

# MODELING THE SPATIAL CONCENTRATION DISTRIBUTION OF ENVIRONMENTAL PARAMETERS AND TOTAL SUSPENDED SEDIMENT IN DIATAS LAKE, WESTERN SUMATRA, INDONESIA

Andojo Wurjanto<sup>1</sup>, \*Harman Ajiwibowo<sup>1</sup>

<sup>1</sup>Faculty of Civil and Environmental Engineering, Institut Teknologi Bandung, Indonesia

\*Corresponding author, received: 18 March 2019, revised: 21 April 2019, accepted: 08 May 2019

**Abstract:** Diatas Lake is one of the five lakes in the Province of West Sumatra, that requires special attention for its sustainability. A numerical hydrodynamic model of Diatas Lake is presented to observe the biochemical oxygen demand (BOD), sulphide, chemical oxygen demand (COD), dissolved oxygen (DO), phosphate and total suspended sediment (TSS). The model used the surface-water modeling system (SMS), developed by the US Army Corps of Engineers. Field data acquisition, such as bathymetry, water level, and lake current velocity are carried out. The water samples are also collected. The model validation shows good agreement between field and model data. The water quality model is used to simulate the distribution of BOD, sulphide, COD, DO, phosphate and TSS concentration for one year. At the end of the simulated year, the BOD, COD, DO, phosphate and TSS concentration are still within a safe range, in accordance with the environmental government regulation. However, the sulphide concentration exceeds the safe regulatory range. For long-term environmental lake conservation, the use of fertilizer should be regulated and enforced.

**Keywords:** *Hydrodynamic modeling, BOD, Sulphide, COD, DO, Phosphate, TSS, Diatas Lake*

## 1. INTRODUCTION

The water is an essential compound in an ecosystem. The use of fertilizers in agriculture causes pollution in the aquatic environment, leading to poor water quality and depletion of aquatic biota [1].

Fifteen lakes are being reviewed in the mid-term National Development Plan for the years 2015–2019. They require special attention to preserve their sustainability [2]. Four of these 15 lakes, namely Maninjau, Toba, Limboto and Rawapening Lake, are in critical condition. These lakes are having various problems, such as vast sedimentation and high sulphide content [3]. The assessment of other lakes is also necessary for environmental conservation in Indonesia.

The hydro-environmental modeling of Dibawah Lake in the province of Western Sumatra, Indonesia, is carried out using the surface-water modeling system (SMS), to observe the distribution of the existing parameters. The model results show that there two rivers on the northern side of the lake are supplying high amounts of sulphide to the lake. The land-use of the upstream of the northern side rivers are mostly plantation farms owned by residents. The fertilizer may cause the high content of sulphide being discharged into the lake [4].

The water quality assessment of Kerinci Lake in the province of Jambi in Indonesia is also studied. The studied parameters are total suspended sediment (TSS), biochemical oxygen demand

(BOD), dissolved oxygen (DO) and phosphate. Several rivers are flowing into the lake and only one river is flowing out of the lake. The water quality model shows that the BOD, DO and phosphate concentration at the mouth of one of the inflowing rivers, namely Merao river, are significantly polluting the receiving lake water more than the other rivers [5].

The investigation of four environmental parameters (TSS, BOD, DO and phosphate) in Singkarak Lake, in the province of Western Sumatra, Indonesia, is also conducted. The model results show that the two main rivers, namely Sumpur and Sumani Rivers, have the most significant effect on the lake water quality [6].

The water quality, trophic state index (TSI) and fish production potential in Diatas Lake, to obtain information on the lake conditions, are also observed. The study includes analysis of water fertility rates and the ability of the lake water to support fish cultivation. The parameters measured are physical, chemical and biological parameters. The results show that the water in Diatas Lake is still suitable for fish cultivation. The TSI ranges from 37–44 and the average fish production is 44 kg/ha/year, and the lake is classified as a low fish production potential [7].

