



Analysis of the Level of Erosion Hazard By Using Remote Sensing and Geographic Information System in the Sub-Watershed of Rindu Hati

Prayogi Dhuha Brahmanto¹, Bambang Sulisty^{1*}, M. Faiz Barchia¹

¹Soil Science Department, University of Bengkulu (Corresponding author)
e-mail: bsulisty@unib.ac.id

ABSTRACT

Rindu Hati sub-watershed is located in District of Central Bengkulu, Bengkulu Province, that has flat until mountainous topography with various slope and annual rainfall up to 4,032 mm year⁻¹ which possible causes erosion. This research was aimed to analyze soil erosion at Rindu Hati sub-watershed based on the Universal Soil Loss Equation formula, using remote sensing imagery data and by applying GIS technique. USLE method were uses five parameters, those were length and slope factor, rainfall erosivity factor, crop management factor and land conservation, and soil erodibility factor. An overlay analysis has been conducted to obtain the erosion. Then, the result is overlaid with soil depth map to get the level of erosion hazard, which is classified into: very light, light, moderate, heavily, and very heavily. The results showed that the total erosion was 12,410,650.59 tons ha⁻¹ year⁻¹, while its level of erosion hazard were very light (15 tons ha⁻¹ year⁻¹) covering an area of 2,983 ha spreading over community agricultural areas and forest areas, the rate of light erosion (> 15-60 tons ha⁻¹ year⁻¹) has the largest area of covering an area of 10,410.05 ha which scattered in plantation areas having flat topography, moderate erosion rates (> 60-180 tons ha⁻¹ year⁻¹) of 1,317.33 ha spread over land areas with shrub land use and relatively flat topography, heavily erosion rates (> 180-480 tons ha⁻¹ year⁻¹) covering 1,735.48 ha spread over land with shrub land use but has a hilly topography and very heavily erosion rates (> 480 tons ha⁻¹ year⁻¹) covering 2,700.42 ha located in the mining area. Erosion potential rate mapping will be very helpful in determining good and appropriate land management and conservation in the study area.

Keywords: erosion, erosion hazard, GIS, USLE, watershed

INTRODUCTION

Watershed degradation has been accelerated by increasing utilization of natural resources as a result of population growth, economic development, policies that do not favor natural resources conservation, and the lack of awareness and participation of the community in the context of natural resource use (Sonapasma, 2010)

The Agency for Watershed and Protection Forest Management of Ketahun (2013) stated that there has been a change of function of the forest area into a mining and plantation area in the Rindu Hati sub-watershed area, the upstream part of the Bengkulu watershed. The conversion of the forest area has led to an increase in degraded land in the upstream area of the Bengkulu watershed with a critical area of 363,583.68 ha. The degraded land is divided into

slightly degraded of 207,414.75 ha (57.05%), degraded of 149,587.52 (41.14%) and highly degraded of 6,581.41 ha (1.81%), while the degraded land outside the forest area reaches 866,176.80 ha consisting of slightly degraded of 295,662.01 ha (34.13%), degraded of 477,113 ha (55.08%), and highly degraded of 93,401.79 ha (10.78%).

One of the causes of the increase in the degraded land is the erosion that occurs on open land that has little vegetation on it as a ground cover. Erosion itself is a process of loss or erosion of soil or parts of land from a place that is transported by water or wind to another place. The eroded land transported by surface runoff will be deposited in a place where water flow slows down such as rivers, irrigation channels, reservoirs, lakes or river mouths. This will have an impact on silting rivers, resulting in more frequent floods in the rainy season and drought in the dry season (Arsyad, 2010)

To get erosion data, it is necessary to predict soil erosion from a model. Erosion is predicted from a model because to get actual erosion data requires a lot of time, energy and cost. Sulistyo (2011) states that one of the erosion prediction models that is widely used in various countries, including Indonesia, is USLE. USLE (*Universal Soil Loss Equation*) is an erosion prediction model that is widely used in various countries, because the model is easy to manage, relatively simple and the number of inputs or parameters needed is relatively small compared to other erosion prediction models (Sulistyo, 2011).

