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Spatial distributed erosion model based on land surface Geometry : Case study in Sayang River Basin, Malang District

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ABSTRACT

Erosion is the process of drifting (losing) or overflowing soil because of pressure wind, water and human actions. Erosion causes topsoil eroded. The erosion process often occurs around of us, especially in agricultural land on the hillside. Sediment in watersheds is an indicator of damaged watersheds. Erosion caused a sedimentation process and make some sediment in the last process. Sediment will settle on the riverbed and part of the sediment will be carried into the reservoir. Generally, erosion prediction models have their advantages and disadvantages. Research of erosion prediction model is still being developed. Based on Moore and Burch's (1986) equations, flux of sediment in an area can be calculated by the equation q_{sx}= $k_t q_x^{p+1} (sin\beta)^n$ where q_{sx} is the sediments, p and n are exponents, β is the slope angle at x, k_t is a characteristic of the river, from the derivation of sediment flux equation, is obtained Potential Erosion Index. Potential Erosion Index influenced by slope, flow accumulation and surface of the soil. Moore and Burch's (1986) equation was applied to the sub-tropics climate so if it is applied to the climate of the tropics needed validation process. The purpose of this study is to modelling Moore and Burch's (1986) equation in numerical form, integrate the geometrical erosion model with Geographic Information Systems (GIS) and apply the geometric erosion models in the Sayang river basin and create an erosion model based on land surface geometry factors from the calibration process expressed in the erosion index geometry and calculate the magnitude of erosion with analytic equations.

Key word: *Erosion, Sediment, Moore and Burch, Potential Erosion Index*

Introduction

Erosion is the process of drifting (losing) or overflowing soil because of pressure wind, water and human action. Erosion causes the topsoil eroded. Soil because of effect from erosion will be carried along with the flow of water so that it becomes sediment that will settle if the water flow is calm or slowed down. Damage because erosion occurs in the soil where the erosion andthe final place for example at the river downstream(Arsyad, 2006). The erosion often occurs in daily life, especially on agricultural land on the hillside. Farmers often find it difficult to control erosion, because if there is no effort to prevent or conserve the land it can cause large erosion around the slope.

Sediment is an indicator of the damage in river basin. The sediment caused by factors of nature and factors of human. Factors of nature such as continuous rain which can erode the top soil. Human factors such as forest conversion into agricultural land, shifting fields and settlements. Erosion due to human activities is very dangerous for the River Basin.

One of the ways that can be used to determine in a simple erosion is hydrological modeling. Defining a model is a simple description of an object.The formation of models and the application of models in an experiment are formed by a simulation. This erosion modeling is combined using Geographic Information Systems (GIS)(Dent,1971).

Sediment is an erosion results, sediment will settle and some of the sediment will be carried into the reservoir. Sediment transport movements can be divided into three types, that is *bed load transport, wash load transport* and *suspended load transport*. *Bed load transport* is sediment in the bottom of a river that moves by rolling, sliding or jumping. *Wash load transport* is sediment in the form of fine particles carried by river flow and settlesif the water flow is calm. And the final types is *suspended load transport. Suspended load transport*is river sediment that hovers in the flow.

Commonly, the types of erosion prediction models are USLE (*Universal Soil Loss Equation*) method, RUSLE (*Revised Universal Soil Loss Equation*), MUSLE (*Modified Universal Soil Loss Equation*), GUEST (*Griffith University Erosion System Template*), ANSWERS (*Areal NonPoint Sources Watershed Environment Response Simulation*) and lastis AGPNS (*Agricultural Non-Point Source Pollution Model).* Generallyprediction of erosion models have advantages and disadvantages of each. The development prediction of erosion models is still being developed until now. The development prediction of erosion models can use an approach through the results of the resulting sedimentation.