This research presents the distribution of environmental parameters in Diatas Lake, in the province of West Sumatra, Indonesia. Fig. 1(a) shows the location of Diatas Lake and the rivers coming into and flowing out of the lake. The inflow

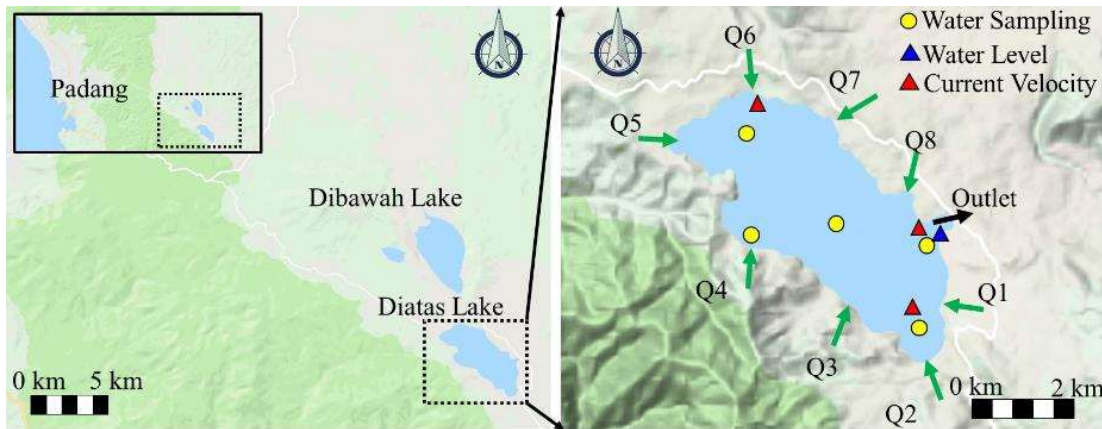


Fig. 1 (a) The orientation for locations of Diatas Lake, and (b) inflow (green inward arrows) and outflow (black arrow) rivers.

and outflow river locations are shown in Fig. 1(b). The field data acquisition is conducted to provide domain and validation for the model. The surface-water modeling system (SMS) is used to predict the distribution of BOD, sulphide, COD, DO, phosphate and TSS in the lake within one year from the date of field data acquisition. The one-year simulation becomes the limitation of the results. Longer model run time is needed for long term results.

## 2. PRIMARY AND SECONDARY DATA

The field data acquisition includes bathymetry, water sampling, water level observation and current velocity measurement. Fig. 2 shows the locations of the field surveys.

### 2.1 Bathymetry Data Acquisition

Diatas Lake is one of the five lakes in West

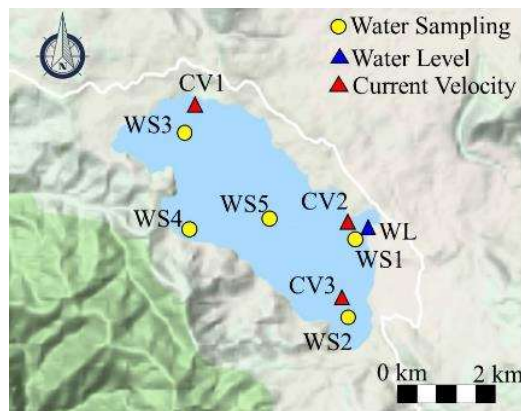


Fig. 2 Water sampling (WS), current velocity (CV) and water level (WL) survey locations.

Sumatra with an area of more than 1,400 hectares [5]. The lake is 1,462 meters above sea water level and has a maximum depth of 309 meters [6]. The total area of bathymetry data acquisition is around 1,100 hectares. Fig. 3 shows the documentation of bathymetry data acquisition.

The lake water depth data are recorded using a single beam echosounder, and they are processed to produce the base map for the model domain. The spatial position and bed elevation are referenced to the Indonesian Geospatial Reference System 2013 (SRGI 2013).

### 2.2 Water Level Observation

The water level observation is carried out to provide the surface water elevation data for the model validation. A staff gauge for water level measurement is set at the location denoted by a blue triangle in Fig. 2, and the documentation can be seen in Fig. 4. The water levels are recorded hourly for 15 days from the 7<sup>th</sup> to 22<sup>nd</sup> July 2017.

### 2.3 Current Velocity Measurement

The three locations of current velocity data



Fig. 3 Bathymetry field data acquisition.

measurement are marked as the red triangles (see Fig. 2). The points are located at the north, center and south of the lake for the representation of the general lake conditions.

## 2.4 Water Samplings

The water samplings are carried out using a water sampler at five points, marked by yellow circles in Fig. 2, and the documentation is shown in Fig. 5. The samples are processed at the local government water laboratory. The lab results are used to provide the initial and boundary conditions of each contaminant in the numerical model.



Fig. 4 Water level observation documentation.



Fig. 5 Tool for water sampling.