In the USLE, there are 6 factors used including erosivity factors (rainfall), soil erodibility factors, slope length factors, slope steepness factors, vegetation cover factors and plant management, and conservation factors soil (Manik *et al.*, 2013). To be able to analyze and calculate erosion can utilize Geographic Information System (GIS) technology. This technology can map and describe the physical condition of the research area spatially. These physical conditions are the parameters that cause erosion. By utilizing GIS, this method can determine, calculate, and show visually areas that need conservation (Santoso, 2014). Based on the description above, this study was conducted to analyze the level of erosion hazard in the Rindu Hati sub-watershed area.

MATERIAL AND METHOD

Location of the research

This research was conducted in the Rindu Hati sub-watershed in the Central Bengkulu area with an area of 19,147 ha, which was conducted from August 2019 to November 2019.

Data Collection

Data needed in conducting this research is erosivity map, topographic map, soil and land unit map and land use map. Before the research activities are carried out, a research plan is first carried out, a literature review, procurement of image maps, land use maps, topographic maps and rainfall data for the Rindu Hati sub-watershed. The analysis is done by converting soil type maps into K (erodibility) map, rainfall data into erosivity map (R), topographic maps into slope map and land use map into vegetation map and soil conservation technique (CP).

Data Analysis

The method of assessing the level of erosion hazard is carried out by overlaying or combining several maps into a unitary and scoring method (assessment).

Erosivity score

$$R_m = 6,119 (Rain_m)^{1,21} \times (Days_m)^{0,47} \times (max P_m)^{0,53}$$

Where:

- R_m = rain erosivity
- Rain_m = monthly average rainfall (in cm)
- Days_m = average number of rainy days in one month
- Max P_m = average maximum rainfall in the month (cm)

Erodibility score

Soil erodibility is the sensitivity of soil to erosion, the higher the erodibility value of a soil, the easier it is to erode. The soil erodibility value obtained from the calculation of the erodibility value using the equation as follows (Wischmeier *et al.*, 1971) :

$$100 K = 1,292 [2,1 M^{1,14} (10^{-4}) (12-a) + 3,25 (b-2) + 2,5 (c-3)]$$

- M = Percentage of very fine sand and dust (diameters from 0.1 to 0.05 and 0.05 to 0.02 mm) x (100 - percentage of clay)
- a = percentage of organic matter
- b = value of soil structure
- c = value of soil permeability

LS score

L Factor

$$L = \left(\frac{La}{22,13} \right)^m$$

Where :

- La = actual slope length (in m)
- m = 0.5

S Factor

For slopes < 25% the factor S value uses the values as presented in Table 1.

Table 1. Slope scores (S)

Class	Slope (%)	Sscore
I	0-3	0.1
II	>3-8	0.5
III	>8-15	1.4
IV	>15-25	3.1

Source : RTKRHL modification, 2009

For slopes >25%, it uses the Gremory formulas:

$$LS = C \times \cos(S_d)^{1.503} \times \left\{ 0,5 \times \sin(S_d)^{1.249} + \sin(S_d) \right\}_{2.249}$$

Where :

- S_d = slope in degrees
- C = constant (34.7046)
- M = 0.5

CP score

The value of plant management and soil conservation is obtained from the land use map and is matched with the value of the results of research that has been carried out as presented in Table 2 and Table 3.

Table 2. C scores (Crop management)

Type of plant	C scores
Rice fields	0.01
Upland rice (dry land)	0.53
Corn	0.64
Soybean	0.4
Peanut	0.4
Cassava	0.7
Talas	0.7
Sweet potatoes	0.4
Cotton	0.7
Tobacco	0.4-0.6*
Chilles, onions, other vegetables	0.7
Coffee	0.6
Chocolate	0.8
Coconut	0.7
Palm oil	0.5
Rubber	0.6-0.75*
Empty land, not procesed	0.95
Empty land, cultivated	1.0
Udisturbed bush	0.01
Forest undisturbed, a little bit	0.005

