Evaluation of Erosion Based on GIS and Remote Sensing for Supporting Integrated Water Resources Conservation Management
Case Study: Manjunto Watershed, Bengkulu Province-Indonesia

Evaluasi Erosi Berdasarkan GIS dan Penginderaan Jarak Jauh Untuk Mendukung Manajemen Konservasi Sumber Daya Air yang Terintegrasi
(Studi Kasus di DAS Manjunto, Bengkulu-Indonesia)

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ABSTRACT

Soil erosion is a major environmental problem in the Manjuto watershed. This has economic implications, as well as social and environmental consequences. The Key factors contribute to the high annual rate of soil erosion are poor agricultural practices, high annual rainfall, and undulating topography. The aim of this study is to evaluate the annual rate of soil erosion in Manjuto watershed by identifying and calculating the risk of soil erosion using GIS, based on digital elevation model (DEM). To find the status and level of soil erosion in the watershed Manjuto, the annual rate of soil erosion is estimated using remote sensing data. A Normalized Difference Vegetations Index (NDVI) derived from remote sensing data (Spot-5) used in this study to assess the vegetative cover. A soil erosion model developed for integrating NDVI and the slope of the land to estimate the annual soil erosion rate. The erosion risk (TBE) rating is performed in faction hierarchies. The results showed that the rate of soil erosion has increased from 0.78 mm/year in 2000 to 1.78 mm / year in 2009. It is concluded that SPT 41, 42, and 47 must be in a high priority, while SPT 2, 39 40, and 45 as medium priority to be conserved through erosion pre-vention program.
Keywords: Soil erosion, GIS, DEM, NDVI, Erosion risk rating.

ABSTRAK

Erosi tanah adalah masalah lingkungan yang utama di DAS Manjuto. Hal ini juga memiliki implikasi ekonomi, serta konsekuensi sosial dan lingkungan. Faktor-faktor kunci yang berkontribusi pada tinggi rata-rata erosi tanah tahunan adalah praktek-praktek pertanian yang tidak bagus, curah hujan tahunan yang tinggi, dan topografi bergelombang. Tujuan dari penelitian ini adalah untuk mengevaluasi tingkat erosi tanah tahunan di DAS Manjuto dengan mengidentifikasi dan menghitung risiko erosi tanah menggunakan SIG, berdasarkan model elevasi digital (DEM). Untuk mengetahui status dan tingkat erosi tanah di DAS Manjuto, tingkat erosi tanah tahunan ditentukan dengan menggunakan data penginderaan jauh. Sebuah *Normalized Difference Vegetations Index* (NDVI) yang berasal dari data penginderaan jauh (Spot-5) yang digunakan dalam penelitian ini untuk menilai penutup vegetatif. Sebuah model erosi tanah yang dikembangkan untuk mengintegrasikan NDVI dan kemiringan tanah untuk memperkirakan tingkat erosi tanah tahunan. Risiko erosi (TBE) Peringkat dilakukan dalam hirarki fraksi. Hasil penelitian menunjukkan bahwa tingkat erosi tanah telah meningkat dari 0,78 mm/tahun di 2000-1,78 mm/tahun pada tahun 2009. Disimpulkan bahwa SPT 41, 42, dan 47 harus dalam prioritas utama, sedangkan SPT 2, 39 40, dan 45 sebagai prioritas menengah untuk dilestarikan melalui program pencegahan erosi.
Kata-kata Kunci: Erosi tanah, Erosi peringkat risiko, GIS, DEM, NDVI.

INTRODUCTION

Since a few decades ago, erosion is recognized as a serious problem in water resources. Erosion in the watershed produces sediments that able to reduce not only the storage capacity of lakes or reservoirs (Chow, 1964), but also make worse the quality of downstream water bodies (Clark & Wallece, 2003). In addition, the erosion, which often carries nutrients needed by plants and pesticides, toxic chemicals and other contaminants, generates additional water quality problems (Renzetti, 2006). To reduce and controll of soil erosion such as soil and water conservation activities and improving methods of land management (Barling & Moore) takes a huge cost, especially when dredging should be carried out to reduce a large amount of sediment load in the reservoir or port (Harringtton, 1985). Various programs and activities to reduce soil erosion in Indonesia did not show significant results. The number of critical watershed always increases from year to year (Ka'ban, 2007).

