Study of Land Erosion and Bed Change Simulation of Danau Diatas and Danau Dibawah

Sadtim¹, Dalrino¹,*, Hartati¹, Suhendrik Hanwar¹, Aguskamar¹

¹Civil Engineering Department, Politeknik Negeri Padang

*dalrino350@gmail.com

Abstract. Numerical bed change study of Danau Diatas and Danau Dibawah was conducted. Hydrodynamic and sedimentation simulations are carried out using monthly discharge input limit conditions obtained from the calculation using the FJ Mock method. The RMA2 numerical model is used to obtain current patterns that are calibrated against the measurement results. Estimated land erosion is calculated using the USLE equation. Sediment discharge obtained from the USLE equation is used as an input of sediment sources to obtain sedimentation patterns using the SED2D module. The results of the modeling of the current pattern get the current velocity ranging from 0 - 0.05 m / s for Danau Diatas and between 0 - 0.04 m / s for Danau Dibawah. The bottom profile change due to the distribution of sedimentation was found to range between 0.12 ~ 0.21 m in one year simulation with a radius of 0.53 and 1.72 km. This study is a preliminary study to get an idea of the potential for sedimentation. The validity of the results is recommended to use bathymetry measurements to see the bed changes that occur with the time of measurement. The initial description obtained has shown the need for efforts to regulate land use and commensurate with lakes in anticipation of silting of lake waters due to erosion.

1. Introduction

Danau Diatas and Danau Dibawah are located in Solok Regency, West Sumatra, on the ridge of Bukit Barisan which extends along the island of Sumatra. The naming of the two lakes refers to the altitude elevation of the lake, namely Danau Diatas is at an elevation of 1,531 m above sea level and Danau Dibawah with an elevation of 1,462 m above sea level. Danau Dibawah and Danau Diatas Lakes are located side by side, separated by the nearest distance of about 2 km so that they are often dubbed Twin Lakes. Meteorological data from 2002 to 2005 indicate that the Bukit Barisan Mountains in this region have a very wet climate (super-humid) with rainfall between 2,500 - 3,000 mm / year, with 140 - 170 rainy days / year, and hyperhumid climate with rainfall > 3,000 mm / year with 180 - 220 rainy days / year. The peak rainy season occurs in April and October while the dry season is from May to June.[1] Based on PERMEN PUPR No. 04 / PRT / M / 2015 concerning the criteria and determination of river areas has defined Lake Above and Below in 2 different river areas namely the Batang Hari river area for Lake Above and the Indragiri Akuaman river area for Danau Dibawah. [2]
Danau Diatas was located, at a geographical position between 1 ° 01'51" - 1 ° 07'39" South Latitude, and between 100 ° 43 '01" - 100 ° 50 '26" East Longitude. Based on its formation, Danau Diatas is classified as a tectonic lake with a concave shape extending from the Northwest to the Southeast as a result of the tectonic process of the large Sumatra fault. Danau Diatas waters are around 12.45 km² with a maximum length and width of 6.4 km and 2.9 km respectively and have a coastline length of 19.9 km. Danau Diatas is a relatively shallow lake with a maximum depth of 47 m. Lake water volume is around 302 million m³ and retention time reaches 7.7 years [2]. The main outlet is Gumanti River which then integrates with Batanghari River and empties into the Berhala Strait, near the Malacca Strait. Danau Diatas has a catchment area of 40.81 km². The rivers that enter the lake are generally in the form of intermittent rivers, which are dry in the dry season. Danau Dibawah is a tectonic lake located in the geographical position of 1 ° 0 '35" North Latitude, and 100 ° 43 '51" East Longitude. Has a height (altitude) 1,462 meters above sea level, with an area of water around 11.2 km² and a volume of water around 2.54 km³ and a maximum depth and averages of 309 m and 227 m. The main outflow from this lake is the Lembang River. The area of Lake Dibawah watershed is 2881.7 ha and is a steep terrain, where the edge of the lake has been utilized for agriculture, cultivation and settlement [1]. Agricultural and cultivation areas appear to be quite intensively planted with horticultural crops such as turnips, mustard greens, tomatoes, red peppers and so on. The lake waters themselves are used as a source of drinking water, and fisheries. Based on the analysis of DEM Aster, it is found that the Danau Diatas and Danau Dibawah watersheds can be divided into 18 and 27 sub-watersheds as shown in Figure 2.

With an average land slope above 25% and dominated by horticultural crop areas and planting patterns in the same direction as slope, it is feared that it will accelerate the rate of land erosion, which results in an increased risk of landslides and sedimentation in lake bodies. Land erosion in Danau Diatas and Danau Dibawah areas can be anticipated by farming activities around the lake which change the land cover condition and have an impact on surface erosion which then becomes sediment deposits in the lake body. Siltation in lake waters can be caused by increased land erosion with a number of eroded
material entering the lake waters. This will reduce the capacity of the lake due to the silting process that occurs. Numerical simulations of currents and sedimentation have been carried out to see condition of current patterns and distribution of sedimentation that can have potential for the bed change of the lake that caused by siltation.