After calculating and assessing erosivity, erodibility, length and slope factors and crop management and soil conservation techniques, the erosion rate (A) can be obtained. Estimated amount of erosion can be determined by the USLE method according to Wischmeier and Smith (1978) that is :

$$A = R \times K \times LS \times C \times P$$

Where :

- A = amount of eroded land (ton / h / year)
- R = erosivity factor
- K = soil erodibility factor
- L = slope length factor
- S = slope factor
- C = factor of land cover vegetation
- P = factor of soil conservation

Table 3. P scores (soil conservation technique)

Soil Conservation Technic	P scores
Bench terrace, good	0.04
Bench terrace, moderate	0.15
Bench terrace, bad	0.40
Traditional terrace	0.35
Plant the slope contour 1-3%	0.4
Plant the slope contour 3-8%	0.5
Plant the slope contour 8-15%	0.6
Plant the slope contour 15-25%	0.8
Plant the slope contour >25%	0.9

Source : RTKRHL modification, 2009

Then the erosion map is overlaid to soil depth map which is then classified into the erosion hazard level. An assessment of the rate of erosion is presented in Table 4.

Table 4. Assessment of the erosion rate of the model predictions USLE

Soil Depth (cm)	Class erosion				
	I	II	III	IV	V
	Erosion (ton/ha/year)				
	<15	15-60	60-180	180-480	>480
Deep >90	0-VL	I-L	II-M	III-H	IV-VH
Moderate 60-90	I-L	II-M	III-H	IV-VH	IV-VH
Shallow 30-90	II-M	III-H	IV-VH	IV-VH	IV-VH
Very Shallow <30	III-H	IV-VH	IV-VH	IV-VH	IV-VH

Source : RTKRHL, 2009

- Remarks :
- 0-VL = Very light; I-L = Light
 - II-M = Moderate
 - III-H = Heavily
 - IV-VH = Very Heavily

RESULT AND DISCUSSION

Erosivity score

The largest erosivity value is 4,032 with an area of 200 ha or (1.045%) spread in the area of Taba Teret Village, Taba Baru Village, Surau Village and Rindu Hati Village (Table 5 and Figure 1).

Table 5. The Area and their percentage for each erosivity value in the Rindu Hati sub-watershed

Erosivity score (R)	Area (ha)	Area (%)
1.950	150	0.78
2.050	328	1.71
2.150	993	5.18
2.250	705	3.68
2.350	894	4.66
2.450	1.299	6.78
2.550	2.175	11.35
2.650	4.310	22.51
2.750	3.303	17.25
2.850	970	5.06
2.950	690	3.60
3.050	599	3.12
3.150	482	2.51
3.250	379	1.97
3.350	377	1.96
3.450	200	1.04
3.550	224	1.17
3.650	254	1.32
3.750	241	1.25
3.850	200	1.04
3.950	174	0.91
4.032	200	1.04
Total	19,147	100.00

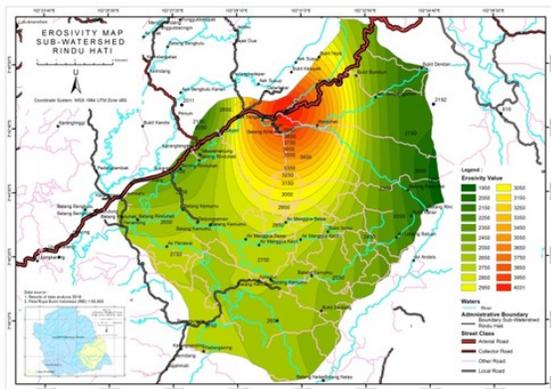


Figure 1. Erosivity Map of Rindu Hati sub-watershed

Erodibility score

Soil types in the Rindu Hati sub-watershed are dominated by inceptisol soil types, while the smallest K value is 0.05 with an area of 1,322.55 ha or 6.90% of the total area. Then Ultisols soil type has an erodibility value of 0.3 and has an area of 149.74 ha or 0.78% of the total area. The soil erodibility value in the Rindu Hati sub-watershed ranges from 0.05 to 0.42. With an average erodibility value of 0.23 included in the medium category, it can be concluded that the Rindu Hati sub-watershed has a soil sensitivity to erosion that is neither too low nor too high (Figure 2 and Table 6).

