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EVALUATION OF EROSION BASED ON GIS AND REMOTE SENSING FOR SUPPORTING INTEGRATED WATER RESOURCES CONSERVATION MANAGEMENT

(Case Study: Manjunto Watershed, Bengkulu Province-Indonesia)”

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Abstracts :

Soil erosion is a crucial environmental problem in the Manjuto watershed. It has economic implications and environmental consequences. Assessment of soil erosion risk is useful to design soil conservation strategies for integrated watershed management. Information obtain from RS and GIS framework can help decision makers prepare spatial maps accurately in less time and cost. The aims of this research are to assess the average annual rate of soil erosion in Manjunto Watershed on the each soil mapping unit. The average annual rate of soil erosion rate was estimated using Remote Sensing data. The basis data used NDVI and Slope. The value of NDVI obtained from satellite imagery processing and Slope value obtained from the DEM processing. The results showed that the eroded catchment area has increased significantly. The average annual rate of soil erosion in the watershed Manjunto in 2000 amounted to 3.00 tons ha^{-1} $year^{-1}$. It was an increase to 27.03 ton ha^{-1} $year^{-1}$ in 2009. The levels of erosion hazard are very heavy category in soil mapping unit number 41, 42 and 47. It should be a first priority in the soil and water conservation activities.

Keywords: *Soil erosion, Remote Sensing, GIS, DEM, NDVI.*

I. INTRODUCTION

Watershed management system which is unintegrated, has led to high soil erosion, thus increasing the number of critical watershed and critical land area in Indonesia significantly. The number of critical watershed is currently more than 62 critical watersheds and critical land area of about 30.2 million ha, of which 23.3 million ha of land classified as highly critical category (Statistics Department of Forestry, 2010). The factors that caused of high soil erosion are the use of land that is not in accordance with its carrying capacity, techniques of farming that do not correspond to the rules of conservation, high rainfall, topography, and slope (Asdak, 2009).

Soil erosion is a natural process of removing and transporting soil material through the action of erosive agents such as water, wind, gravity, and human disturbance (Lal, 2001). However, if the soil erosion is occurring faster than necessary due to human disturbance, it will cause negative impacts on the environment and the economy (Lal, 1998, Ananda et al, 2003). The strategic efforts to reduce soil erosion is through the program of soil and water conservation. Spatial data are necessary to planning, monitoring and evaluation of conservation activities (Honda, 2001; Ande et al, 2009). The complete spatial data with a variety of scales can assist in preparing a variety of strategies for all levels of the organization and to determine the effective action in priority setting and location of conservation programs (Morgan, 2005).

Rapid development occurring in the technology of Remote Sensing (RS) and Geographic Information Systems (GIS) provide a new approach to meet various demands related to the modeling of resources (Mermut and Eswaran, 2001 Salehi et al., 2003) including soil and water conservation (Hazarika et al, 2009). Green (1992) stated that the integration of RS in a GIS database can reduce costs, reduce time and improve the detailed soil survey information. Therefore, the use of the technology of Remote Sensing and Geographic Information Systems in watershed management will vastly assist managers in making decisions. Satellite data can be used for mapping, monitoring and estimation of soil erosion (Hazarika & Honda, 2001).

Although soil erosion mapping using GIS and RS conducted in many countries, such as those conducted by Spanner et al (1982) which combines GIS with USLE for soil erosion and loss assessment. Hazarika and Honda (1999) mapped the threat of erosion in Thailand to evaluate the conservation activities in Mae Ao watershed, northern Thailand. Milevsky (2008) introduced a GIS method to estimate soil erosion in the watershed based digital elevation model (DEM) and satellite imagery analysis. Ande et al (2009) approach to estimate the erosion Morgan and Finney Model (MMF) in Southwest Nigeria. Kevi and Yoshino (2010) using RUSLE, remote sensing and GIS to estimate the hazard of erosion on agricultural productivity in watershed Tunisia. However, erosion mapping studies have not been carried out extensively in Indonesia (Arsyad, 2010). Map of soil erosion that published is the mapping performed by Dames (1955) by using traditional methods in the watershed of Central Java, which covers 1.6 million hectares. The use of GIS to evaluate land degradation first performed by Lanya (1996), estimated rates of soil erosion that occurs done by identifying morphological changes in the soil in-situ.