## 2.5 Hydrology Analysis

The hydrology analysis is carried out to determine the river discharges flowing into the Diatas Lake. Eight rivers supplying water into the lake are denoted as green arrows, and an outflowing river is marked as a black arrow, as seen in Fig. 1b. The climatological data from the weather stations in the rivers and lake watershed are processed to calculate the monthly average river discharges, using the empirical method written by Mock (1973) [8]. The watershed area is delineated using the map, that is processed from the open source data of the shuttle radar topography mission (SRTM). The resulting monthly average river discharges are

given in Fig. 6. The inflow river discharges are denoted by Q1–Q8, respectively. The outflow river discharge is denoted by “Outlet.”

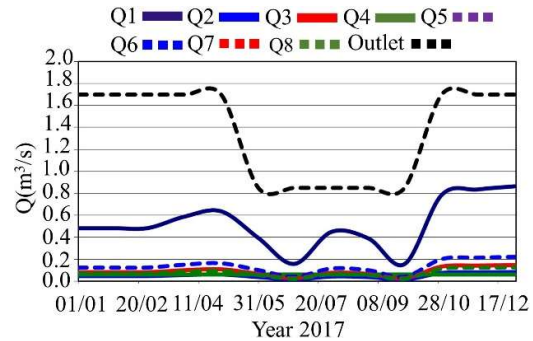


Fig. 6 The monthly average river discharges coming into and out of Diatas Lake.

## 3. NUMERICAL MODEL

A finite element model, the SMS, is used to model the distribution of the environmental parameters in the lake. This tool has been widely used for various applications. Ajiwibowo *et al.* [9] used SMS in a study of the effect of reclamation in Jakarta Bay, Indonesia. Ajiwibowo [10] conducted sedimentation modeling of the Muan River in the province of East Kalimantan, Indonesia.

### 3.1 Governing Equations

RMA2 is a two-dimensional depth-averaged finite element hydrodynamic numerical model, and it is a module within the SMS. The RMA2 models the water surface elevations and horizontal velocity components for a subcritical, free-surface two-dimensional flow field [11]. The RMA2 computes a finite element solution of the Reynolds form of the Navier-Stokes equation for the turbulent flow. The friction is calculated using Manning's coefficient in the Chezy equation, and the eddy viscosity coefficient is used to define the turbulence characteristics. Both steady and unsteady (dynamic) problems can be analyzed.

The governing equations are given below. Equation (1) is the continuity equation. Equations (2) and (3) are the x-direction and y-direction of the momentum equation, respectively.

$$h \frac{\partial u}{\partial t} + hu \frac{\partial u}{\partial x} + hv \frac{\partial u}{\partial y} - \frac{h}{\rho} \left[ E_{xx} \frac{\partial^2 u}{\partial x^2} + E_{xy} \frac{\partial^2 u}{\partial y^2} \right] + gh \left[ \frac{\partial a}{\partial x} + \frac{\partial h}{\partial x} \right] + \frac{gun^2}{\left( 1.486h^{1/6} \right)^2} (u^2 + v^2)^{1/2} - \zeta V_a^2 \cos \psi - 2hv\omega \sin \Phi = 0 \quad (1)$$

$$h \frac{\partial v}{\partial t} + hu \frac{\partial v}{\partial x} + hv \frac{\partial v}{\partial y} - \frac{h}{\rho} \left[ E_{yx} \frac{\partial^2 v}{\partial x^2} + E_{yy} \frac{\partial^2 v}{\partial y^2} \right] + gh \left[ \frac{\partial a}{\partial y} + \frac{\partial h}{\partial y} \right] + \frac{g v n^2}{\left( 1.486 h^{1/6} \right)^2} (u^2 + v^2)^{1/2} - \zeta V_a^2 \sin \psi + 2hu\omega \sin \Phi = 0 \quad (2)$$

$$\frac{\partial h}{\partial t} + h \left( \frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} \right) + u \frac{\partial h}{\partial x} + v \frac{\partial h}{\partial y} = 0 \quad (3)$$

where  $x$  and  $y$  are the cartesian coordinates,  $h$  is the water depth,  $t$  is time,  $u$  and  $v$  are the velocities in Cartesian coordinates,  $E$  is the eddy viscosity coefficient,  $\rho$  is the fluid density,  $a$  is the elevation of the bottom,  $g$  is the acceleration due to gravity,  $n$  is the Manning's roughness  $n$ -value,  $\zeta$  is the empirical wind shear coefficient,  $V_a$  is the wind speed,  $\psi$  is the wind direction,  $\Phi$  is the local latitude,  $\omega$  is the rate of angular rotation of the earth and 1.486 is the conversion from SI to non-SI units in the momentum equation.