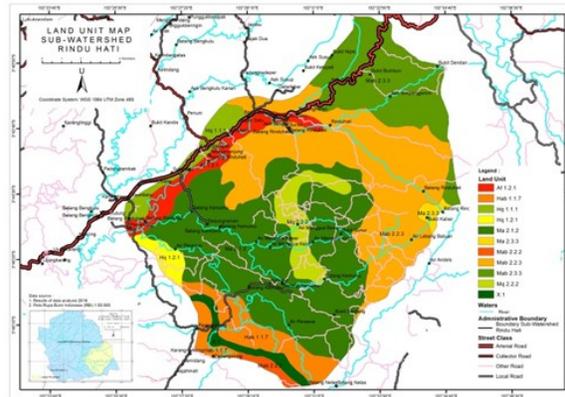


Figure 2. Erodibility Map of Rindu Hati sub Watershed

Table 6. Soil type and Erodibility Value in the Rindu-Hati sub-watershed

Land Unit	Type of Soil	K Scores	Area (ha)
Af 1.2.1	Inceptisol	0.28	909.60
Hab 1.1.7	Inceptisol	0.05	1,322.55
Hq 1.1.1	Inceptisol	0.31	605.28
Hq 1.2.1	Inceptisol	0.28	304.01
Ma 2.1.2	Inceptisol	0.20	6,518.51
Ma 2.3.3	Inceptisol	0.30	132.18
Mab 2.2.2	Ultisol	0.30	149.74
Mab 2.2.3	Inceptisol	0.25	5,301.75
Mab 2.3.3	Inceptisol	0.42	2,710.89
Mq 2.2.2	Inceptisol	0.08	826.33
X.1	Inceptisol	0.10	364.93
Total			19.147

Source : Data analysis, 2019

LS score

Length and slope factors are obtained from slope maps created using 25 meter contour interval data. The slope class of the Rindu Hati sub-watershed is divided into six classes, namely flat (0-3%), slightly flat (> 3-8%), sloping (> 8-15%), rather steep (> 15-25%), steep (> 25-45%) and very steep (> 45%). The slope map can be seen in Figure 3, while their area is presented in Table 6.

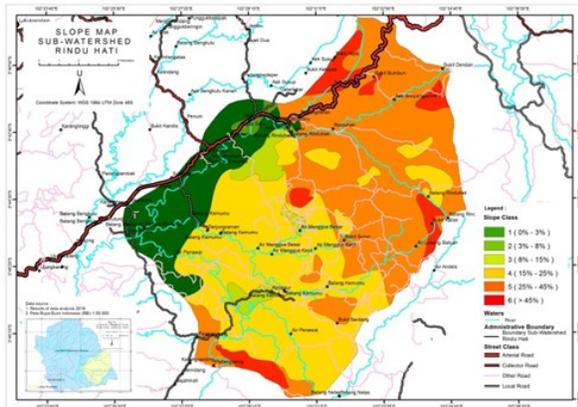


Figure 3. Slope Map of Rindu Hati sub-watershed

Table 6. The area for each Slope and LS Score

Class	Slope (%)	LS scores	Area (ha)	Area (%)
I	0-3	0.1	2,648.18	13.83
II	>3-8	0.6	145.94	0.76
III	>8-15	2.0	699.09	3.65
IV	>15-25	12.0	7,105.04	37.10
V	>25-45	14.3	7,444.90	38.88
VI	>45	19.7	1,107.25	5.78
Total			19,147	100