According to Moore and Burch Moore and Burch (1986), sediment flux in an area can be calculated with the following equation:

$$q_{sx} = k_t q_x^{p+1} (sin\beta)^n$$

The Potential Erosion Index equation is obtained from the decrease in the sediment flux equation and is influenced by several factors, such as topography without ignoring the rainfall factor, soil factor and land use factor. Potential Erosion Index illustrates the accumulation of sediment erosion because the influence of slope. Rahardjo (2017) explains that the Potential Erosion Index has considerable variation and high range because the influence of the topographic shape from the earth's surface. The effect of the shape from earth's surface also affects the accumulation of water flow. Water flow erodes the surface of the soil and causes erosion so that the results of erosion will accumulate in areas that have low elevation. Determination of the Potential Erosion Index is strongly influenced by the slope, flow accumulation and soil surface shape so that if land management in the study area is not good it will produce alarge erosion. The application of the Potential Erosion Index in the Java area requires parameter calibration because the Moore and Burch (1986) equation was initially applied to the sub-tropical regions. The prediction model was calibrated using the results of observations sedimentation from the research location that is the Sayang River Basin, Malang Regencyand produced a new erosion equation based on the surface of geometry.

Materials and Methods

Case Study

The research location is in the Natural Resources and Environmental Engineering Laboratory, Faculty of Agricultural Technology, Brawijaya University. While the application of the erosion geometry model is located in the Sayang River Basin which is geographically located at 112⁰22'09'' BT and 07⁰50'34'' LS. The position of the Sayang River Basin is between Ngantang and Pujon Districts, Malang Regency, East Java Province. Figure 1 shows the area used as a research case study.

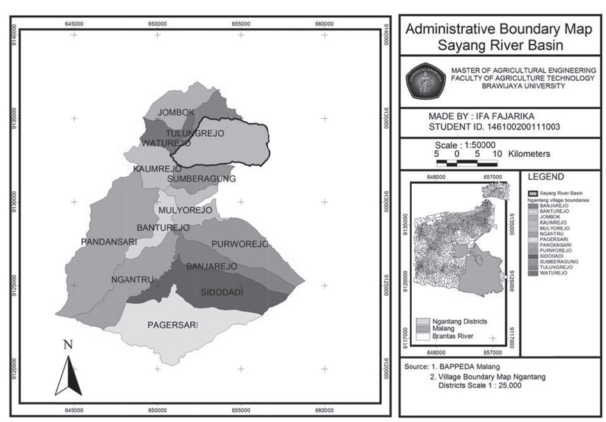

Fig. 1. Sayang River Basin, Ngantang Districts

Data Analysis

Primary data in this research : flow velocity data, water level data are used to input sediment yield data. Determination of sediment yield data also requires sediment specific gravity data and river characteristic data. Sediment density was obtained from the analysis of sediment samples conducted at the Soil and Water Laboratory of the Irrigation Department, Brawijaya University. In addition to the specific gravity of the analysis carried out is a filter analysis. Hydrometric analysis was not carried out because the percentage of clay in the sample was only small. Analysis of sediment data using the Meyer-Peter and Muller equation (1934) :

$$\gamma R_h \left(\frac{k}{k'}\right)^{\frac{3}{2}} S - 0,047(\gamma_s - \gamma)\, d_m = 0,25 \left(\frac{\gamma}{g}\right)^{1/3} (q_B)^{2/3}$$

Validation

Model validation is based on testing the model using observational sediment results, field observational data and laboratory analysis results data. The multiplier coefficient is obtained from testing the model using the Moore and Burch equation (1986) and using total field observation sediment data (Yx). This validation produces a multiplier coefficient that can be used to determine erosion in the Sayang River Basin. After the calibration process the data results are verified.

Model Results

After testing the model and obtaining some parameters needed to perfect the Geometric Erosion Model, the next step is to verify the results of the model testing. The multiplier coefficient is used to determine erosion for the entire Sayang River Basin.