The RMA4 is a finite element water quality transport numerical model, in which uniform depth concentration distribution is assumed. It computes concentrations for up to 6 constituents, either conservative or non-conservative, within a one-and/or two-dimensional computational mesh domain [12]. The water quality model, RMA4, is designed to simulate the depth-average advection-diffusion process in an aquatic environment; the form of the depth-averaged transport equation is:

$$h \left( \frac{\partial c}{\partial t} + u \frac{\partial c}{\partial x} + v \frac{\partial c}{\partial y} - \frac{\partial}{\partial x} D_x - \frac{\partial}{\partial y} D_y - \sigma + kc + \frac{R(c)}{h} \right) \quad (4)$$

where  $x$  and  $y$  are the Cartesian coordinates,  $h$  is the water depth,  $t$  is time,  $u$  and  $v$  are the velocities in the cartesian coordinates,  $c$  is the pollutant concentration of a given constituent,  $t$  is time,  $D_x$  and  $D_y$  are turbulent mixings (dispersion) coefficients,  $k$  is first-order decay of a pollutant,  $\rho$  is source or sink constituent, and  $R(c)$  is the evaporation/rainfall rate.

### 3.2 Model Setup and Validation

The numerical model domain covers the water area of Diatas Lake and includes eight inflow rivers and one outflow river. Fig. 7 shows the bathymetrical map and the model's grid. The elements are generated to adjust to lake geometry. The outputs of the RMA2 module are the water elevation and currents in the lake. The water level data resulting from the model are validated using the water level observations at point WL (Fig. 2).

The validation result can be observed in Fig. 8. The current velocity distribution resulting from the model is also validated at locations CV1, CV2 and CV3 (Fig. 2). The result of validation can be observed in Figs. 9–11. The validation shows good agreement.

The validated current velocities and water levels resulted from the RMA2 are becoming forcing for the water quality transport model RMA4. The initial and boundary condition values for the RMA4 model are taken from the field data results, as shown in Table 1.

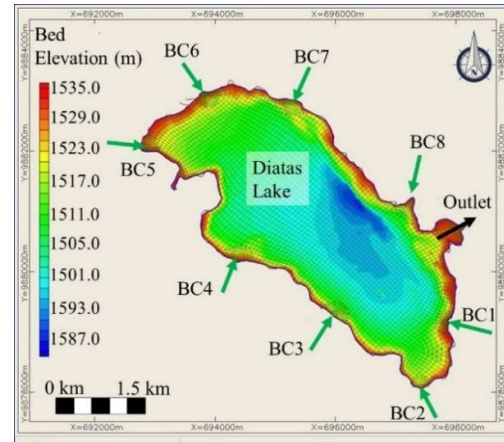


Fig. 7 The bed elevation and mesh of the model domain

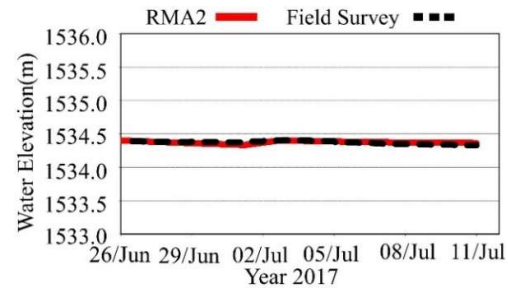


Fig. 8 Water level validation results at point WL

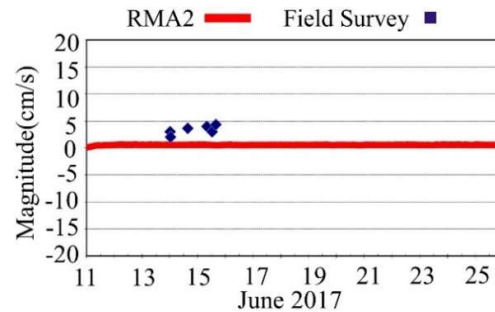


Fig. 9 Current velocity validation results at Location CV1



Table 1 The water quality parameter values for the initial and boundary conditions

BC	BOD mg/l	Sulphide mg/l	COD mg/l	DO mg/l	Phosphate mg/l	TSS mg/l
BC1	1.470	0.048	5.130	8.100	0.029	4.000
BC2	1.470	0.048	5.130	8.100	0.029	4.000
BC3	1.470	0.048	5.130	8.100	0.029	4.000
BC4	1.470	0.049	5.130	8.100	0.030	6.000
BC5	1.840	0.058	5.130	8.100	0.026	4.000
BC6	1.840	0.058	5.130	8.100	0.026	4.000
BC7	1.840	0.058	5.130	8.100	0.026	4.000
BC8	2.210	0.085	11.010	8.110	0.038	9.000
Initial	1.470	0.480	5.130	8.100	0.026	5.000