2. Methodology
Erosion is a process in which the land is detached and then moved to another place by the forces of water, wind, and gravity [3]. Erosion is the result of interactions of climate, soil, topography, vegetation, and human activities on natural resources. The eroded material then settles to a certain location and becomes the ultimate material destination of the material deposited into sedimentation [4]. Sedimentation studies to predict lake bottom siltation have been carried out at various location. Several measurement techniques have also been developed to detect the presence and age of sedimentary geology [5], [6], [7], [8]. Suggestions for handling sedimentation problems to the lake using the reservoir Saboworks to overcome the problem of sediment and debris flow entering the lake body have been given [9]. The use of GIS in estimating the potential of land sedimentation and river flow has been carried out [10], [11], [12]. The use of RMA2 and SED2D in analyzing sediment flow and transport patterns has been carried out [13]. Hydrodynamic modeling of Danau Diatas and Danau Dibawah is carried out to obtain the pattern of currents and sedimentation distribution that affect changes in the lake bed. Modeling results are calibrated to the flow of field measurements. The input boundary condition used in the model is the monthly discharge obtained from the calculation using the FJ Mock method (Figure 3).

![Figure 3. Monthly Discharge as Input of model boundary conditions](image)

The RMA2 numerical model is used to solve mass and momentum conservation equations that are integrated with depth (depth-averaged) in two horizontal dimensions. Average depth flow velocity, \( U \) used by RMA2 is expressed in the following equation:

\[
U = \frac{1}{h} \int_0^h u(z) dz
\]  

(1)

Where \( U \) is the average depth of current velocity (in the x direction), \( h \) is the depth of the elemental waters, \( u(z) \) is the flow velocity as a function of the vertical direction and \( z \) is the vertical coordinate. The form of the RMA2 governing equation that has been solved in the x and y directions is as follows:
where \( h \) is the vertical depth, \( u, v \): Flow velocity in the x, y; \( \rho \): Coefficient of eddy viscosity, \( g \): Acceleration of gravity; \( a \): Elevation of water bottom; \( n \): Coeffici ent of Manning roughness (U.S. Army Corps of Engineer, 1984). Inflows that move into the lake waters will provide sedimentation input in the lake. Sediment distribution patterns are modeled using the SED2D module. The governing equation used in the SED2D module is as follows.

\[
\frac{\partial C}{\partial t} + u \frac{\partial C}{\partial x} + v \frac{\partial C}{\partial y} = \frac{\partial}{\partial x} \left( D_x \frac{\partial C}{\partial x} \right) + \frac{\partial}{\partial y} \left( D_y \frac{\partial C}{\partial y} \right) + \alpha_1 C + \alpha_2 \tag{4}
\]

where \( C = \) concentration \( (\text{kg/m}^3) \); \( t = \) Time \( (\text{seconds}) \); \( u = \) Direct current velocity \( x \) \( (\text{m/s}) \); \( x = \) main axis direction of flow \( (\text{m}) \); \( v = \) current direction velocity \( y \) \( (\text{m/s}) \); \( y = \) Axis perpendicular to the x-axis \( (\text{m}) \); \( D_x = \) Diffusion coefficient in the direction of \( x \) \( (\text{m}^2/\text{sec}) \) and \( D_y = \) coefficient of diffusion in the direction of \( y \) \( (\text{m}^2/\text{sec}) \). The condition of the downstream boundary is the lake water level based on data obtained when measuring the water level. Figure 11 shows the boundary conditions carried out in the modeling.

Bed changes model due to sedimentation is done using input current values obtained in RMA2 modeling using the SED2D module. The source of the sediment simulation comes from rivers that flow into the lake area and also from land erosion which was predicted previously using the USLE equation. Of the several methods for estimating the amount of surface erosion, the Universal Soil Loss Equation (USLE) method is the most commonly used method [14], [15]. Universal Soil Loss Equation (USLE) equation can be write as:

\[
A = R \cdot K \cdot L \cdot S \cdot C \cdot P \tag{5}
\]