To evaluate the soil erosion, map of soil erosion is indispensable. Soil erosion map may include erosion risk map or maps of erosion occurrence (Arsyad, 2010). Erosion risk map is usefull for land use planning, while map of erosion occurrence is useful for planning erosion control or reclamation of barren land.

Mapping of soil erosion occurrence in Indonesia is first performed by Dames (1955) using traditional methods (Asdak, 2010) in Central Java watershed area of 1.6 million hectares. Lane (1996) conducted research on land degradation using GIS. Determining the level of erosion occurrence is done by identifying morphological changes in the soil in-situ. Parameters measured were changes in color and distance from the existing ground surface to the argillic horizon. This study did not use differences in land surface reflectance on satellite imagery.

Hazarika and Honda (1999) evaluate soil erosion and the value of soil erosion using GIS by using the algorithm of NDVI (Normalized difference vegetation index) and DEM (Digital Elevation Model). Milevsky (2008) introduces a method of GIS to estimate soil erosion in watershed-based DEM and satellite imagery analysis. The methods of soil erosion risk estimation is cluster classification of erosion-related digitally derived spatial parameters. Cluster classification of basic topographic and vegetation indices. Kevi & Yoshino (2010) estimate the threat of erosion on agricultural productivity using RUSLE, remote sensing and GIS. This research was conducted in Tunisian watershed. Crop management factor (C) were determined by multi-temporal satellite images using algorithms Transformed Soil Adjusted Vegetation Index (TSAVI). Linear programming opti-mization technique is used to optimize land productivity. This study stated that the combined RUSLE with TSAVI give fairly accurate results for mapping of soil erosion risk.

In general, there are three approaches to identify areas at risk (Eckelmann et al, 2006): A qualitative approach, quantitative approach, and model approaches. The aim of this study is to evaluate the annual rate of soil erosion in Manjuto watershed by identifying and calculating the risk of soil erosion using GIS, based on digital elevation model (DEM).The study was conducted in Manjuto watershed, Indonesia as part of doctoral research, namely the optimization model of integrated watershed management and sustainability viewed from the aspect of bio-physical and socio-economic. The results of this study will be used to determine the erosion parameters for each land use type and its valuation.

RESEARCH METHODOLOGY

Identification of Land Use

The information of land used obtained through the interpretation of Landsat Thematic Mapper (TM), namely Landsat 7 (Ls-7) ETM path 126/row 062 dated July 22, 2000 acquisition and digital Spot 4 dated May 17, 2009 acquisition of 355 271/row path using ER Mapper 6.4 after the first correction of geometric disturbances and radiometric. Method of supervised classification using Maximum Likelihood Classification (MLC) to determine changes in land use (2000-2009) is overlaying maps of land use in 2000 and 2009.

Land and Soil Map Unit.

The land units map (SPT) was obtained from land unit map of Sungai Penuh Sheet (0813) Sumatra Island, 1:250.000 scales, published by The Project of Planning and Evaluation of Land Resources and Agro climate, The Centre of Soil Research and Development Agricultural (Puslitanah), Indonesia.

Erosion Estimation Model

To estimate the level of erosion threat that occurred in each of SPT (soil mapping unit) and land use in Manjuto watershed is done by combining the USLE, Remote Sensing and GIS. Mathematical equations used to estimate the erosion is (Honda, 2001):

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

Where E = the annual rate of soil erosion in the watershed Manjuto (mm/yr), S=gradient or slope (degrees), S_{30}=Value of Tan 30^0 and E_{30} is the rate of erosion that occurred on the slope of 30^0 is obtained by using the following equation:

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

The value of maximum erosion (E_{maks}) and minimum erosion value (E_{min}) obtained from field surveys and NDVI can be calculated from the following equation (Honda, 2001; Panuju, et al, 2009):

$$NDVI = \left[\left(\frac{B_4 - B_3}{B_4 + B_3}\right) + 1\right]\cdot 100 \qquad (3)$$

NDVI is vegetation index. It reflects the green level of vegetation condition (Malingreau, 1986).