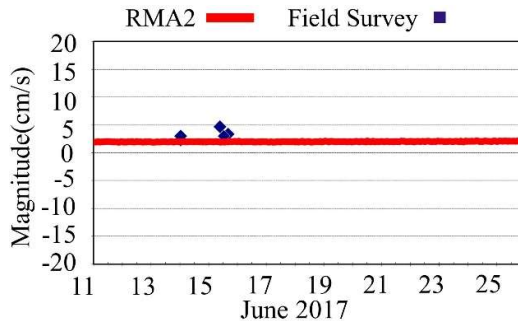


Fig. 10 Current velocity validation results at Location CV2

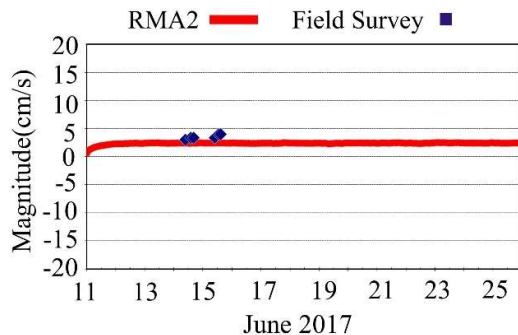


Fig. 11 Current velocity validation results at Location CV3

#### 4. RESULTS AND DISCUSSION

The surface water circulation in the lake is shown in Fig. 12. The bold red pattern shows the direction of water flow. The lake water flows clockwise in the north side of the lake before reaching the outflow river. The lake water flow circulates counter-clockwise in the southern part of the lake before flowing to the outflow river.

The paper presents the spatial distribution and comparison with regulations for six parameters: BOD, sulphide, COD, DO, phosphate and TSS.

Two regulations are compared with the resulting values, they are the Indonesian Government Decree Number 82 The Year 2001 [13] and the Governor Regulation Number 24 The Year 2010 [14], denoted as Reg. A and Reg. B in Table 2, respectively.

The Reg. A divides the quality into four classes. The first class classifies the lake as suitable for drinking water. The second class is for recreational water facilities, cultivation of freshwater fish and livestock water to irrigate crops. The third class is for the cultivation of freshwater fish and livestock water to irrigate crops. The fourth class means the lake is only suitable for irrigating crops. The Reg. B only sets the maximum threshold of any contaminants in a lake water.

The allowable concentrations, according to Reg. A and Reg. B, for BOD, sulphide, COD, DO, phosphate and TSS are given in Table 2. The 11 output parameter observation locations (K01-K11), as shown in Fig. 13, are marked with blue circles.

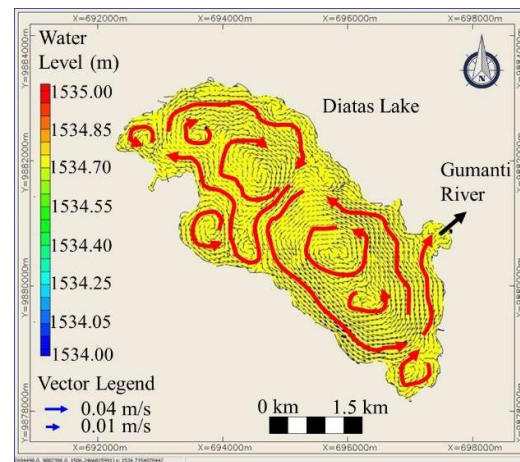


Fig. 12 Surface water circulation

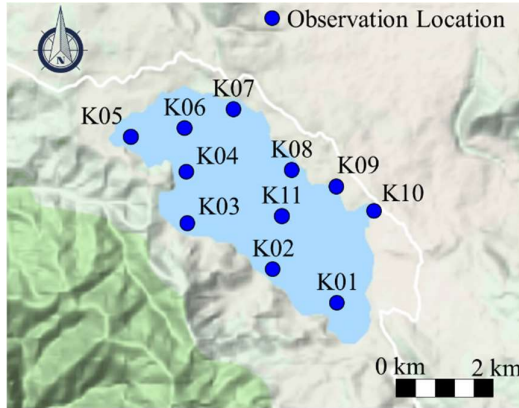


Fig. 13 Output parameter observation locations

Table 2 Water quality standard according to government regulation

Parameters (mg/l)	Reg. A [13] Classes				Reg. B [14]
	I	II	III	IV	
BOD	2	3	6	12	3
Sulphide	0.002	0.002	0.002	-	0.002
COD	10	25	50	100	25
DO	6	4	3	0	4
Phosphate	0.2	0.2	1	5	0.1
TSS	50	50	400	400	25

