Application Of GIS Software For Erosion Control In The Watershed Scale

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Abstract: Land degradation in form of soil erosion due to uncontrolled farming is occurred in many watersheds of Indonesia particularly in Java Island. Soil erosion is decreasing watershed function as a rainwater harvesting area. Good conservation practices need to be applied to prevent more degradation. This study aims to investigate the effectiveness of land conservation practice for erosion control through land use modeling in the watershed scale. The modeling was applied in the Sempor watershed Indonesia. Three scenarios of land use were used for modeling. Soil erosion measurement and land use modeling were performed by using Universal Soil Loss Equation (USLE) method and Geographic Information System (GIS) software ArcGIS 10.1. Land use modeling was conducted by increasing permanent vegetation coverage from existing condition 4% to 10%, 20% and 30%. The result showed that the modeling can reduce heavy class erosion about 15-37% of total area. GIS provides a good tool for erosion control modeling in the watershed scale.

Index Terms: ArcGIS 10.1, land degradation, land use, modeling, permanent vegetation, sempor watershed, soil erosion

1. Introduction

Disasters are commonly occurred during wet season in Indonesia due to land degradation in the upstream of watershed as reported by Fulazzaky [1], Iskandar and Sugandi [2], and Hapsari and Zenurianto [3]. One of the watersheds with land degradation problem in the upstream is Sempor [4]. About 30-40% of watershed area is in critical condition characterized by heavy erosion, soil depth <60 cm, less fertility of soil, land cover area 25-50%, slope degree 15-30% [5], [6]. Heavy class erosion was occurred in the same area due to farming activity without good agricultural practice procedures where land occupancy for farming in the Sempor watershed was more than 85% [7]. Erosion is one of the most important issues on environmental degradation in the last decade. Generally, erosion is influenced by some factors such as rainfall intensity, topography, soil characteristics, vegetation coverage and land use types [8]. Erosion bring the soil particle into the water in the form of sediment and settle in the lower area such as rivers, reservoirs, lakes, irrigation canals, and some other places [9]. To reduce soil erosion, some conservation practices are needed where informations about erosion are required as basic data to determine appropriate approaches. Erosion has been investigating since 1923 when Duley and Miller were conducting an experiment to understand the process of erosion. In the period of 1940-1950, Ellison an agricultural engineer conducted some erosion researches and in around of 1960, Wischmeier and Smith found a good model for erosion value assessment namely USLE [10]. Currently, erosion assessment methods including USLE have been developed by using remote sensing and GIS technology as reported by Jain and Kothyari [11], Jabbar [12], Naik [13], Vijith et al. [14], Parsakhoo et al. [15], Vallebona [16]. Application of those technologies can improve the accuracy of erosion assessment. This study is focusing on erosion assessment in the existing condition and land use modeling for erosion reduction. USLE method supported by Arc GIS 10.1 software are used for the assessment and modeling. GIS software gives a good alternative solution for erosion control by land use management in the watershed scale.

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2. Materials and Methods

There are two main activities in this study those are erosion assessment and land use modeling for erosion control. Some materials are required for analysis such as rainfall data, rain gauge map, soil type map, digital elevation model (DEM), and land use map which were collected from Office of Probolo River System Central Java and National Coordinator for Survey and Mapping Agency, Indonesia in the period of 2005-2014.

2.1 Study Area

Sempor watershed is located in Kebumen Regency, Central Java Province, Indonesia and covers an area of 44 km^2 (Fig. 1). Climatically, the watershed is in the tropical region where there are two seasons in one year, wet season from October to March and dry season from April to September and the annual rainfall was more than 3,000 mm. Sempor watershed has an important role as catchment of a reservoir (capacity 52 million m^3) in the downstream which is providing water for many uses such as fishery, water consumption, power plant, and irrigation. The reservoir also has role for flood control and for soil and water conservation in the area of Kebumen regency.

