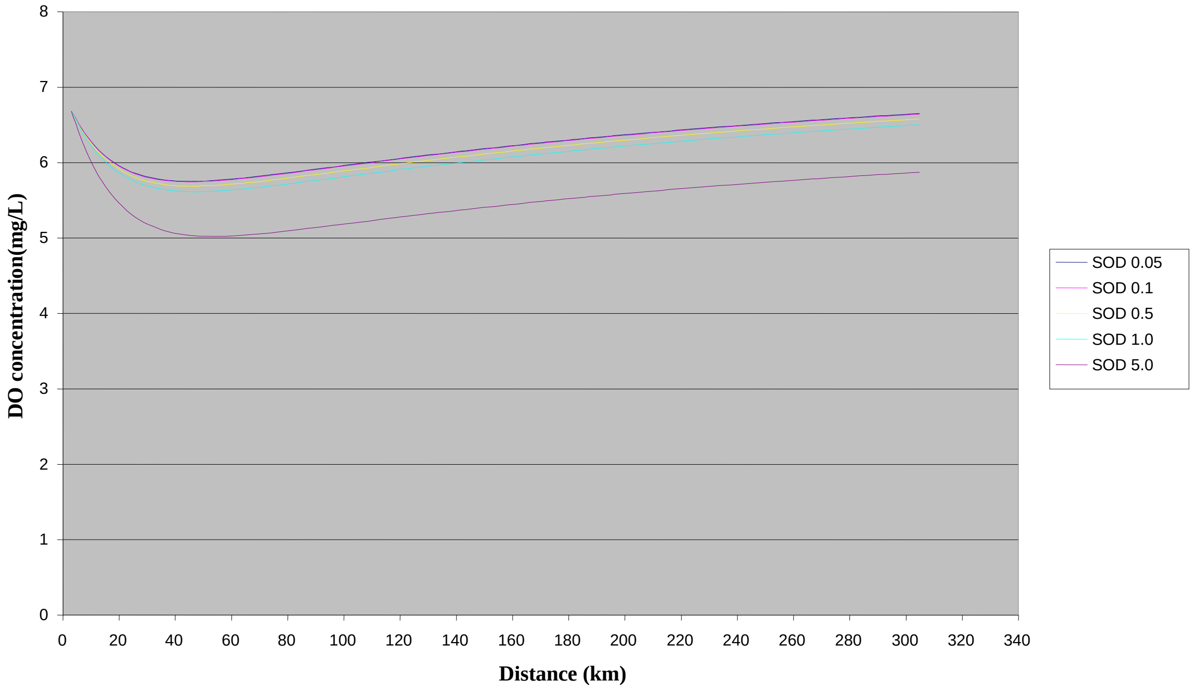

Figure 3. Sensitivity of DO concentration to changes in SOD

The results of the sensitivity analysis or simulation show that the river water quality prediction model is consistent with the theory that SOD is the primary cause of low DO concentrations in rivers with high organic matter levels. This occurs because biological processes or mechanical flocculation aid in sedimentation(Doyle & Lynch, 2005). The deposited solids will form "benthal deposits" (microorganisms at the bottom of the water) that will decompose (if organic substances) due to anaerobic processes and immediately absorb oxygen in the system(Salmin, 2000; Tebbutt, 2013).

Increased erosion and landslides in the catchment area will result in an increase in sediment load downstream of the river. The impact of forest encroachment is a two to threefold increase in sedimentation in rivers that drain water from the affected catchment area. Sediment load increased from 180 ppm prior to encroachment to 320 ppm in the first year and to 520 ppm two years later(L. S. Hamilton & King, 1983).

The management that must be done to increase SOD is to carry out reforestation activities so that erosion does not occur, and it is sought to obtain the SOD concentration of Deli River water is 0.05, so that the DO concentration of Deli River water is in the range of 6.0.