Results and Discussion

Characteristics of the Research Area

The Sayang River Basin areas located between Ngantang District and Pujon District, Malang Regency, East Java Province. The administrative boundary of the Sayang River Basin, the north is Jombok Village and Waturejo Village, the west is Kaumrejo Village, the east is Ngabab Village and the south is Sumberagung Village. The majority of the area around the Sayang River Basin works as dairy farmers and farmers. Landuse in the Sayang River Basin is used for settlements (26,162 ha), grass (0,403 ha), elephant grass (9,946 ha), rice fields (194,405 ha), coffee plantations (787,369 ha), rice fields (3,551 ha), shrubs (158,298 ha) and dry fields (105,773 ha). Based on the Soil Map of the Brantas River Watershed Management Center Surabaya (2010), the soil type in the upstream areas of the Sayang River Basin are brown andosol complex and lithosol. The middle area includes reddish brown latosol soil type and downstream including andosol and brown ultisol soil types. The upstream condition of these River Basin is the majority of plants like as pine forests and coffee plants. While the majority of plants in downstream areas are elephant grass. The middle part in River Basin are some rice plants and elephant grass.

Flow Speed Calculation

Hydrometry measurements in this study were conducted to obtain data on flow velocity (v) and water flowrate (Q). The results of measurements on April 1, 2017, data generated flow velocity is 0.589 m/s and the flow of water is equal to 1.8962 m^3/s. Flow velocity measurement data is measured by dividing the segments, namely the top (I), middle (II), and bottom (III).

Specific Gravity and Debit Calculation

Flow discharge calculation in this study uses cross sectional area and flow velocity data. It is known that the cross-sectional area of the river is 3,220 m^2 and the average flow velocity data is 0.589 m/s, using the formula Q = A x v where A is the cross-sectional area with m^2 units and V is the flow velocity of the unit m/s. Obtained flow discharge data is 1.8962 m^3/s.Calculation of sediment density in this study resulted in a value of 3,238432. Sediment specific gravity value used to get the multiplier coefficient.

Laboratory Test on Soil Characteristics

Soil sampling is at three location points that is location 1 at coordinates $70^0$84'20''LS and 112^0 37' 35'' BT, location 2 is at coordinates $70^0$84'25''LS and $112^0$37'30 '' BT and location 3 is at coordinates 70^0 84'27' 'LS and 112^0 37' 26''BT. Soil sampling locations are near sediment sampling sites both bed load and suspended load. Soil permeability is the ability of soil to pass water that can be measured using water within a certain time and is usually expressed in units of cm/ hour. Based on Table 1, the permeability value of sample 2 is at least 12.5 cm/hour,

Table 1. Laboratory Test on Soil Characteristic Sayang River Basin

Sample	Structure	Texture			Class	Permeability	Organic Material
		Sand	Dust	Clay			
1	Granular Smooth	30	28	42	DustyClay	18.9	1.43
2	Medium Rough Granular	30	47	23	Clay	12.5	1.99
3	Granular Smooth	25	20	55	Clay	20.9	2.13

Source : Results of soil Laboratory Analysis (2017)

this means that the soil permeability is quite fast, the permeability value of sample 3 is 20.9 cm/hour, which means the soil permeability speed is quite fast.

Sediment Observation Results

Sediments were analyzed at the Soil and Water Laboratory, Water Resources Department, Brawijaya University. Sediments taken are bed load sediment and suspended load. The analysis used in the bed load sediment sample is a filter analysis and sediment density, to determine the floating sediment concentration, TSS or Total Suspended Solid analysis is performed. Measurement of floating sediment concentration using the TSS Analyzer so that the concentration can be identified in mg/liter units. The results of Sediment Concentration are shown in Table 2.

Table 2. Result of Floating Sediment Concentration of the Sayang River Basin

Time	Segment			Average
	I (mg/L)	II (mg/L)	III (mg/L)	(mg/L)
A	85	117	116	106
	166	108	43	105.667
	78	53	44	58.333
B	107	106	87	100
	119	167	65	117
	83	107	53	81

Note : A = Collection on March 15, 2017, B = Collection on April 01, 2017

Table 2 shows the results of the calculation of suspended loadobservation sediments in the Sayang River Basin. TSS (Total Suspended Solid) is a material consisting of mud, fine sand and microorganisms results from the process of soil erosion. Calculation of bed loadsediments using the method of Mayor Peter and Muller (1934) or MPM (1934). Calculating bed load content at the point of sediment are shown in Table 3.