The aim of this research is to evaluate the potential of soil erosion on a watershed scale using E_{30} models in each Soil mapping unit. The result of this study expected to be used as guidelines for the determination of strategy and site selection that will be the main priority on soil and water conservation activities. The selection model based on the condition of land cover in the study area.

II. MATERIALS AND METHODS

2.1. Location and Description of Study Area

The study area is located on between 02°10'30" and 02°30'15" South Latitude, and 101 °5'30" and 107°35'00" East Longitude in the District of Mukomuko, Bengkulu Province, Indonesia (Figure 1) and covers an area abouth 79,581 ha. It is dominating by forests. Based on data from BMG (Meteorological and Geophysical Agency) of Mukomuko district of Bengkulu province, average rainfall of the study site was 3,329.70 mm year^{-1} and average annual temperature of 23.0^{o}C. Based on the results of a survey conducted by Puslitanah Bogor (1982) with the soil classification system based on the FAO/UNESCO (1974), the most dominant soil type in research site is Endoaquepts, Udifluvents, and Eutrudepts.

Figure 1. Study Site.

2.2. Digital Image Processing to Produce Land Cover Map

Analysis of land cover over the interpretation of Landsat Thematic Mapper images (TM), the Landsat 7 (LS-7) ETM+ path 126/row 062, acquisition date in July 22, 2000 and Spot 4 path 355/row 271 acquisition date in May 17, 2009. Methods for the identification of land cover in this study using maximum likelihood methods are unsupervised and supervised classification. The steps of image processing are as follows : a). repair of geometric and spatial imagery covering the whole band used, b). the manufacture of composite colors to band 3 red (R), for band 2 green (G) and band 1 blue (B), c). image interpretation of land use with land coverage of the approach, d). after the image processing as described above, then unsupervised classification with the distribution of types of land cover classes. The types of land cover classes as follows: 1). Forest, 2). Estates, 3). Dryland farming, 4). Farm/moor, 5). Bush, 6). Village, 7). Wetland farming, 8). Open land, and 9). The water bodies. The classification result used to determine the sample points in field activities. Delineation of the image generated based on the results of field inspection and land cover classification do using digital visual methods using supervised classification, in order to obtain maps of watershed land use Manjunto 2000 and 2009 from satellite imagery.

2.3. Soil Mapping Unit (SMU)

Soil mapping units used in this study compiled with reference to the land unit and soil mapping of Sungai Penuh sheets, Sumatra; the mapping did by Puslitanah Bogor with scale 1:250.000. Method of determining the class of each soil mapping unit according to the spread of the dominant soil types in quantitative and grouped into five classes, namely: 1). Very dominant (P): if spread> 75% of the unit area of land, 2). Dominant (D): if the spread between 50-75% of the unit area of land, 3). Enough (F): if the spread between 25-49% of the unit area of land, 4). Bit (M): if the spread between 10-24% of the area of the land units, and 5). Few (T): if spread <10% of the area of the land units. Then do the grouping and numbering of each soil map units based spread most dominant soil type at that location.