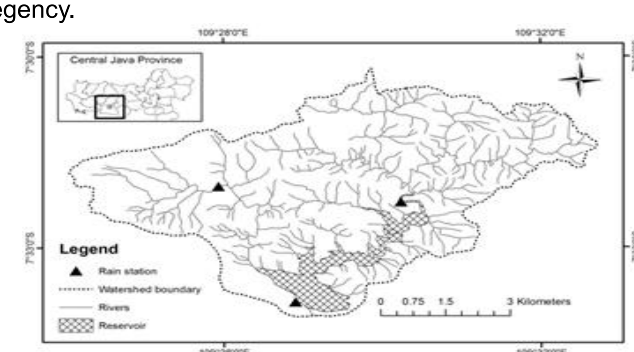

Fig. 1. Location of Sempor watershed

2.2 Erosion Assessment

USLE method (1) supported by ArcGIS 10.1 software was used for erosion assessment.

$$A = R\ K\ LS\ C\ P \quad (1)$$

where A is predicted soil loss, R is rainfall factor, K is a soil erodibility factor, LS is a topographic factor, C is a cropping and management factor and P is a conservation practice factor [8]. Value of K, LS, C and P factor were obtained from soil type map, DEM, and land use map of the watershed using 1: 50.000 topographic scale and 30 m map resolution (pixel). Meanwhile, the rainfall data for R factor value calculation was collected from three rain stations in the watershed.

2.3 Modeling using GIS

GIS applications have been introduced for many purposes particularly for erosion measurement. In erosion assessment, GIS was used for maps overlaying analysis of R, K, LS and CP factor. The assessment performed by using raster calculation of map algebra in the spatial analysis tools which was available in the Arc Toolbox of ArcGIS 10.1. All of maps in shape file format were containing the value of USLE factor and were converted into raster data for the assessment In land use modeling, GIS was used to select and change cells of land use map. The modeling was conducted by changing permanent vegetation coverage (shrub, grass and forest) in the existing condition about 4% into some scenarios (10%, 20% and 30%). Land use management approach had proved can reduce erosion effectively based on investigation in some regions (eg. Zhou et al. [17], Zhang et al. [18]; Cadaret et al. [19]). Land use types of Sempor watershed in the existing condition are shown in the Table 1. Selecting cell determined mainly based on the land slope and type of land use where the cells excluded of permanent vegetation with high slope were automatically selected and replaced into permanent vegetation. Total area of selected cells can be obtained easily due to GIS works based on grid analysis method where each cell will has an equal area.

TABLE 1. *LAND USE TYPE IN SEMPOR WATERSHED*

Id	Land use type	Area (km^2)	%
1	Shrub	1.53	3.46
2	Forest	0.01	0.01
3	Garden	30.81	69.77
4	Settlement	2.78	6.30
5	Grass	0.11	0.25
6	Wet rice field	0.27	0.62
7	Dry rice field	3.00	6.80
8	Moor	3.09	6.99
9	Water body (reservoir)	2.56	5.79

3. RESULTS AND DISCUSSION

3.1 Rainfall Erosivity Factor

Rainfall erosivity (R) reflects the potency of soil to be washed and moved into downstream by rain water. The annual erosivity was calculated by using Bols equation (2) which is developed for tropical region of Indonesia [20].

$$EI_{30} = 6.12\ (Pm)^{1.21}\ (N)^{-0.47}\ (Pmax)^{0.53} \quad (2)$$

Where Pm is the average monthly rainfall amount (in cm), N is the average number of rain days per month and Pmax is the average maximum 24 hour precipitation per month (in cm). Average rainfall was calculated by using Thiessen method from three rain stations. Annual erosivity was obtained by totalizing monthly erosivity where the value was 3,993 cm. Rainfall map of Sempor watershed are shown in the Fig. 2