Source : Data analysis, 2009

CP score

The Rindu Hati sub-watershed consists of 9 types of land use, namely forest, open land, rubber, coffee, rice fields, oil palm, scrub, mining and settlement. Land use in the Rindu sub-watershed is dominated by forests with a lot of litter and includes coffee plantations with an area of 13,333.716 (69,63%) ha, but for coffee plantations that are not included in the forest has an area of 4,658 ha (0.024%) and for the lowest land use namely shrubs covering an area of 2,034.528 ha (10.625%), oil palm plantations covering 1,295.193 ha (6.764%), rubber plantations covering an area of 40,321 ha (0,211%), open land

335,372 ha (1.751%), coal mining covering an area of 1,372.476 ha (7.168%), settlements covering 221,152 ha (1.155%). Map of land use in the Rindu Hati sub-watershed can be seen in Figure 4. The value of plant management (C) and soil conservation (P) factors can be seen in Table 7.

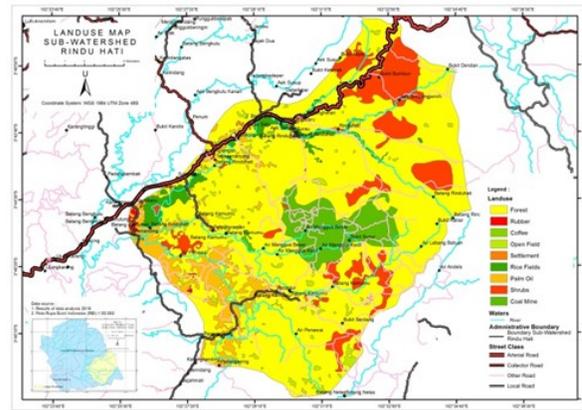


Figure 4. Landuse Map of Rindu Hati sub-watershed

Tabel 7. Extensive data for each CP Value of Land

Landuse	CP scores
Forest	0,001
Open field	0,95
Rubber	0,4
Coffee	0,24
Rice filed	0,0035
Young plam oil	0,3
Palm oil	0,45
Shrubs	0,01
Coal mine	1
Settlement	1

Source: RTkRHL, 2019

Soil Depth

The soil depth in the Rindu Hati sub-watershed is dominated by a depth of 60-90 cm. The soil depth table is presented in Table 8 and the soil depth map of the Rindu Hati sub-watershed can be seen in Figure 5

Tabel 8. Soil depth

Soil Depth (cm)	Area (Ha)	Area (%)
>90	4,615	24.1
60-90	14,531	75.9
Total	19,147	100.0

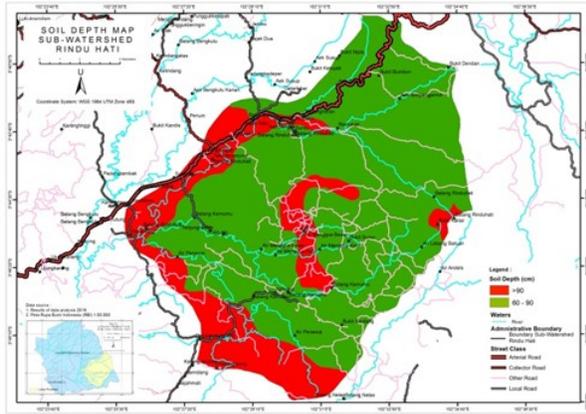


Figure 5. Soil Depth Map of Rindu Hati sub-Watershed

The Level of Erosion Hazard

The role of GIS in analyzing the level of erosion hazard map is in the overlay process by combining each erosion factor into new data with more complete attributes. From the overlay results there will be attribute table that has the value fields of R, K, LS, C and P which then used for the erosion calculation by multiplying the erosion parameters and then overlaying it again with a soil depth map so that a map of erosion hazard level is obtained (Figure 6). From the results of this calculation an erosion hazard classification of five classes was carried out, and it is presented in Table 9.