5.1.3 Sensitivity Analysis of DO Concentration to BOD

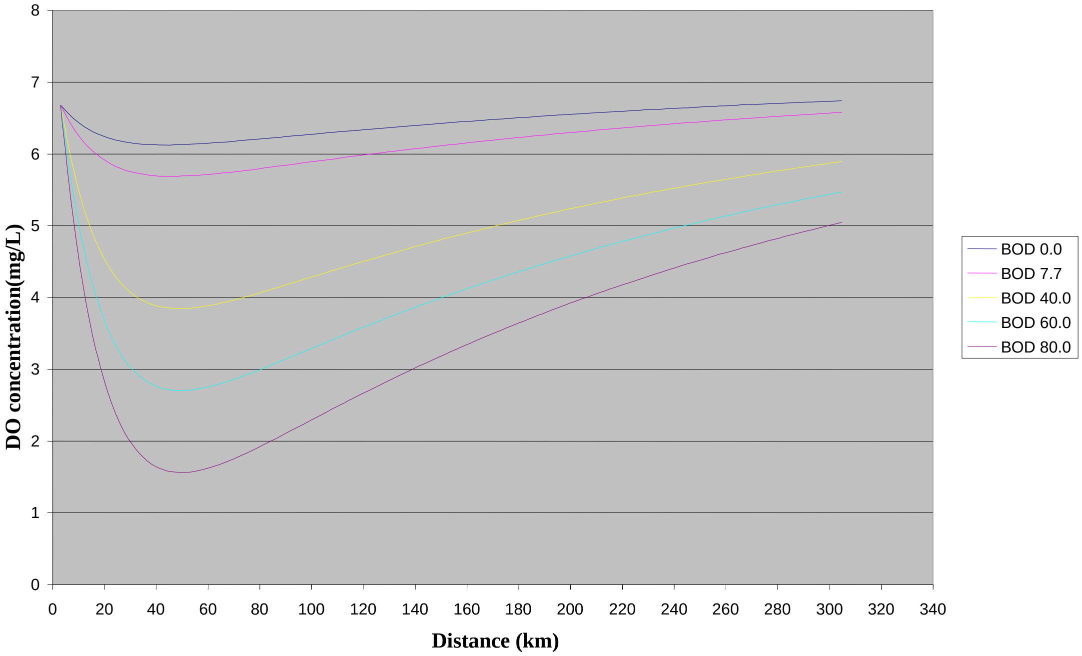

Figure 4. Sensitivity of DO concentration to changes in BOD

Changes in DO concentration at 0.0 BOD concentration were not very significant along the flow, with DO concentrations ranging from 6.1 to 6.7 at a distance of more than 50 km. However, at 80.0 BOD concentrations, the change in DO concentration was more significant. The DO concentration ranged from 1.5 to 5.0 at a BOD concentration of 80.0 at a distance of more than 50 km, as shown in the graph. This means that the higher the BOD concentration in river water, the lower the DO concentration. Higher BOD concentrations resulted in greater changes in DO concentration.

The sensitivity analysis or simulation results show that the river water quality prediction model is consistent with the theory of (Manahan, 1994; Salmin, 2005), which states that higher BOD concentrations result in lower DO concentrations. This occurs because the decomposition process of organic matter (a contaminant whose concentration is measured as BOD) requires more oxygen at higher BOD concentrations, which is taken from the DO concentration of river water, causing the DO concentration to drop. As shown below, oxygen in water is rapidly consumed through oxidation by organic substances (CH_2O)(Manahan, 1994; Salmin, 2005).

$$\{CH_2O\} + O_2 \xrightarrow{\text{microorganisms}} CO_2 + H_2O$$

When the concentration of BOD was increased, the concentration of DO decreased. To increase the concentration of BOD, the waste must be treated for point sources before being discharged into the river in order to obtain a concentration of BOD 2, so that the DO concentration of Deli River water is in the range of 6.0.