2.4. Estimate of Soil Erosion with E30 Model

To estimate the hazard of soil erosion that occur in each soil mapping unit used the following equation (Hazarika and Honda, 2001):

$$E = E_{30}\left(S/S_{30}\right)^{0.9} \qquad (1)$$

Where E = rate of annual soil erosion in the Manjunto watershed (ton $ha^{-1}year^{-1}$), S = gradient of the point under consideration (%), S_{30} = Tan (30^0), and E_{30} = the rate of soil erosion that occurs on a slope of 30^0, obtained using equation 2 (Hazarika and Honda, 2001).

$$E_{30} = \exp\left[\left(\frac{LogE_{\min} - LogE_{\max}}{NDVI_{\max} - NDVI_{\min}}\right)\cdot\left(NDVI - NDVI_{\min}\right) + LogE_{\max}\right] \qquad (2)$$

The maximum erosion values and the minimum obtained from the data of the Public Works Department of Bengkulu Province; E_{max} is 242 tons ha^{-1} $year^{-1}$ and E_{min} is 0.1 tons ha^{-1} $year^{-1}$. NDVI can be calculated from the satellite image of the ratio calculations constructed from two spectral channels, namely spectral infra red (IR) and near infra red (NIR). The general equation of NDVI as follows (Honda, 2001; Panuju, et al, 2009) :

NDVI=(IR-NIR)/(IR+NIR) (3)

If the channel, that recording infrared wave is Band 4 (B_4) and near infrared wave are Band 3 (B_3), so the equation 3 can be changed as equation 4. To avoid negative values and for easy handling of digital data, NDVI values re-scale, so the NDVI equation is as follows:

$$NDVI = \left[\left(\frac{B_4 - B_3}{B_4 + B_3}\right) + 1\right] x100 \qquad (4)$$

Where NDVI is a vegetation index that reflects the level of greenness of vegetation condition (Malingreau, 1986).

3. RESULTS AND DISCUSSION

3.1. The slope Map

Slope map of DEM processed with the help of Arc Gis 9.3 present in Figure 2.

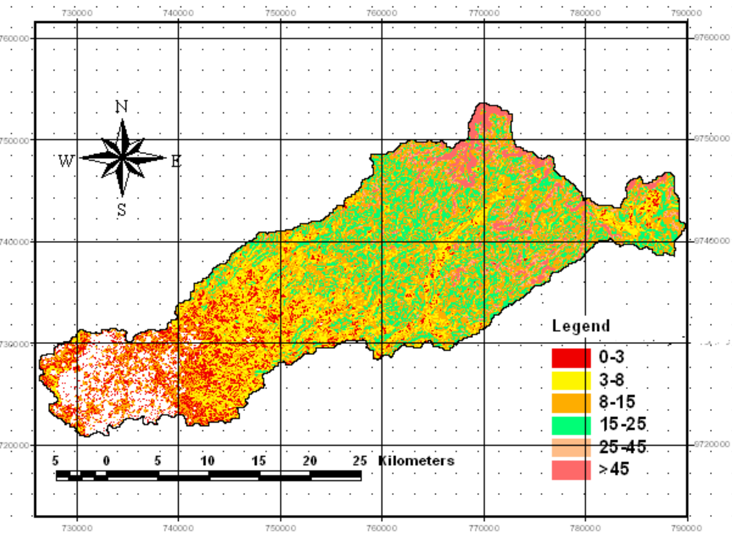


Figure 2. The slope map of Manjunto Watershed

Data processed by GIS contains information on slope and the number of pixels or extensive information. Information about slope of it presented in Table 1.

Table 1. The slope of the watershed Manjunto

No.	Slope Class (%)	Area	Persentage
		(Ha)	(%)
1	0 - 8	20,923.88	26.292
2	8 - 15	31,949.35	40.147
3	15 - 25	15,155.85	19.045
4	25 - 45	5,667.83	7.122
5	> 45	5,883.77	7.393
		79.580,678	**100,000**

The mayor of study site has the slope above 8%. The Slope factor will influence the speed and volume of surface runoff. Small slope will provide more opportunities the water rain to infiltration so that runoff volume will reduce. In the other side, a low percentage of slope will reduce runoff velocity so that its ability to erode and transport the soil to be small.

3.2. Soil Mapping Unit (SMU)

The results of the identification of classes of each unit of land by the spread of the dominant soil types present quantitatively in Figure 3.