Calculation of bed loadsediments using the equation of Mayor Peter and Muller (1934) is as follows:

Table 3. Empirical Calculation Data

Description	Value	Unit
Hydraulic Radius (Rh)	0.366265252	m
Cross-sectional area	3.220	m^2
Around the cross section	9.799095	m
Average depth	1.444444	m
Flow Speed	0.5888889	m/s
Discharge	1.8962	m^3/s
Cross Section Width	9.00	m
Specific Gravity	3.238432	mg/l
Slope	0.145676	m
D35	0.00051	
D50 (d_m)	0.000393	
D60	0.0003	m
D65	0.00028	
D90	0.0001613	

Source : Calculation Results, 2017

a. the value of a hydraulic radius

$$R = \frac{A}{P}$$

With :
R = hydraulic digits
A = cross sectional area
P = wet circumference of flow

$$R = \frac{3.220}{9.799095}$$

= 0.32860 meters

b. the value of*ripple factor*

$$\mu = \left(\frac{ks}{ks'}\right)^{\frac{3}{2}}$$

With :
µ = *ripple factor*
k_s= value of loss of energy riverbed shape
k_s'= value of loss of energy friction with granules

$$\mu = \left(\frac{22.0739}{79.83617}\right)^{\frac{3}{2}}$$

$$\mu = 0.010568$$

c. Bed Load Sediment calculation with MPM (1934) equation :

$$\gamma R_h \left(\frac{k}{k'}\right)^{\frac{3}{2}} S - 0.047(\gamma_s - \gamma)\, d_m = 0.25 \left(\frac{\gamma}{g}\right)^{\frac{1}{3}} (T_B)^{\frac{2}{3}}$$

Tb = 0.05819 kg/m.s or 0.2021439 m^3/s

Sediment observations in this study were carried out starting from low rainfall intensity to high rainfall intensity. Research on the sedimentation process is very important because the research on sediment helps the government in the construction of reservoirs. The sedimentation process can reduce reservoir capacityso that it results in expensive operation and maintenance.

According to Effendi (2000), TSS or *Total Suspended Solid* is a suspended material which generally consists of fine sand, mud and microorganisms that can be retained on a filter with a pore diameter of 0.45 meters. TSS can be used as an indicator of water quality in waters such as rivers. High TSS levels indicate a level of pollution that can cause disruption of aquatic biota. Sediment discharge ton/day indicates the large amount of sediment released by the river per day. The value of suspended load in this study is 0.060672 m^3/s. So the total value of the sediment is 0.2628159 m^3/s.

Digital Elevation Model or DEM Processing

The surface of the earth is modeled in a grid size of 10 meters x 10 meters which means that one DEM grid represents a grid cell size of 10 meters x 10 meters on the surface of the earth, so it can be calculated for the study area to be around 182,390 cell grids, which are formed from 305 columns and 598 rows. The modeling that was carried out resulted in an area of 12,819,300 m^2 or 1281.93 hectares. The modeling value is clearly different from the actual area of the Sayang River Basin, which is around 1298.718 hectares. This is because there are no data cells in the modeling grid.

Grid maps heights that have through the process of *the fill sink* produce a *theme* that is *filled grid (*the term of this process is depression DEM *(Digital Elevation Model)*. The process *fills the sink* is required in identifying *sinks*contained in the map. If the depressed DEM process is not carried out there are some grid cells that cannot define the direction of flow, and if a direction of flow is determined it will form quite a lot of flow but the direction of flow is short because cut by grid cells that cannot define the direction of *flow.The theme of* the height grid is then carried out the process of *flow direction* or determination of the value of the flow direction through the *hydro* menu with the choice menu of *flow direction menu.According* toHaji (2005), the determination of flow direction is used as a guideline for connecting one cell with another cell, so that it is obtained the synthetic river network in the entire watershed. The value generated on *the* flow direction *grid* only illustrates or shows the direction of the flow, for this reason the flow from this cell will flow toward the cell that has the steepest relative slope to the cell to be determined its flow direction.