5.1.4 Sensitivity of DO Concentration to Changes in Solar Radiation

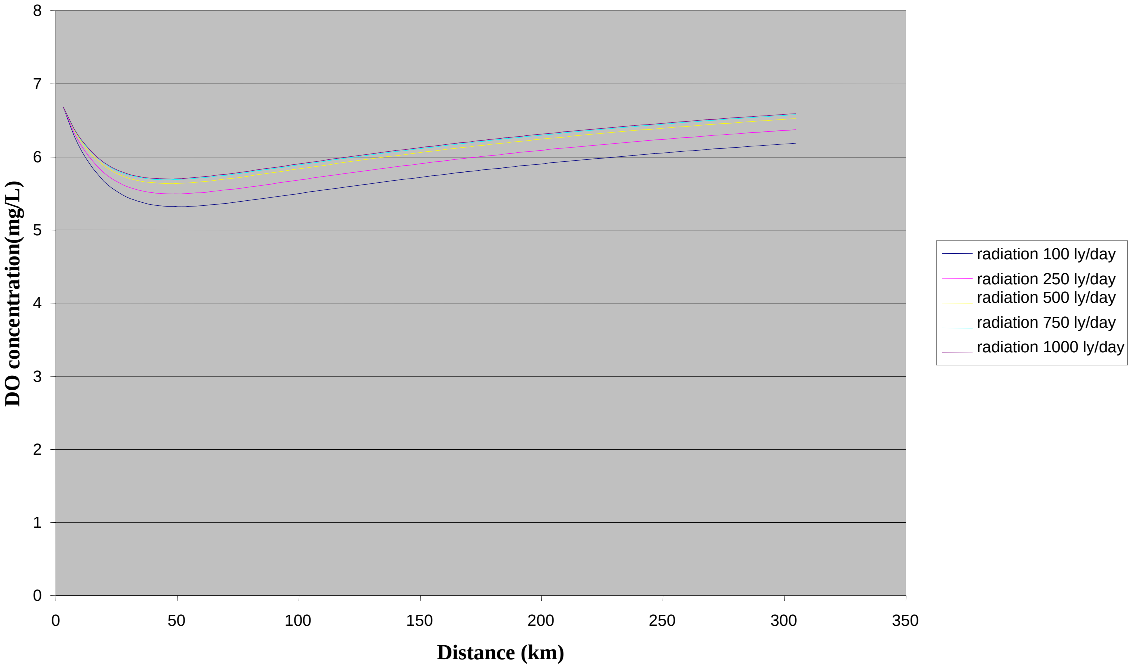

Figure 5. Sensitivity of DO Concentration to Changes in Solar Radiation

The DO concentration was higher in the 1000 radiation stream than in the 100 radiation flow. The DO concentration ranged from 5.3 to 6.2 for 100 radiation at a distance of more than 50 km. DO concentrations ranged from 5.6 to 6.5 at a distance of more than 50 km from radiation 1000. This means that as the radiation level rises, so will the concentration of DO in river water. However, the change in DO concentration with changes in radiation is minimal.

The sensitivity analysis or simulation results show that the river water quality predictive model is consistent with (Manahan, 1994)'s theory, which states that photosynthetic plants use solar radiation and CO_2 from the atmosphere to form organic substances and oxygen, so the higher the radiation, the higher the DO concentration(Manahan, 1994). The reaction is as follows:

$$CO_2 + H_2O \overset{h\upsilon}{\rightarrow} \{CH_2O\} + O_2$$

Solar radiation management is impossible because solar radiation is uncontrollable by humans.