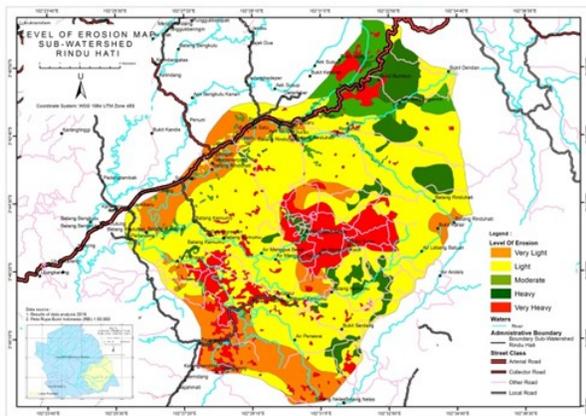


Figure 6. The Level of Erosion Hazard of Map Rindu Hati sub-watershed

The erosion hazard class in the Rindu Hati sub-watershed consists of 5 classes: **very light**, **light**, **moderate**, **heavily** and **very heavily**. Based on the calculation, the amount of land lost due to erosion is 12,410,650.59 tons $\text{ha}^{-1} \text{year}^{-1}$. The **very light** erosion class has an area of 2,983.11 ha (9.06%), the **light** erosion class has the largest area of 10,410.05

ha (54.37%), the **moderate** erosion class is 1,317.33 ha (14.1%), a **heavily** erosion class of 1,735.48 ha (15.58%) and a **very heavily** erosion class of 2,700.42 ha (6.88%) The mining area has a large erosion value, this is because in mining activities the process is carried out soil dredging will change the contour of the soil so that it is cause faster and more eroded.

Table 9. Level of Erosion

Erosion Total (ton $\text{ha}^{-1} \text{year}^{-1}$)	Level of Erosion	Area (ha)	Area (%)
<15	Very Light	2,983	9.06
>15 – 60	Light	10,410.05	54.37
>60 – 180	Moderate	1,317.33	14.1
>180 – 480	Heavily	1,735.48	15.58
> 480	Very Heavily	2,700.42	6.88
Total		19,147	100

Source : Data analsys, 2019

CONCLUSION

Rindu Hati sub-watershed has a **light** to **very heavily** erosion rate. Land lost due to erosion ranged from 0.01 tons $\text{ha}^{-1} \text{year}^{-1}$ to 23,146.68 tons $\text{ha}^{-1} \text{year}^{-1}$ with a **very light** erosion rate (15 tons $\text{ha}^{-1} \text{year}^{-1}$) having an area of 2,983 ha spread over community agricultural areas and forest areas , the rate of **light** erosion (> 15-60 tons $\text{ha}^{-1} \text{year}^{-1}$) has the largest area of 10,410.05 ha spread over plantations that have flat topography, **moderate** erosion rates (> 60-180 tons $\text{ha}^{-1} \text{year}^{-1}$) of 1,317.33 ha spread over land area with shrub land use and relatively flat topography, **heavily** erosion rate (> 180-480 tons $\text{ha}^{-1} \text{year}^{-1}$) of 1,735.48 ha spread over land area with shrub land use but have topography hilly and **very heavily** erosion rate (> 480 tons $\text{ha}^{-1} \text{year}^{-1}$) has an area of 2,700.42 ha located in the coal mining area. The mining area has a large erosion value because in mining activities a dredging process is carried out which will change the contours of the soil so that it is cause faster and more eroded.

References

Abdurachman, A. (1989). Rainfall Erosivity and Soil Erodibility in Indonesia: Estimation and Variation