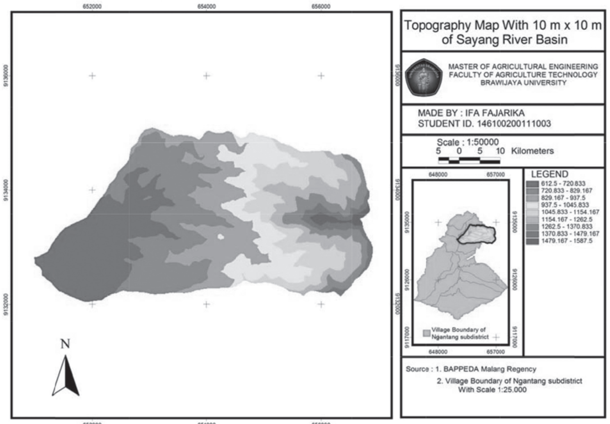

Fig. 2. Topography Map of Sayang River Basin

Modeling of Potential Erosion Index

Potential Erosion Index requires some data that *catchment area* (A_{sx}), a derivative of the *catchment area***,** slopeand the derivative of the slope (*slope of the slope*). Modeling the surface of the earth is done in a 10 meters*grid* size, then to determine the *catchment area* by multiplying *the flow accumulation grid* by (grid size)^2. The process to get *the grid of catchmentarea is to* use the Calculation menu in Arc View 3.3.The lowest derivative value is 0 (zero) m^2 and the highest derivative value is 12,819,300 m^2 or 1281.93 hectares. Formation *grid of catchment area* through many processes for example *filled grid* , *flow direction* and *flow accumulation*. After the *grid ofcatchment area*is formed, the map is then lowered so that the *catchment area is* derived. The *catchment area* derivative is obtained from processing the *surface* menu then the *derive slope* isselected. The value of the *catchment area* that is formed is still in units of degrees, if used for further calculations, the unit must be changed by changing the units of degrees to radians, from units of radians converted to decimal units by multiplying the tangent of the angle formed.

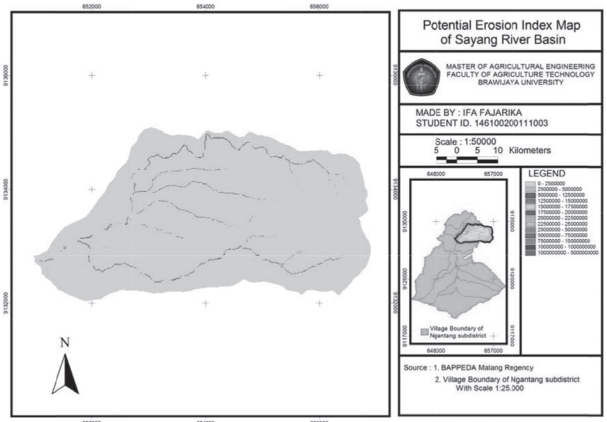

Fig. 3. Potential Erosion Index Map of Sayang River Basin

Model Validation

Model validation process in this study are the calibration process and the verification process. The calibration process is a process used to test the correctness of the model parameters of the equation used. Because the equation is applied to sub-tropical climates, the calibration of the equation is needed especially in areas that have a tropical climate, for example the State of Indonesia. Determination of the Potential Erosion Index has a very large value so that there are several parameters that need to be calibrated or a multiplier coefficient is needed, so that an erosion index value does not change in a model. The verification process is to guarantee the truth of a model stated in mathematical form (Geometric Erosion Model).