#### 4.1 BOD

The BOD spatial distribution results are given in Fig. 14. As presented in Table 1, rivers Q5, Q6, Q7, and Q8 contain more BOD than the other rivers. The highest accumulated BOD is found at the north part of Diatas Lake and near the Gumanti River, as observed in Fig. 13. The value ranges from 1.77–1.82 mg/l, while at other parts of the lake, the value is around 1.72–1.77 mg/l. With the values from the model results (Fig. 15), Diatas Lake is found to satisfy the standards in the two regulations. The BOD value satisfies Class II, III and IV of Reg. A, and the Reg. B standard.

#### 4.2 Sulphide

The spatial distribution of sulphide concentration after a one-year simulation is shown in Fig. 16. The high concentration results in an excessive sulphide value at some rivers' inlet area, which is nearly 0.05 mg/l. Mostly in the north part of Diatas Lake, the value is around 0.04875–0.0490 mg/l, whereas at the center and south part, the value is 0.0485–0.0480 mg/l. The maximum sulphide concentration is 0.002 mg/l, which far exceeds the regulation's standard, indicating the lake may not be utilized for any important/crucial purposes, as observed in Fig. 17.

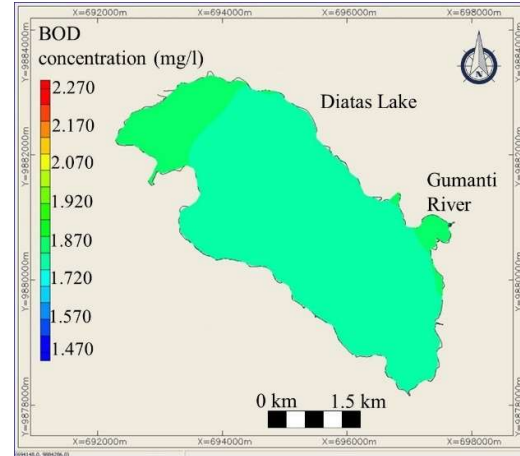


Fig. 14 Spatial BOD distribution

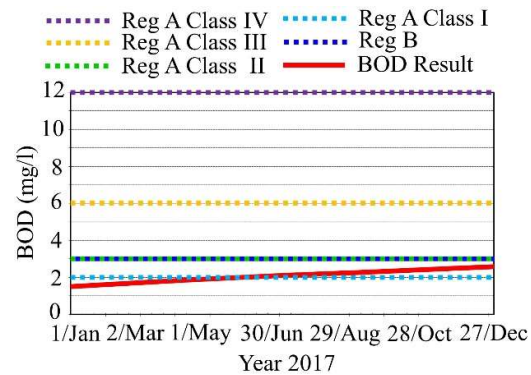


Fig. 15 Comparison of Annual BOD model results with the regulations

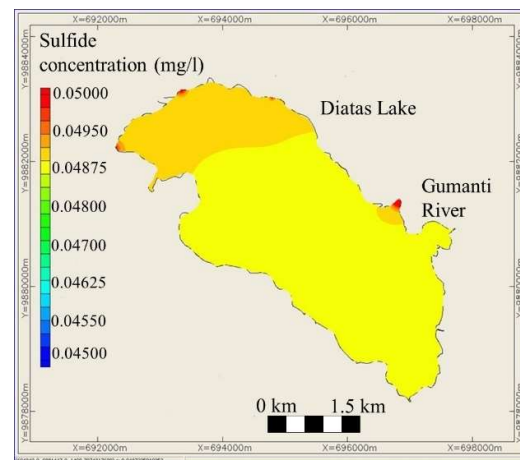


Fig. 16 Spatial sulphide distribution

#### 4.3 COD

The spatial distribution of COD concentration after a one-year simulation is shown in Fig. 18, and the comparison to the regulations are presented in

Fig. 19. According to Fig. 19, the maximum value of COD is 5.795 mg/l, and this level is far below the thresholds in Reg A. and Reg B.