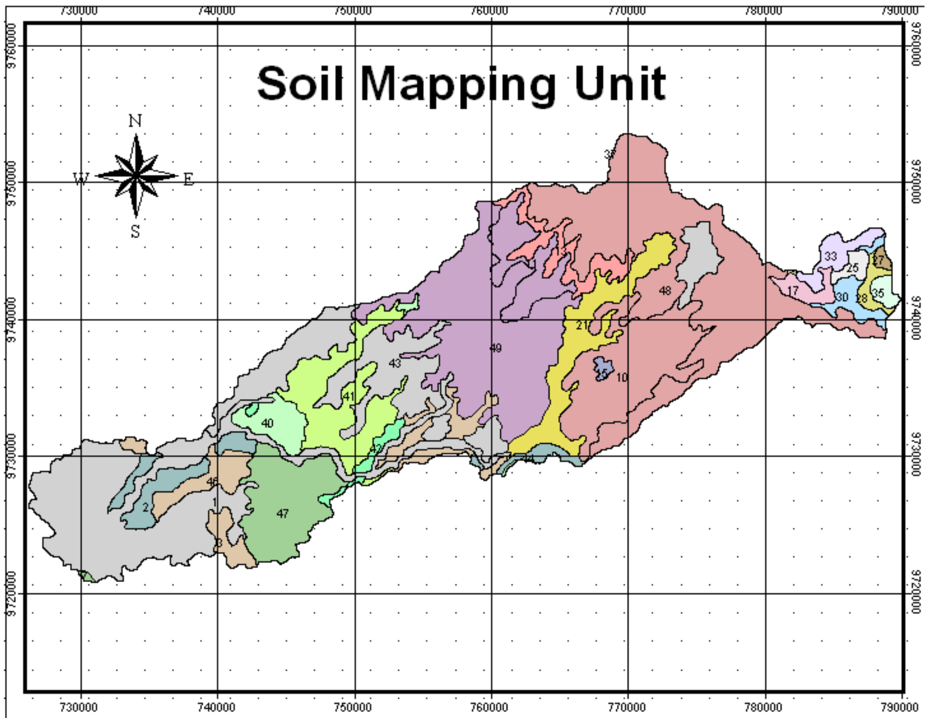


Figure 3. Soil Map Unit of Manjunto Watershed

Most of the study area has the slope above 8%. Slope affects the speed and volume of surface runoff. Small slope will provide more opportunities to the rain water to infiltration so that runoff volume will be low. Small slope will reduce runoff velocity so that its ability to erode and transport the soil also will be small.

3.3. Land Cover

Based on the identification of land cover in 2000 and 2009, it is showing that the conversion of land use and the reduction of forest from deforestation. Changes in land use can be seen at Figure 4 and 5.