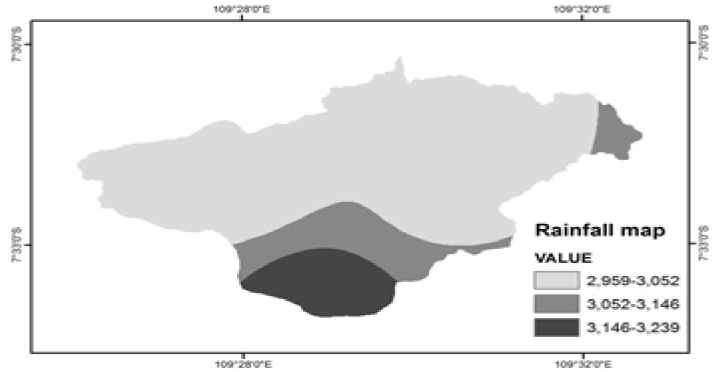

Fig. 2. *Rainfall Map of Sempor Watershed*

3.2 Soil Erodibility Factor

Soil erodibility (K) reflects the ability of soils to resist from erosion based on the physical properties of soil. Soils with high permeability rates and higher organic matter have a greater resistance toward erosion. K for tropical region of Indonesia determined based on soil type refer to K value by Lenvain in 1975 and Bols in 1979 [20], [21]. There are two types of soil in Sempor watershed as described in the Table 2. Generally the watershed dominated by soil type of latosol which is covering about 95.6% of total area and podsolic about 4.4% located in the south part of watershed (Fig. 3).

TABLE 2. *SOIL TYPE AND VALUE OF K FOR SEMPOR WATERSHED*

ID	Soil Type	Area (km^2)	%	K value
1	Podsolic	1.94	4.4	0.13
2	Latosol	42.22	95.6	0.19

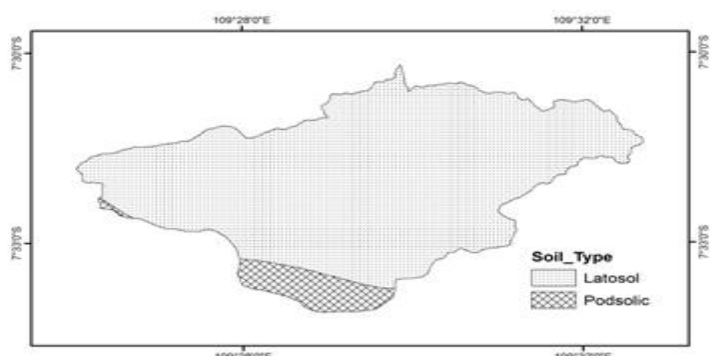

Fig. 3. *Soil Type Map of Sempor watershed*

3.3 Topographic Factors L and S

Length factor (L) and slope steepness (S) were computed as slope length factor (LS). LS are reflecting the effect of slope length slope steepness on erosion process. LS factor of Sempor watershed was determined from land slope map which were classified into four classes as described in Fig. 4.

Land slope map generated from DEM of the watershed. LS value was 0.8 for class 0-8%, 1.5 for class 8-15%, 4.0 for class 15-25% and 7.5 for class 25-45% refer to Wood and Dent in 1983 [20]. Generally the watershed dominated by area with slope between 8-15% (42% of total area). Meanwhile, area with slope 0-8%, 15-24% and 25-45 cover about 24%, 27% and 7% of total area respectively.