Where; \( A = \) the amount of land eroded in t/ha/year; \( R = \) Rainfall factor, i.e. the number of rain erosion index units, which is the multiplication of total rain energy \( (E) \) with a maximum rainfall intensity of 30 minutes \( (\text{I}30) \); \( K = \) soil erodibilities factor, i.e. erosion rate per unit of erosion index for a soil obtained from a standard homogeneous experimental plot, with a length of 72.6 feet \( (22 \text{ m}) \) located on a slope of 9% without plants; \( L = \) slope length factor is 9%, namely the erosion ratio of the soil with a certain slope length and the erosion of the soil with a slope length of 72.6 feet \( (22 \text{ m}) \) under identical conditions; \( S = \) slope steepness factor, which is the ratio between the amount of erosion from a slope to the steepness of a particular slope, to the amount of erosion from the soil with a slope of 9% under identical conditions; \( C = \) factors of vegetation cover and plant management, namely the ratio between the amount of erosion from an area with vegetation cover and management of certain plants to the amount of erosion from identical soils without plants and \( P = \) factor of soil conservation measures, ie the ratio between the amount of erosion from soils treated by soil conservation measures such as contour management, planting in strips or terraces to the amount of erosion from soils treated in the same direction in the same slope.

3. Result and Discussion

With an average land slope above 25% and dominated by horticultural crop areas and planting patterns in the same direction as slope, it is feared that it will accelerate the rate of land erosion, which results in an increased risk of landslides and sedimentation in lake bodies. Image analysis in the area around the
lake obtained the density of settlement conditions. The upstream boundary location of the model is
determined as a monthly discharge input condition obtained from the Mock model at a location with a
high topographic slope which is considered to represent field conditions (Figure 7).

![Figure 4. Topographical Conditions of Danau Diatas and Danau Dibawah](image1)

![Figure 5. Slope Conditions in the Catchment Area of Danau Diatas and Danau Dibawah](image2)

![Figure 6. Existing land cover areas of Danau Diatas and Danau Dibawah](image3)

The results of current pattern modeling get the current velocity in Danau Diatas ranges from 0 - 0.05 m / s, while for the current velocity in Danau Dibawah ranges between 0 - 0.04 m / s. (Figure 8). The current survey was conducted to determine the speed and direction of the current at Danau Diatas and Danau Dibawah locations and used as calibration data on the results of hydrodynamic modeling. The calibration results show the calculated flow velocity value of the simulation results is quite close to the measurement result value at the specified location. Figure 9 and Figure 10 shows the plotting results of the current simulation against the measurement results at the location of point on Danau Diatas and Danau Dibawah.
Figure 7. Boundary conditions of the model

Figure 8. Current pattern of simulation results of Lake Above (a) and Lake Below (b)

Figure 9. Location of calibration points for current speed and calibration results Danau Diatas
Figure 10. Location of calibration points for current speed and calibration results Danau Dibawah

Modeling of bed changes due to sedimentation is done using input current values obtained in the previous RMA2 modeling using the SED2D module. The source of the sediment simulation comes from rivers that flow into the lake area and also from land erosion which was predicted previously using the USLE equation. Of the several methods for estimating the amount of surface erosion, the Universal Soil Loss Equation (USLE) method is the most commonly used method. The simulation results obtained the distribution pattern of sedimentation originating from river mouths and land resulting in an increase in the bottom elevation at the edge of the lake shown in Figure 11 and Table 1.

Figure 11. Bed Changes for 1 year simulation for Danau Diatas (a) and Danau Dibawah (b)

| Tabel 1. Predicted sediment thickness and Radius due to simulation results |
|-----------------------------------|-----------------|-----------------|-----------------|
| Lair of the lake                  | Danau Diatas    | Danau Dibawah   |
| Predicted sediment thickness (m)  | Radius (m)      | Predicted sediment thickness (m) | Radius (m)     |
| 0.21                              | 112             | 0.21            | 93              |
| 0.18                              | 200             | 0.18            | 230             |
| 0.15                              | 322             | 0.15            | 530             |
| 0.12                              | 530             | 0.12            | 1720            |
Bed changes due to the distribution of sedimentation were found to range between 0.12 – 0.21 m in one simulation year and spread over an area of 0.53 km for Danau Diatas and 1.72 km for Danau Dibawah.

4. Conclusion
The cropping conditions around Danau Diatas and Danau Dibawah areas put pressure on the capacity of the existing lakes. This is caused by the occurrence of land erosion which is also influenced by the topography of the lake area. The results of current modeling using the RMA2 module have obtained good validation at the measurement location. The results of the modeling of current patterns in Danau Diatas and Danau Dibawah get the magnitude of the current speed in ranges between 0 - 0.05 m/s, and 0 - 0.04 m/s. Simulation results that show the distribution of sediments into the lake body indicate the need for efforts to regulate land use and commensurate lakes in anticipation of silting of the lake waters due to erosion. This study is a preliminary study to get an idea of the potential for sedimentation. Erosion values are obtained from the use of empirical equations and have not been validated in real terms with field conditions. It is recommended to take measurements of the sediment rating curve and changes in bathymetry in subsequent studies to obtain validated erosion and sedimentation values.

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