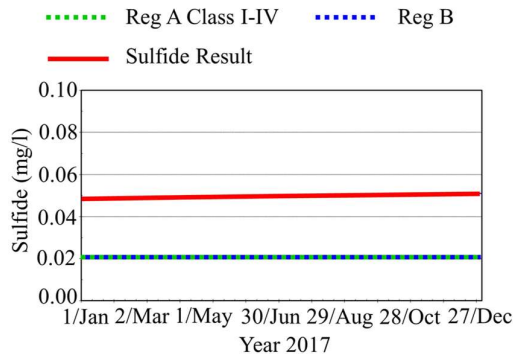


Fig. 17 Comparison of annual sulphide model results with the regulations

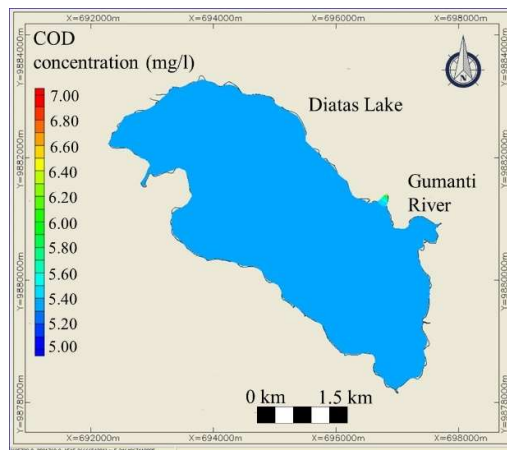


Fig. 18 Spatial COD distribution

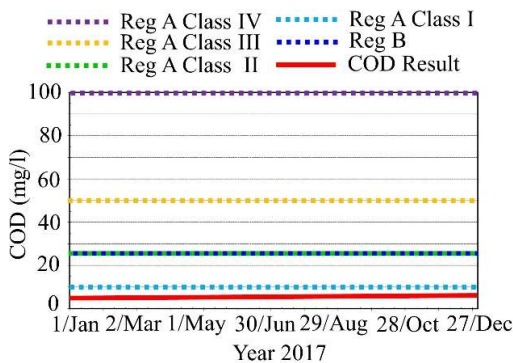


Fig. 19 Comparison of annual COD model results with the regulations

#### 4.4 DO

The spatial distribution of DO concentration after a one-year simulation is shown in Fig. 20. According to Reg. A and Reg. B (Fig. 21), the maximum DO concentration is 8.127 mg/l, which is more than the standard minimum regulations.

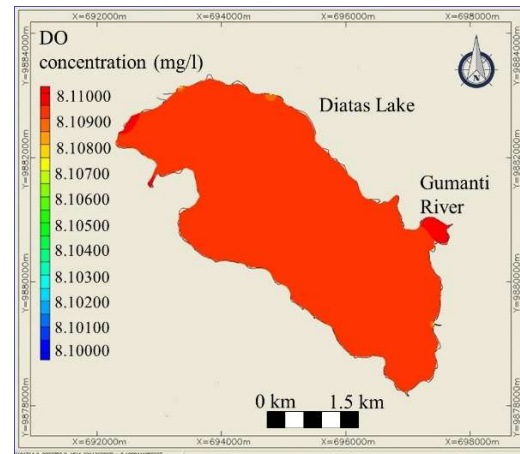


Fig. 20 Spatial DO distribution

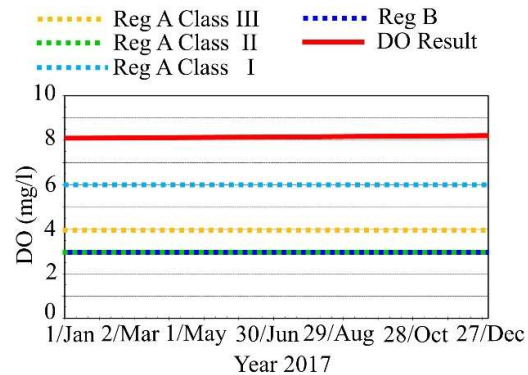


Fig. 21 Comparison of annual DO model results with the regulations

#### 4.5 Phosphate

The spatial distribution of phosphate for a one-year simulation is shown in Fig. 22, which is almost uniform, and the value is 0.026 mg/l. The inflow river input shows a maximum value of 0.0276 mg/l (denoted by Q8 in Fig. 1b); this river inflow contains a high value of phosphate compared with the other river inflows. The local government should give more attention to this problem. The phosphate value satisfies all the regulations, as shown in Fig. 23.

#### 4.6 TSS

The spatial distribution of TSS for a one-year simulation is shown in Fig. 24. The maximum value of the TSS concentration is 5.25 mg/l, which satisfies the regulations as shown in Fig. 25. Although the TSS concentration meets applicable regulatory standards, the increase in lake bottom elevation needs to be considered, especially in the Gumanti River area, where a one-year increase in bed change can reach 0.17 meter, as shown in Fig. 26.