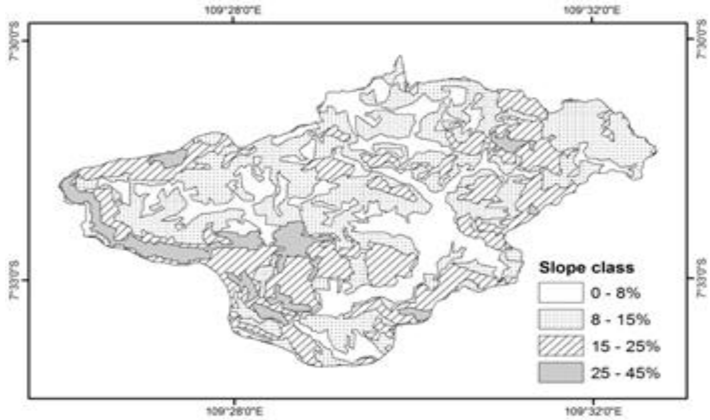

Fig 4. *Land Slope Map of Sempor Watershed*

3.4 Cropping (C) and Control Practice (P) Factor

Cropping factor (C) describes the effect of vegetation coverage on erosion. The C value ranges were from 0 to 1, where value of equal to 0 means 100% protection of against erosion. P factor reflects the impact of support practices on erosion. C and P were calculated as CP factor where the values were determined based on land use type. The value of CP was for shrub 0.1, 0.01 for forest, 0.02 for garden, grass, wet rice field, dry rice field, 0.2 for settlement, 0.28 for moor and 0 for water body refer to CP value for tropical region of Indonesia as described by Asdak [22].

3.5 Annual Erosion Value

Erosion values classified into five classes: 1) very low (0-15 ton/ha/yr), 2) low (>15-60 ton/ha/yr), 3) moderate (>60-180 ton/ha/yr), 4) heavy (>180-480 ton/ha/yr), 5) very heavy (> 480 ton/ha/yr) refers to Department of Forestry Indonesia (DFI) classification in 1998 [23], [24]. The result shows that the largest area was moderate erosion class which is covering about 33.71% of total area. Meanwhile, heavy and very heavy class covers respectively about 26.56% and 18.28% of total area. Heavy class erosion commonly occurs in the area with high land slope. Erosion class distribution can be seen in the Fig. 5.

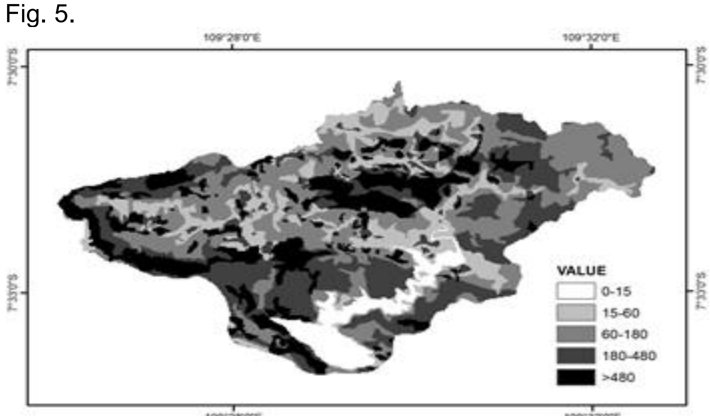

Fig. 5. *Soil Erosion Class Distribution in Sempor Watershed*

3.6 Soil Erosion Control Modeling

The modeling was conducted to reduce erosion through land use management approach. Land use type was reclassified into four classes those were land farm (garden, dry rice field, wet rice field and moor), permanent vegetation (forest, shrub and grass), settlement and reservoir (water body). Land use map was adjusted in 30 m cell size for obtaining optimal result. The modeling was performed by changing all land farm cell from existing condition (4% of permanent vegetation) into scenario I and II (10% and 20% of permanent vegetation) and some settlement cell in the scenario III. Land use appearance in those scenarios condition can be seen in the Fig. 5, Fig. 6, and Fig 7. All selected cells were focused in the upstream part of watershed (north part). The result shows that scenario I, II and II can reduce about 15%, 28% and 37% respectively area with heavy and very heavy class erosion (Table 3). Land use modeling was significant enough for reducing erosion by increasing permanent vegetation.