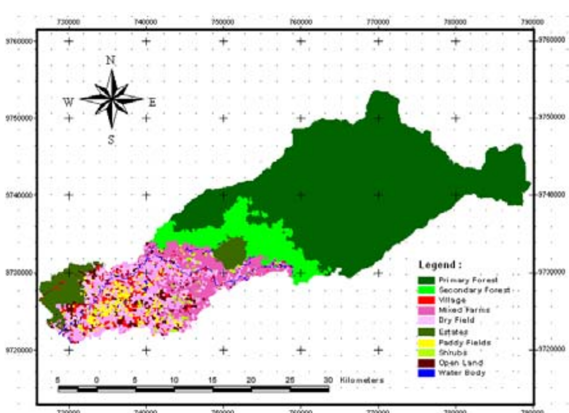


Figure 4. Land Cover Map 2000

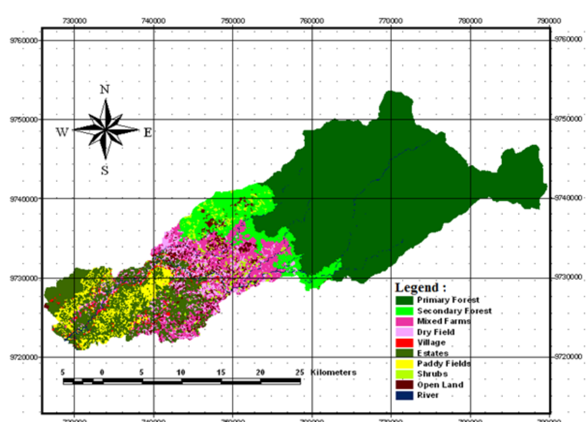


Figure 5. Land Cover Map 2009

Land cover changed on every class of land use shown by Figure 4 and 5. The total area of forest significantly reduced, while the plantation or estates area increased significantly. Changes in land use influenced by the local livelihoods of the majority are as a farmer. The detail of Land use conditions shown in Table 2.

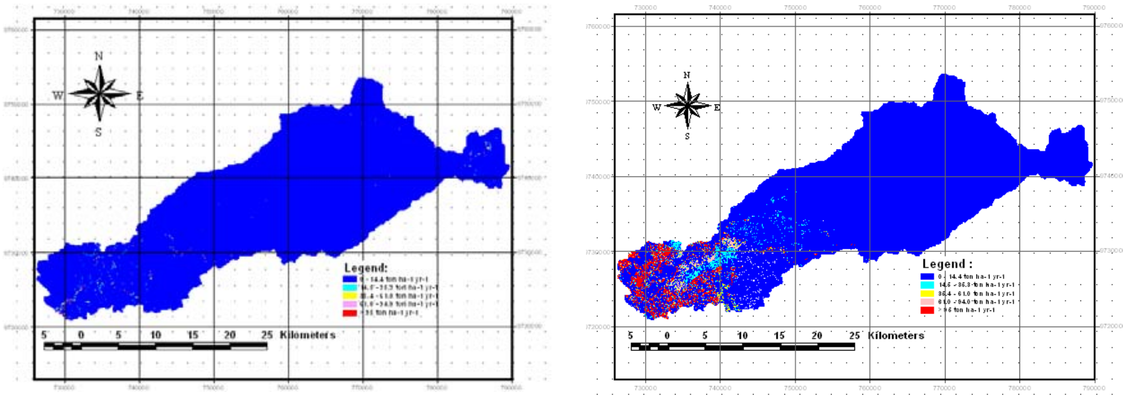
Table 2. Land Cover Conditions of Manjunto Watershed in 2000 and 2009

No.	Land Used	Area (ha)		Difference	
		2000	2009	Area (ha)	Percentage (%)
	1	2	3	4	5
1	Primary Forest	47.063,970	44.899,657	2.164,313	2,720
2	Secondary Forest	6.646,500	6.630,890	15,610	0,020
3	Mixed Farming	7.147,260	6.046,885	1.100,375	1,383
4	Dryland Farming	2.821,680	605,094	2.216,586	2,785
5	Estates	2.420,280	8.595,327	(6.175,047)	(7,759)
6	Bush	2.126,880	1.677,248	449,632	0,565
7	Wetland Farming	8.195,940	7.374,733	821,207	1,032
8	Roads	57,600	250,160	(192,560)	(0,242)
9	Water Body	925,650	929,865	(4,215)	(0,005)
10	Open Land	2.113,920	2.342,791	(228,871)	(0,288)
11	Village	61,110	228,140	(167,030)	(0,210)
	Total	**79.580,790**	**79.580,790**		

The information obtained from Table 2 that has been a change of each land cover. The percentage reduction in the area of some land cover is primary forest (2.72%), secondary forest (0.02%), mixed farms (1.383%), Dryland Farming (2.785%) and Wetland Farming (1.032%). Addition of a couple of percentage land cover is estate (3.041%), road (0.242%), open land (0.288%) and villages (0.21%). Changes in land cover strongly influenced by socio-economic conditions and local culture. The main factors affecting changes in land cover is a source of livelihood. Most of the people who live in Manjunto Watershed is farmers.