- with Time. *Thesis Doctor*. Faculty of Agricultural Sciences, Ghent, Belgium.
- Asdak, C. (2010). *Hidrologi dan Pengelolaan Daerah Aliran Sungai*. Gadjah Mada University Press, Yogyakarta. (in Indonesian)
- Bols, P.L. (1978). *The Iso-Erodent Map of Java and Madura*. Belgian Technical Assistance Project ATA 105 Soil Research Institute, Bogor.
- Balai Pengelolaan Daerah Aliran Sungai dan Hutan Lindung Ketahun. (2013). *Profil Kondisi Daerah Aliran Sungai Air Bengkulu*, Kota Bengkulu. (in Indonesian)
- Direktorat Jenderal Reboisasi dan Rehabilitasi Lahan, Departemen Kehutanan. (2009). *Pedoman Penyusunan Rencana Teknik Lapangan Rehabilitasi Lahan dan Konservasi Tanah Daerah Aliran Sungai*. Balai Pengelolaan Daerah Aliran Sungai Jeneberang-Walanae, Makassar. (in Indonesian)
- Fatmagara, M. Adi. (2013). *Pemanfaatan Citra PJ Multitemporal untuk Kajian Tingkat Bahaya Erosi (Kasus di Sub DAS Karang Mumus, Kalimantan Timur)*. *Skripsi*, UGM, Yogyakarta. (in Indonesian)
- Gee, G. W. & Bauder, J.W. (1986). Particle size analysis. p.383-411. *In: A. Klute (Ed.). Methods of Soil Analysis (Part I)*. *Agronomy 9. Soil Sci. Soc. Amer.*, Madison, WI, USA.
- Gunawan, T. (1991). *Penerapan Teknik Penginderaan Jauh untuk Menduga Debit Puncak Menggunakan Karakteristik Lingkungan Fisik DAS*. (in Indonesian)
- Hann, M.J. & Morgan, R.P.C. (2006). Evaluation erosion control measures for bio restoration between the time of soil reinstatement and vegetation establishment. *Earth Surface Processes and Landforms*, 31, 589-597.
- Jaya. 2006. *Teknik-teknik Permodelan Spasial dalam Pengelolaan Sumber daya Alam dan Lingkungan*. Fakultas Kehutanan IPB, Bogor. (in Indonesian)
- Jetten, V. & Favis-Mortlock, D. (2006). *Modelling Soil Erosion in Europe*. *In: J. Boardman, & J. Possen (Eds), Soil Erosion in Europe (pp.695-716)* Chichester, John Wiley & Sons Ltd, England.
- Manik, Y.W, Sumono, Ichwan, N. & Susanto, E. (2013). Penentuan nilai faktor tanaman jagung dan ubi kayu dengan metode usle dan petak kecil pada tanah Ultisol di Kecamatan Siborongborong Kabupaten Tapanuli Utara. *Jurnal Rekayasa Pangan dan Pert.*, 1(2), 27-31. (in Indonesian)
- Renard, G.R., Foster, G.A., Weesies, D.K., McCool, & Yoder, D.C. (1997). *Guide Conserv Plan*.
- Santoso. (2014). Analisis ancaman bencana erosi pada kawasan DAS Beringin Kota Semarang menggunakan Sistem Informasi Geografis. *Jurnal Geodesi UNDIP*, 3(4), 60-68. (in Indonesian)
- Sonapasma, D.M. (2010). *Prediksi Erosi dan Perencanaan Konservasi Tanah dan Air pada sub DAS Unda Hulu*. *Skripsi*. Jurusan Tanah. Fakultas Pertanian. Universitas Udayana, Denpasar. (in Indonesian)
- Sulisty, B. (2011). Pengaruh erosivitas hujan yang diperoleh dari rumus yang berbeda terhadap pemodelan erosi berbasis raster (Studi Kasus di DAS Merawu, Banjar Negara, Jawa Tengah), *Jurnal AGRITECH*, 31(3), 250-259. (in Indonesian)
- Sulisty, B. (2011). Pemetaan Faktor C yang diturunkan dari berbagai indeks vegetasi data penginderaan jauh sebagai masukan pemodelan erosi di DAS Merawu. *J. Manusia dan Lingkungan*, 18(1), 68-78. (in Indonesian)
- Sutanto. (1986). *Penginderaan Jauh Jilid 1*. Gadjah Mada University Press., Yogyakarta. (in Indonesian)
- Tomlin, C. Dana. (2012). *GIS and Cartographic Modeling*. Esri Press, USA.
- Wischmeier, W.H. & Smith, D.D. (1978). *Predicting Rainfall Erosion Losses: A Guide to Conservation Planning*. U.S. Dept. Agric., Handb., 537, USA.