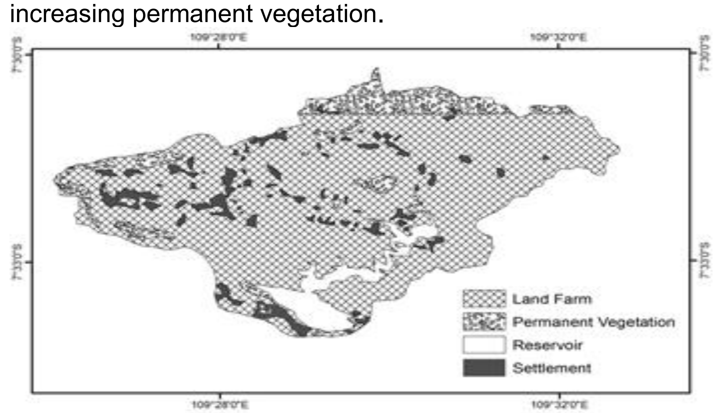

Fig. 6. *Permanent Vegetation 10%*

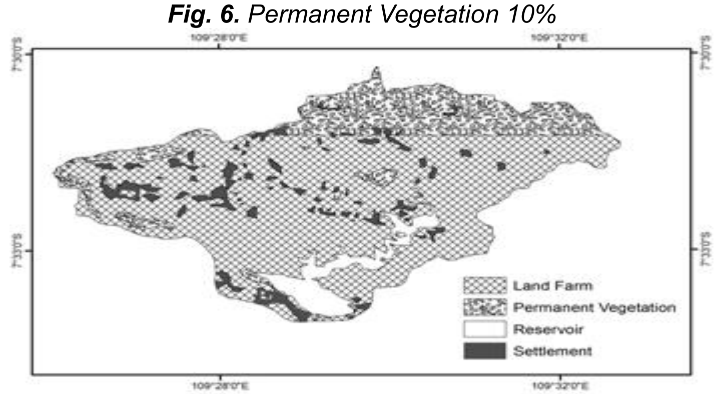

Fig. 7. *Permanent Vegetation 20%*

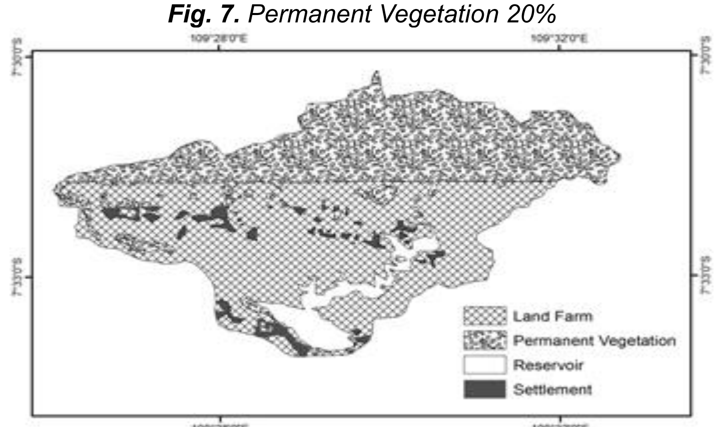

Fig. 8. *Permanent Vegetation 30%*

Erosion problem in the Sempor watershed cannot be solved totally just by increasing permanent vegetation into 30%. Increasing vegetation more than 30% must considering social economic aspect where the land occupancy by farmer was very high. A complex approaches must be considered for achieving a realistic action of conservation practices.

TABLE 3. *EFFECT OF VEGETATION COVERAGE ON EROSION*

Erosion Class	Category	Percentage Area (%)			
		4% PV	10% PV	20 PV	30 PV
0-15	Very low	5.76	9.6	14.06	29.45
15-60	Low	15.68	28.46	35.56	39.07
60-180	Moderate	33.71	31.37	32.7	23.54
180-480	Heavy	26.56	19.26	12.33	6.82
>480	Very heavy	18.28	11.31	5.35	1.12

PV= Permanent Vegetation

Combination approach between land use management and soil conservation engineering practices such as terracing, mulch application, drop structure application and others could be good way to reduce erosion into low level class. Involving community for conservation practices provides good alternative solution for erosion control.

4. CONCLUSIONS

Land use management approach by increasing permanent vegetation coverage from existing condition 4% into 10%, 20% and 30% can reduce erosion significantly about 15-37% in the tropical watershed of Sempor. GIS has a good ability for erosion control through land use modeling. In the area with heavy erosion class, soil conservation practices by engineering approach could be the best choice for short term erosion control. Meanwhile, land use management provides a good alternative way for long term erosion control.

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