5.1.5 DO Concentration Sensitivity Analysis on Changes in River Depth

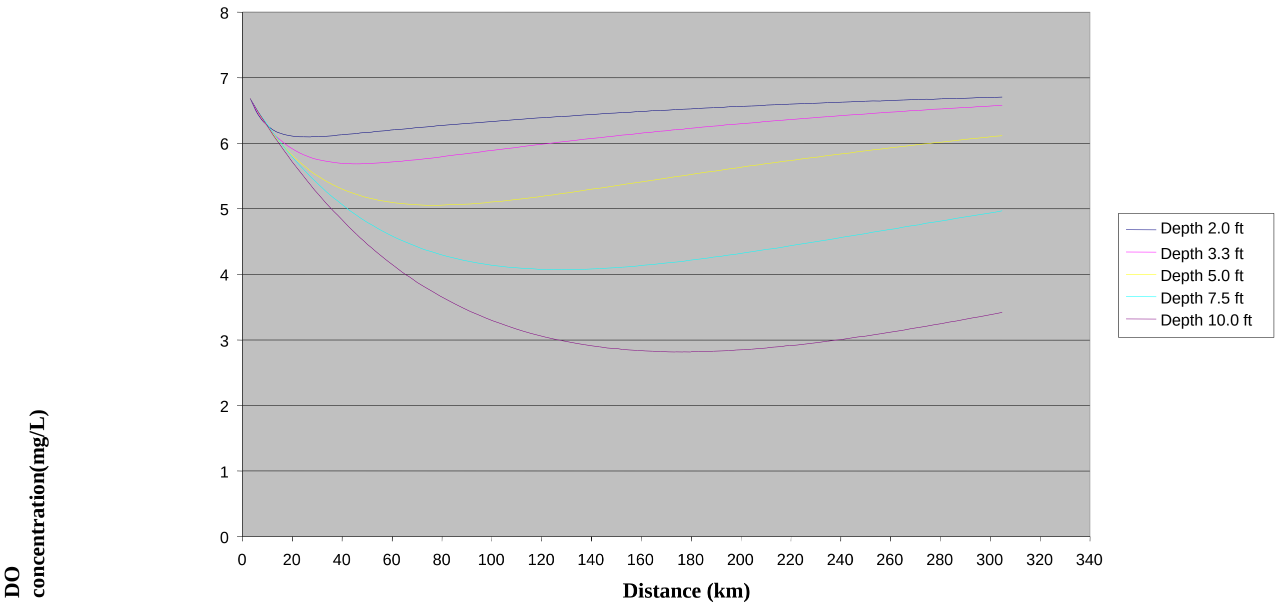

Figure 6. DO Concentration Sensitivity to Changes in River Depth

The concentration of DO is between 6.0 and 6.6 at a river depth of 2 feet and a distance of more than 20 kilometers. DO concentrations ranged from 2.9 to 3.4 at a depth of 10 feet and a distance of more than 200 kilometers. This means that as river depth increases, the concentration of DO decreases. In deeper rivers, changes in DO concentration are more pronounced.

The results of the sensitivity analysis or simulation show that the river water quality prediction model is consistent with (Manahan, 1994; Salmin, 2005)'s theory, which states that the average river depth is an important factor in the reaeration coefficient. The reaeration coefficient decreases as river depth increases, resulting in a decrease in the rate of oxygen transfer between the water and the atmosphere. The oxygen produced by phytoplankton decreases as the river depth increases due to a lack of solar radiation in the photosynthesis process(Manahan, 1994; Salmin, 2005).

The sediment load must be dredged as part of the management of the river's depth. Because of the lack of photosynthesis, deep rivers produce less oxygen. As a result, it is not necessary to dredge the sediment to a depth; the dredging is only to prevent silting of the river, which can cause flooding during heavy rains.

5.1.6 Sensitivity Analysis of DO Concentration to Changes in Chlorophyll Concentration

The concentration of chlorophyll is important in the reaeration coefficient because the reaeration reaction occurs throughout the flow. The flow of the flow and the amount of chlorophyll concentration influence the increase in DO concentration. DO concentration increased as chlorophyll concentration increased.