RESULTS AND DISCUSSION

Location

The geographical position of the study area is located on 02° 10'30''- 02°30'15" South Latitude (LS) and 101°5'30" - 107°35'00" East Longitude (BT) and the administration included in the region Mukomuko District, Bengkulu Province-Indonesia. Location of the study can be seen in Figure 1.

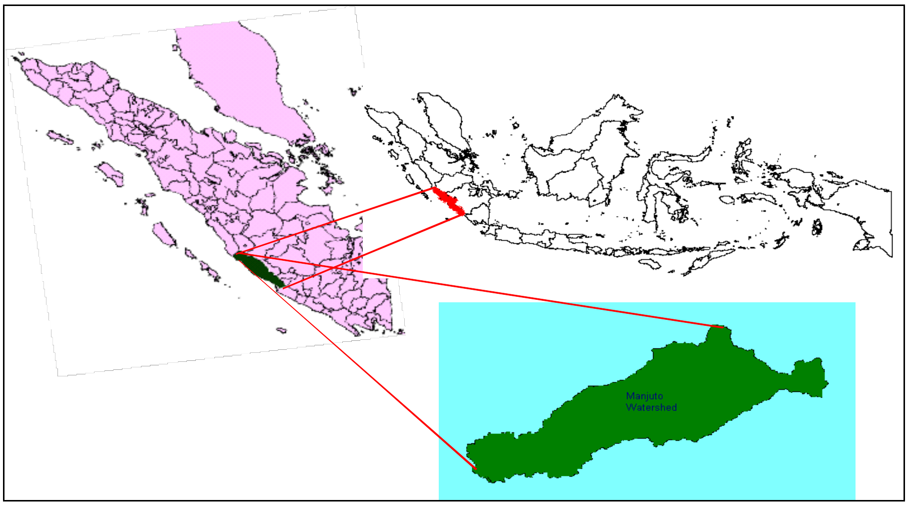

Figure 1. Geographic Location of Manjuto Watershed

Topography

Based on DEM data, it is known that the slopes of research area are very diverse. The distribution of slope conditions of the study area is presented on Table 1.

Slope is one of the main factors that affect the rate of soil erosion (Zing, 1940). The slopes in the watershed Manjuto obtained from DEM data (digital elevation model), and corrected by using a simple empirical coefficient in the form of α using the equation: α = α* (1+(α/150)).

Table 1. Slope of Study Area

No.	Slope (%)	Area (are)	Percentage (%)
1	0 - 3	7,510.97	9,44
2	3 - 8	13,412.91	16,85
3	8 - 15	31,949.35	40,15
4	15 - 25	15,155.85	19,04
5	25 - 40	5,667.83	7,12
6	40 - 45	2,182.37	2,74
7	> 45	3,701.40	4,65
	Total	**79,580.68**	**100,00**

The results show that the average slope of watershed areas Manjuto is 15^o. The biggest area (40.15%) has a slope of 8-15^o, the second (19.04%) of 15-25^o or both covers 59.19% of watershed area. For moderate slope of 15^o erosion is usually occurred in the form of sheet erosion or inter-rill erosion (erosion between the grooves). On area with steeper slope of 15-25^o the most probable occurrence is gully erosion, that resulted from the barren land which can also cause landslides. For the region with milder slope of 0-8^o covering 26.28% of total area, in some cases associated with soil deposition.

From the river morphology point of view, the length of Manjunto with elongated shape from upstream to downstream is relatively short. With an undulating topography, the existence of the falling rain in the upstream part will move quickly towards the downstream part. If the land use patterns increasingly become vegetation free, the rapid concentration of runoff will affect the likelihood of landslides, as well as floods and sediment transport.