Determination of the MultiplierCoefficient

The data needed in the calibration process is the observation sediment as input data Yx, k values obtained from the structureanalysis (m), texture (b), permeability (c) and organic matter (a) and then entered into the determination equation k(Smith 1978)):

$k = 0.027\ M^{1.14} 10^{-4}(12\text{-}a)+0.0325(b\text{-}2)+0.025(c\text{-}3)$

A_{sx} as a *catchment area*, dz/dx as a slope, second derivative of dz/dx ($\frac{d^2z}{dx^2}$), *catchment area* derivative and rational rainfall as a *r*. The following will be explained calibration stages in this study:

a. Determination of Observation Sediment

The result of the bed load sediment research using the MPM equation (1934) is 0.2021439 cubic meters per *second* added with *suspended load* sediment of 0.060672 cubic meters per *second*, resulting in 0.2628159 cubic meters per *second*. The results of sediment observationthen used as input data in determining the coefficient or multiplier constant. Sediment data is used as Y_x input data.

b. Observation Point Parameter Value

The parameter values obtained from the observation point observation point value or sediment collection point on each map k, Asx, $\frac{dz}{dx}$, $\frac{\partial^2 z}{\partial x^2}$, $\frac{\partial A_{sx}}{\partial x}$. Parameter values are entered into the Moore and Burch equation (1986). The known parameter values are as follows:

k = 0.290848

Asx = 18900 m^2

$\frac{dz}{dx}$ = 0.14567876 m

$\frac{\partial^2 z}{\partial x^2}$ = 0.0037522 m^2

$\frac{\partial A_{sx}}{\partial x}$ = 2222.268799 m^2

n and p value are 1.2 and 0.6.

c. Determination of Rain Intensity

The effect of rain water is obtained from the rational r calculation of rainfall, by the equation:

$Q = C \times r \times A$

With a C value or run off coefficient of 0.2 and A value 12987,185.45 m^2. So that the value of r is 7.3 x 10^{-7} m/s. The rational method is used to calculate the rainfall that occurs in the field with the assumption that the intensity of rain that occurs is uniform and evenly distributed throughout the drainage area.

d. Calibration Process

The steps to determine the multiplier coefficient for the calibration of the Moore and Burch (1986) equation are as follows:

$$koef. = \frac{SedimenYield\ (Yx)}{\left[kA_{sx}^{p}\left(\frac{\partial z}{\partial x}\right)^{n-1}\right] \times \left[\left(nA_{sx}\left(\frac{\partial^2 z}{\partial x^2}\right)\right) + \left((p+1)\left(\frac{\partial z}{\partial x}\right)\left(\frac{\partial A_{sx}}{\partial x}\right)\right)\right] r^{p+1}}$$

The value of 1.09585 x 10^{-5} (multiplier coefficient) is obtained. The validation process produces a multiplier coefficient that is used for multiplier constants in the Sayang River Basin so that it can be concluded that the validation process is considered very important for a model in representing a data.

e. Verification Process

The verification and validation process hasimportant step in this research. The calibration process of Moore and Burch (1986) produces a multiplier coefficient that can be combined in the sediment flux reduction equation. The verification process is applied to the SayangRiver Basin. The following equation is produced from calibration and verification.

$$IEG = 1.09585 \times 10^{-5}\left[kA_{sx}^{p}\left(\frac{\partial z}{\partial x}\right)^{n-1}\right] \times \left[\left(nA_{sx}\left(\frac{\partial^2 z}{\partial x^2}\right)\right) + \left((p+1)\left(\frac{\partial z}{\partial x}\right)\left(\frac{\partial A_{sx}}{\partial x}\right)\right)\right] r^{p+1}$$