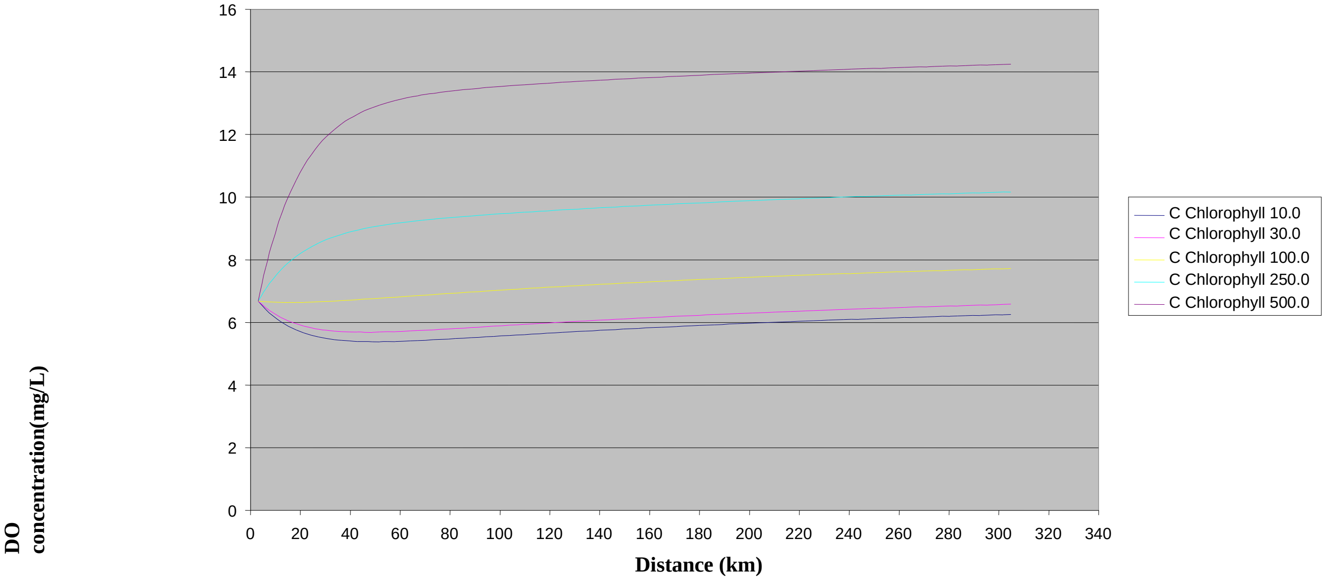

Figure 7. DO Concentration Sensitivity to Changes in Phytoplankton Chlorophyll Alpha Concentration

The DO concentration did not change significantly along the flow distance at chlorophyll 10 concentration. The DO concentration at a distance of more than 50 km is between 5.5 and 6.1. The DO concentration ranged from 6.8 to 7.8 at a distance of more than 50 km and a chlorophyll concentration of 100. At a chlorophyll concentration of 500 and a flow distance of 48 kilometers, the DO concentration ranged from 12.9 to 14. This means that the higher the chlorophyll concentration, the higher the DO concentration. DO concentration changes were greater at higher chlorophyll concentrations.

The sensitivity analysis or simulation results show that the river water quality prediction model is consistent with the theory of (Sediadi & Edward, 1993; Tebbutt, 2013), which states that all algae are photosynthetic plants that are generally multicellular. These freshwater algae use the pigment chlorophyll and are the most prolific producers of organic substances in the aquatic environment. Carbon dioxide, ammonia nitrogen, nitrate nitrogen, and phosphate are examples of inorganic substances that algae use to form new cells and produce oxygen(Sediadi & Edward, 1993; Tebbutt, 2013).

Afforestation in the Deli watershed is managed by algae life that uses chlorophyll pigment as an oxygen producer. When reforestation is done with the goal of reducing erosion, chlorophyll cannot carry out the photosynthesis process perfectly, and the rate of diffusion of oxygen from the air decreases(Salmin, 2005).