Land use

The analysis of land use changing on Manjunto watershed conducted for 2000 and 2009 conditions through interpretation of Landsat 7 and SPOT imagery. The results are presented in Figure 2.

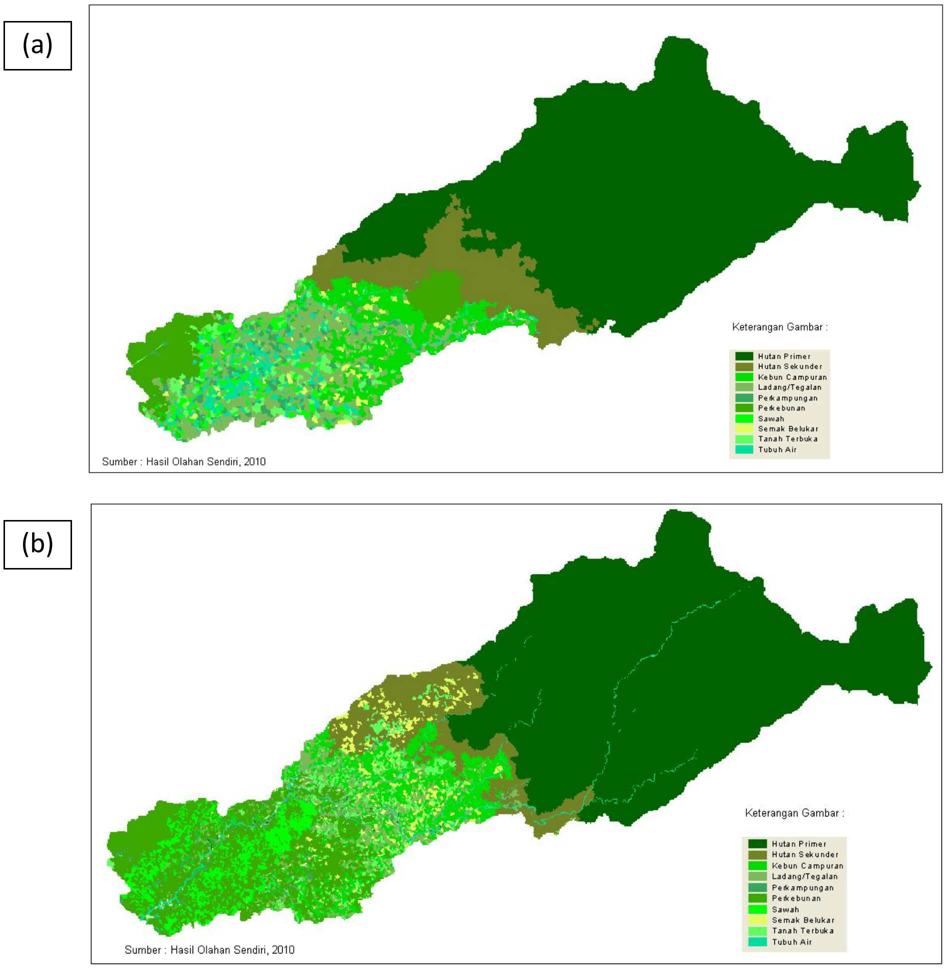

Figure 2. Manjunto watershed land use in 2000 (a) and 2009 (b)

In consequtive 9-year period the land use has changed significantly in Manjuto. The plantation increased by 10.8%, while the primary forest reduces by 2.72 %.

Estimation of annual soil Erosion rate

Annual erosion rate increased from 0.78 mm/year in the year 2000 to 1.78 mm/year in 2009, equivalence 57.13 tons/ha/year. Figure 3 presents the average of annual soil erosion rates in the year 2009.

For all soil mapping units (SPT), the average of erosion rate is 17.76 tons/ha/year, while the erosion hazard index equal to 0.72. Based on the magnitude of erosion and the soil loss in the watershed Manjuto; found that the level of erosion hazard in the area under study is in the medium category. The relatively low erosion rate in Manjuto because most of the watershed remains dominated by forest. In 2000, forest area identified by 62.49%. In some locations at the down stream part, erosion hazard level already in the category of medium-heavy.