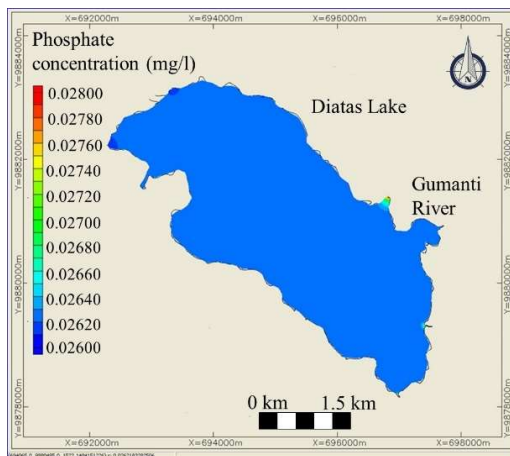


Fig. 22 Spatial phosphate distribution

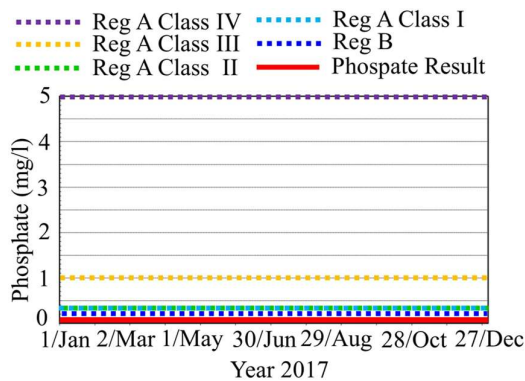


Fig. 23 Comparison of annual phosphate model results with the regulations

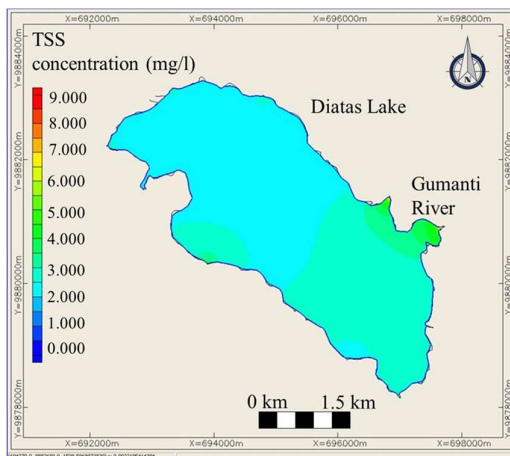


Fig. 24 Spatial TSS distribution

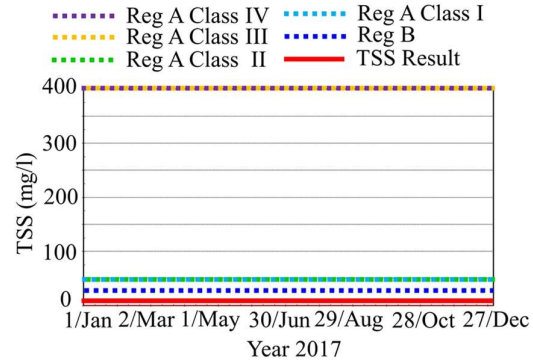


Fig. 25 Comparison of annual TSS model results with the regulations

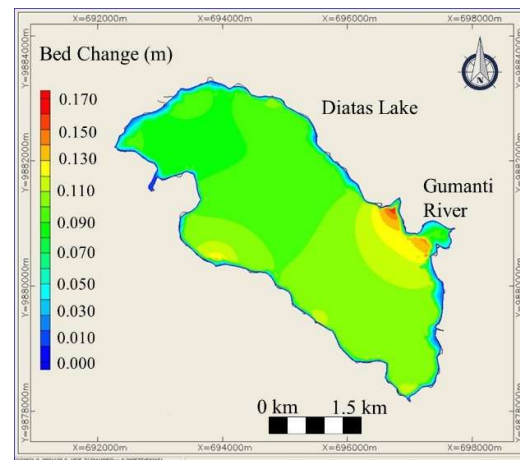


Fig. 26 Bed change of the bottom elevation

## 5. CONCLUSION

The resulting flow model using RMA2 in SMS shows good agreement with the field data. The environmental model using RMA4 shows that the sulphide concentration exceeds the environmental regulations.

From these findings, more effort is needed to manage the use of fertilizer in farming activity to decrease the accumulation of sulphide. Additionally, sedimentation increase in the bed lake needs more attention, especially at the river mouth of the Gumanti River.

## 6. ACKNOWLEDGMENTS

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