The waste must be treated before it is discharged into the river in order for the chlorophyll concentration to be at the carrying capacity limit. The normal ratio of nitrate nitrogen and phosphate in water is 7:1 (Brotowijoyo, Tribawono, & Mulbyantoro, 1995); if waste discharged directly into the river causes the ratio of N:P to be 15:1, the phytoplankton population will explode (blooming)(Praseno, 1980).

5.1.7 DO Concentration Sensitivity Analysis to Changes in River Temperature

At a temperature of 20°degrees Celsius and a distance of more than 25 kilometers, the concentration of DO is between 5.7 and 6.5. Temperature 35°degrees Celsius at a distance of more than 25 kilometers DO concentration is between 4.9 and 7.2, indicating that at higher temperatures the DO concentration is lower. The change in DO concentration is greater at higher temperatures.

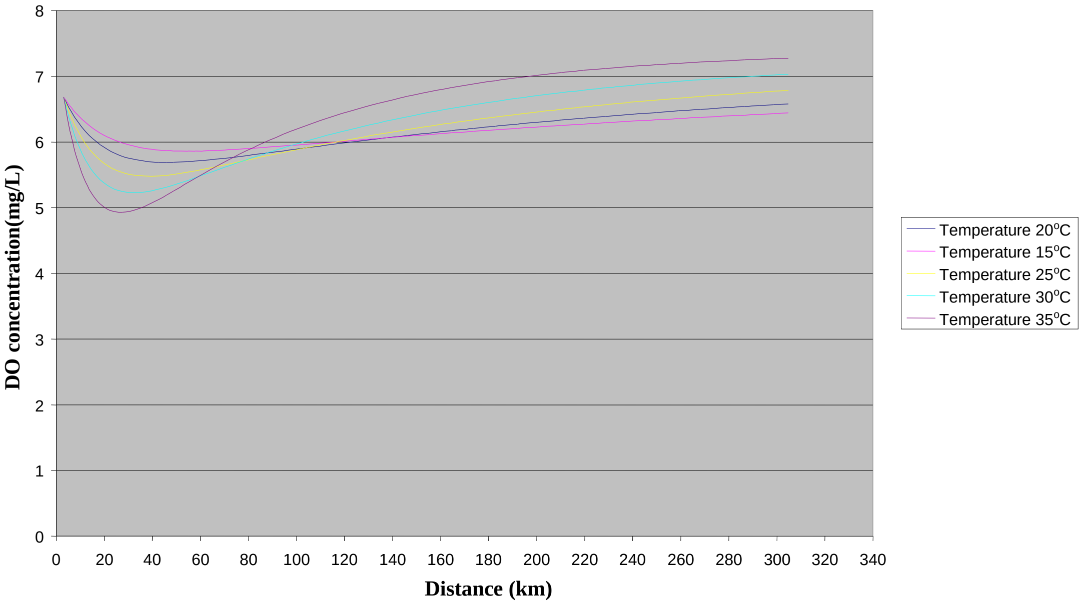

Figure 8. DO Concentration Sensitivity to Changes in River Temperature

The results of the sensitivity analysis or simulation show that the river water quality prediction model is consistent with (Manahan, 1994)Manahan's (1995) theory, which states that the solubility of oxygen in water is low at higher temperatures, while the respiration rate of aquatic organisms increases at those temperatures. The combination of these two conditions results in a significant decrease in oxygen concentration. DO concentrations were 14.7, 8.3, and 7.03 mg/L at temperatures of 0℃, 25℃, and 35℃, respectively (Manahan, 1994). DO concentrations were 14.6, 11.3, 9.1, 7.6 mg/L at temperatures of 0°, 10℃,20℃,30℃(Tebbutt, 2013).

River water temperature management is impossible because the river temperature is not under human control.