3.4. Soil Erosion Mapping

The value of soil erosion that occurs at each pixel based on the results of calculations using equation 1 present in the form of annual soil erosion rate maps (Figure 6).



(a) (b)

Figure 6. Map of average annual erosion in the year 2000 (a) and 2009 (b)

From Figure 6 above known that the watershed area eroded increased when compared with conditions in 2000. Total amount of lost land in the watershed Manjunto 2000 at 1,399,209 tons and in 2009 amounted to 23,004,391 tons. Erosion rate of the annual average in 2000 is a 3 tons ha^{-1} $year^{-1}$, and 2009 was 27 tons ha^{-1} $year^{-1}$. High erosion occurs in the lower reaches of the basin's land use types, namely Dryland Farming. Factors causing the high rate of erosion is a way of farming that pays little attention to the rules of conservation and high rainfall.

To determine the level of soil erosion that occurs in each of soil mapping unit then soil mapping unit overlay with maps of soil erosion, the results as exhibited in Table 3 (attachment 1).

The planning of soil and water conservation need the information of average annual rate of soil erosion on soil mapping unit. The location of priority can be selected based on the dignity of the danger of erosion or erosion hazard index value. The location is the top priority is to have the level of danger of erosion or erosion hazard index is the highest. From Table 3 above know the number 41, 42 and 47 of soil mapping unit are a first priority for conserve, numbers 40 and 45 the soil map unit is the second priority for conserve. The selection of conservation strategies should be adapted to the socio-economic conditions and local culture.

4. CONCLUSION

The conclusion of this study are the eroded catchment area has increased significantly. The average annual rate of soil erosion in the watershed Manjunto in 2000 amounted to 3.00 tons ha-1 year-1. It was an increase to 27.03 ton ha-1 year-1 in the year 2009. Some soil mapping unit has the levels of erosion hazard are very heavy category. It should be a priority in the soil and water conservation activities. To reduce the rate of erosion is happening we need a system of sustainable agriculture and conservation management systematically.

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Attachement 1. Table 3. The average erosion rate of the annual soil mapping unit.

SMU Number	The Mean Erosion (ton/ha/year)	Erosion Hazard	The Mean Soil Loss (mm/year)	Erosion Hazard Index	The Dignity Erosion Hazard Index
(1)	(2)	(3)	(4)	(5)	(6)
1	7,36	Very Low	0,74	0,28	Low
2	31,51	Low	3,15	1,19	Middle
3	7,89	Very Low	0,79	0,30	Low
6	25,64	Low	2,56	0,97	Low
9	0,13	Very Low	0,01	0,00	Low
10	0,48	Very Low	0,05	0,02	Low
11	0,36	Very Low	0,04	0,01	Low
12	0,11	Very Low	0,01	0,00	Low
13	0,59	Very Low	0,06	0,02	Low
14	1,22	Very Low	0,12	0,05	Low
15	0,17	Very Low	0,02	0,01	Low
16	0,17	Very Low	0,02	0,01	Low
19	1,17	Very Low	0,12	0,04	Low
20	1,42	Very Low	0,14	0,05	Low
21	0,15	Very Low	0,01	0,01	Low
24	1,79	Very Low	0,18	0,48	Low
25	0,03	Very Low	0,00	0,00	Low
27	1,33	Very Low	0,13	0,05	Low
28	1,47	Very Low	0,15	0,06	Low
29	1,71	Very Low	0,17	0,06	Low
33	1,82	Very Low	0,18	0,83	Low
40	48,36	Middle	4,84	1,83	Middle
41	153,33	Very Heavy	15,33	5,81	High
42	219,58	Very Heavy	21,96	8,32	High
43	1,22	Very Low	0,12	0,05	Low
45	55,93	Middle	5,59	2,12	Middle
47	242,47	Very Heavy	24,25	9,18	High
48	1,56	Very Low	0,16	0,06	Low
52	1,52	Very Low	0,15	0,06	Low