Identification of Soil Erosion Risk Areas

There are several GIS-based methods to estimate the risks of erosion. The selection depends on the purpose of the study, the tools available and expected results. However, in general, these methods can be grouped into two categories: relative (qualitative) and absolute (quantitative). This study used the quantitative methods.

The result (Figure 3) shows that SPT 41, 42, and 47 have the highest level of soil erosion risk (TBE), while SPT 2, 39, 40, and 45 have lower TBE. The factors that caused the high rate of soil erosion risk in this region are: high rainfall, slope, poor cropping management with no attention to soil and water conservation practices, as well as deforestation.

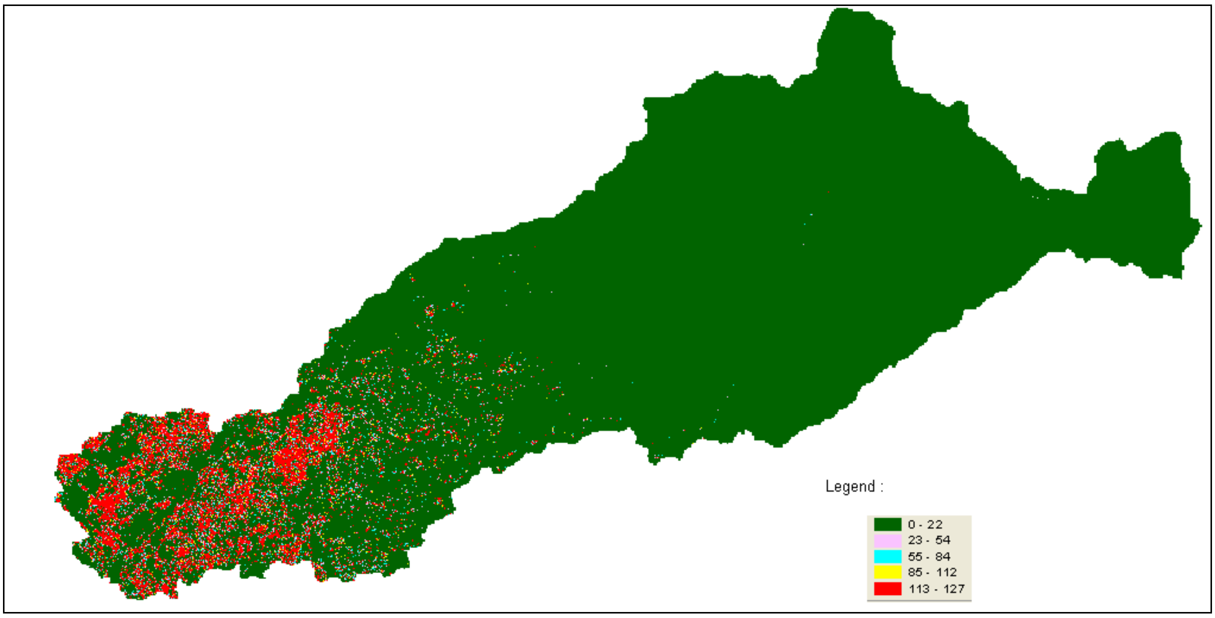

Figure 3. Soil Erosion Map Showing 2009 Annual Erosion Rate

CONCLUSION

The conclusions of the study are as follow:

1. GIS and Remote Sensing can be used to evaluate soil erosion and create soil erosion risk maps to support soil and water conservation.
2. With the annual erosion rate 57.13 tons/ha/year and the amount of soil loss is 1.78 mm/year, the rate of erosion hazard at site is at intermediate level. Therefore, soil and water conservation activities are urgently required.
3. As a guideline for ensuing conservation activities, SPT 41, 42, and 47 should be at first priority since the level of soil erosion risk is in heavy category, and then followed by SPT 2, 39, 40, and 45 as medium level.

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