5.1.8 DO Concentration Sensitivity Analysis on Three Weather Conditions with Three Discharge Points

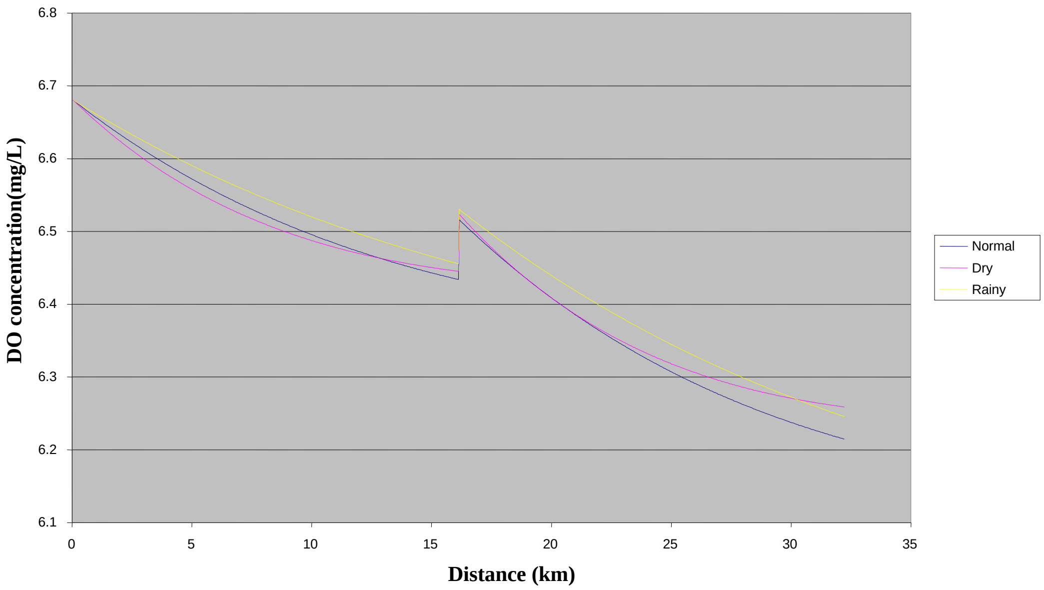

Figure 9. DO concentration sensitivity to three weather conditions with three discharge points.

The DO concentration decreased along the flow in different climatic conditions, namely normal, rainy, and dry. Changes in DO concentration are low under normal, dry, and rainy conditions because the difference in DO concentration is not too great. DO concentrations ranged from 6.44 to 6.66 at a distance of 16 km in the three climatic conditions. Changes in high DO concentrations in normal, dry, and rainy conditions as waste disposal points are added.

The sensitivity analysis or simulation results show that the river water quality prediction model is consistent with the theory of (Manahan, 1994; Salmin, 2005), which states that the addition of a discharge point increases the concentration of waste, causing the DO concentration to decrease. This occurs because the decomposition process of organic matter (a contaminant whose concentration is measured as BOD) requires more oxygen at higher BOD concentrations, which is taken from the DO concentration of river water, causing the DO concentration to drop(Tebbutt, 2013). As shown below, oxygen in water is rapidly consumed through oxidation by organic substances (CH_2O)(Manahan, 1994; Salmin, 2005).

$$CH_2O + O_2 \xrightarrow{\text{microorganisms}} CO_2 + H_2O$$

Waste disposal is managed by treating waste before it is discharged into a river. After processing, waste BOD is expected to have a concentration of 2. This is done to reduce the concentration of BOD produced by waste to be discharged into the river, thereby preserving river life.

The model's sensitivity analysis revealed that the Deli River water quality prediction model produced results that were consistent with real-world data, so the hypothesis was accepted.