Where :
k = *soil erodibility index*
p and n value 0.6 and 1.2
Asx = *catchment area* unit m^2
$\frac{dz}{dx}$ = *the first derivative slope* unit meter
$\frac{\partial^2 z}{\partial x^2}$ = *the second derivative slope* unit m^2
$\frac{\partial A_{sx}}{\partial x}$ = *the first derivative catchment area* unit m^2

f. Application of the Model

Verification aims to test the calibration results of parameters a model. The results of the verification produce coefficient values that can help in the process of forming a model. The coefficient is used for the entire region in the Sayang River Basin. The lowest Geometry Erosion Index is (0) while the highest is 153,923,488. When compared using the Potential Erosion Index is different. The value of erosion estimation using the Moore and Burch (1986) equation is greater when compared to using the geometry erosion index. For this reason, calibration is needed for implementation, especially in Java. Estimating the value of potential erosion using the Moore and Burch (1986) equation was previously used for subtropical regions, so if it is applied to the tropics it needs calibration. Whereas for the geometry erosion index the area expansion is the highest value which is12,278,842 and for the lowest value is 0(zero).

Effects of Geometry Factors

Some factors influence the amount of erosion are soil geometry, slope, catchment area, slope of slope.

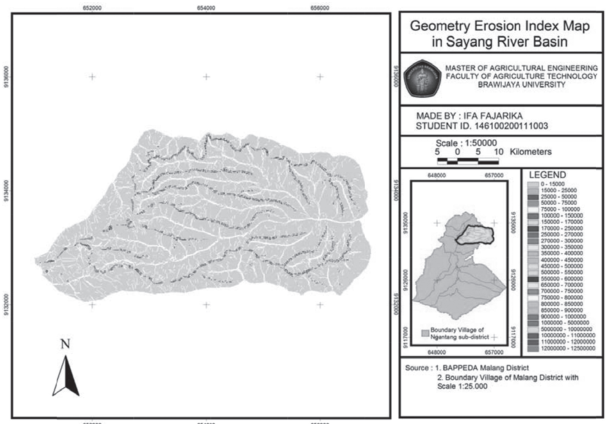

Fig. 4. Geometry erosion index Map in sayang river basin

Soil geometry is a form of land surface in an area. The soil geometry factor is mentioned as the k value in the study. The value of is influenced by soil texture, soil structure, soil permeability and organic matter. The greater the k value is obtained, the greater the surface erosion that occurs. The next factor is the shape of the slope, the slope is obtained from the topographic processing with the *derive slope* menu. If an area has a tight contour, the slope will be steep and otherwise if it is increasingly rare, the slope is getting sloping. The catchment area is used to store rainwater and drain it through branch, surface runoff. The catchment area is bounded by the highest point of the topographic barrier. The boundary is in the form of a back or a mountain. If the catchment area is tighter, the erosion process will be faster and can cause erosion and sediment cumulation. If there is little vegetation in the catchment area, it also causes faster erosion. The last factor is slope. The slope is the convex or concave shape of an area. If the slope is sloping thenerosion will slow but if the slope is steep it will result in faster erosion.

Conclusion

The conclusion of this researchare the equation for calculating the value of the Geometry Erosion Index is

$$IEG = 1.09585 \times 10^{-5}\left[kA_{sx}^{p}\left(\frac{\partial z}{\partial x}\right)^{n-1}\right] \times \left[\left(nA_{sx}\left(\frac{\partial^2 z}{\partial x^2}\right)\right) + \left((p+1)\left(\frac{\partial z}{\partial x}\right)\left(\frac{\partial A_{sx}}{\partial x}\right)\right)\right] r^{p+1}$$

Geometry factors that influence the amount of erosion are *soil geometry, slope, slope of slope and catchment area*. If the value of the geometry factor is getting higher (close to 1), the surface erosion is greater (potential erosion). The erosion equation based on the potential erosion index in the Sayang River Basin requires calibration and a multiplier coefficient is obtained for the entire Sayang River Basin is 1.09585×10^{-5}. The lowest Geometry Erosion Index is (0) while the highest is 153,923,488. When compared using the Potential Erosion Index is different. The Potential Erosion Index obtained from the integration of the Moore and Burch equation (1986) produces the lowest potential erosion index value is zero (0) and the highest is 4,750,318,080.

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