5.2. Model validation

The model was validated by comparing the Dissolved Oxygen (DO) profile from the experimental results to the model calculation results. The goal of model validation is to demonstrate that the model is correct and can be used to predict the water quality of the Deli River and other rivers. The following is depicted in the illustration below:

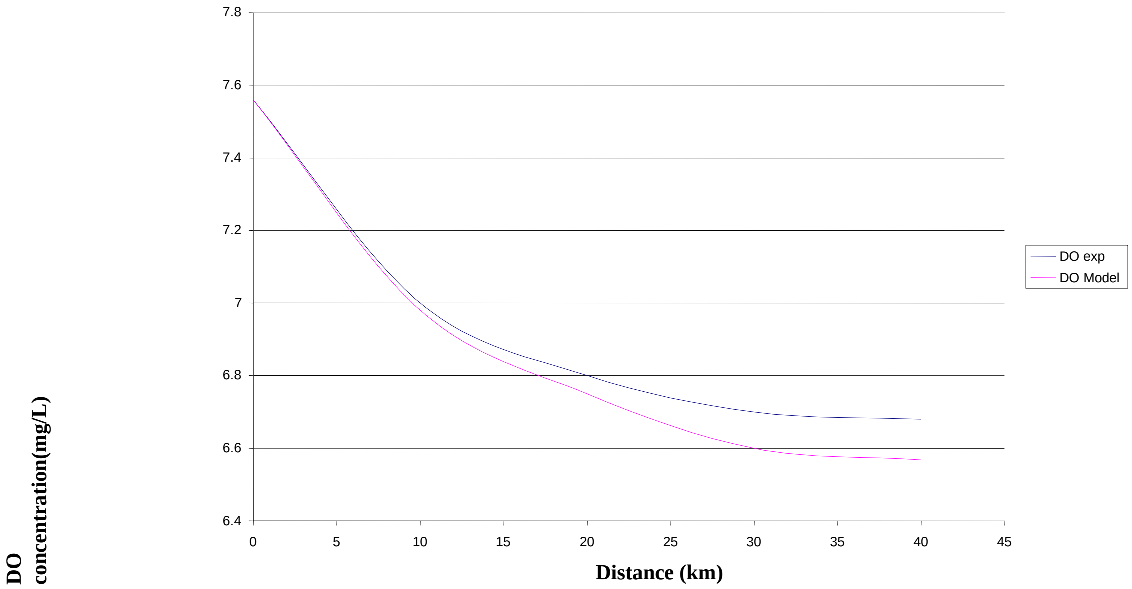

Figure 10. DO Experiment Concentration and DO Model

The experimental DO concentration is 7.0 at a distance of 10 kilometers, 6.8 at a distance of 20 kilometers, and 6.7 at a distance of 30 kilometers. At a distance of 10 km, the Model's DO concentration is 6.98, at a distance of 20 km, the DO concentration is 6.75, and at a distance of 30 km, the DO concentration is 6.6. The graph shows that the experimental DO concentration is higher than the model DO concentration; this occurs because, due to the dynamic physical nature of the river, there is an influence from changes in the condition of the research location at every distance during the study. The physical properties of a dynamic river have an impact on flow velocity, SOD, BOD, radiation, chlorophyll, river depth, and temperature. While the model's DO concentration is made with constant input parameters. The river water quality prediction model is considered valid because the graph between the research DO concentration and the model DO concentration has the same tendency and a DO concentration value that is not significantly different. It is concluded that the Deli River water quality prediction model can predict changes in Deli River water quality as the river flow changes.

By measuring water quality at only one sampling point, this model can be used to predict changes in water quality along the Deli River. Pollution load data from any point in the river can be directly entered into the model formula to obtain predictive results. This means that using this model can save money because it eliminates the need to measure water quality at multiple sampling points along the Deli River. This model, based on the same principles, can be used to forecast changes in the water quality of other rivers.

6. Conclusion

The following are some conclusions drawn from the study's findings:

1. An ordinary differential equation model is used to represent the resulting integrated and dynamic Deli river water quality prediction model. Can be used to forecast changes in Deli River water quality as the river flows.

2. Through sensitivity analysis of the model, managerial recommendations for the management of Deli River water quality, which is the primary goal of modeling, can be implemented in a more focused and effective manner.
3. The resulting model is unique in that it combines the hydraulic submodel, population density around the river, and river water quality submodels.

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