Application Of GIS For Degradation Level Assessment In Tropical Watershed

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Abstract: High land occupancy for farming activity particularly in the upstream area was causing land degradation problem in many tropical watersheds. Land cultivation without good agricultural practice was resulting disasters in the downstream during wet season in form of debris flow, flood and sedimentation and in dry season in form of drought. Land conservation practices are required to conserve the function of watershed as rain water catchment area. Information about degradation level in the watershed is required for determining conservation strategies. This study was focusing on degradation level assessment in watershed scale by using Geographic Information System (GIS) in a tropical watershed. Five indicators were used for the assessment such as soil erosion, farm land occupancy index, vegetation coverage index, sediment delivery ratio and land slope average. The assessment was performed by applying scoring and weighting factor in each indicator. All parameters were analyzed using data from various sources. The result showed that indicator of farm land occupancy index and vegetation coverage index has bad category. Meanwhile, soil erosion, land slope index and sediment delivery ratio has good category, respectively. Total score of indicators was 2.6 means that the watershed was in moderate degradation level. GIS provides a good tool for degradation level assessment in the sub watershed scale.

Index Terms: GIS, land degradation, sediment delivery ratio, soil erosion, vegetation coverage.

1. INTRODUCTION

This study was conducted in Tritis watershed (17.73 km^2), a part of Wadaslintang river system which is administratively located in the Wonosobo Regency, Central Java Province, Indonesia (Fig. 1). Average annual rainfall was more than 3,000 mm where the rain was mainly occurred during wet season from October to March. Another season was dry season from April to September with no rain in normal condition.

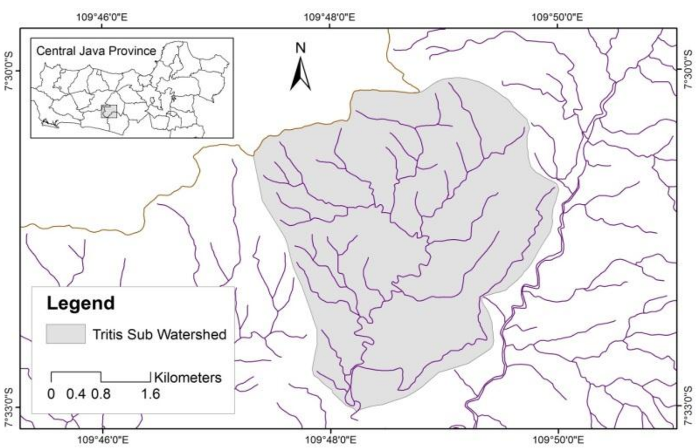

Fig. 1. *Location of Tritis watershed*

The land elevation spreads from around of 150 m.a.m.s.l (in the south) to 500 m.a.m.s.l (in the north). The watershed area was dominated by area with slope between 0-12% and the highest slope was 36% in the north and east. Average daily temperature was about 26˚C, with the lowest and highest temperatures were 20˚C and 33˚C respectively.

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As an agricultural watershed, Tritis has important role for supporting the economy of local inhabitants through farming sector. On the contrary, farm activities could lead land degradation problem due to soil cultivation without applying good agricultural practices. Excessive farming activities have been reported as one of the main causes land degradation problem in Indonesia [1], [2], [3]. Some studies nearby this study area reported land degradation problems in form of soil erosion and sedimentation due to farming activities [4], [5], [6], [7]. To ensure the land function sustainability, some conservation practices are needed to be applied in the Tritis watershed. Watershed assessment for determining degradation level is required to determine the best conservation strategies. Watershed assessment is one of the monitoring and evaluation components and one of the basic requirements for watershed preservation [8], [9]. Watershed assessment concept was involved investigation of the specific processes and must be developed based on local issues [10], [11]. Therefore, the approach for watershed assessment could be decided by considering local condition. In the area with limited data, the determination of assessment parameters has become a challenge to catch a good result. Presently, the application of spatial technology such as GIS and remote sensing provides a good alternative ways to obtain the values of assessment parameters. GIS has been used and proved a good performance for watershed assessment studies [12], [13]. Watershed assessment studies mostly were conducted by focusing on simple or single parameter such as Bhuyan et al. [14], Dai et al. [15], Ioja et al. [16], Golden et al. [17], Merkuryeva et al. [18], Getahun and Keefer [19]. In this study we used five parameters for assessing degradation level of the watershed. All of parameters values were calculated using GIS software Arc GIS 10.1. This present study results an alternative approach for assessing degradation level in the watershed scale in tropical region by using local issues and data availability.

2. MATERIALS AND METHODS

One of the most common challenges in data collection process of studies is lack of data availability. For a monitoring and evaluation of watershed, have need a long series data. In this study, the data such as rainfall, soil type map, digital elevation model (DEM), land use types and land cover map, and water inflow data were collected from various sources generated from Wadaslintang watershed data.

2.1. Parameters of assessment

Five main parameters were proposed for this study those were soil erosion, farm land occupancy index, vegetation coverage index, sediment delivery ratio and land slope. Selection of parameter was mainly considering for a simple and rapid application of degradation level assessment in the small watershed or sub watershed level. All of parameters values were quantitatively calculated using scoring and weighting factors. Each parameters had three possibility category values, such as: good (score 1), moderate (score 3) and bad (score 5) as shown in the Table 1.

***TABLE 1.** PARAMETERS OF DEGRADATION LEVEL ASSESSMENT*

Id	Parameter	WF* (%)	Unit	Quant. Value	Category	Score
1	Average soil loss	20	ton/ha/yr	>180	bad	5
				60-180	moderate	3
				0-60	good	1
2	Land farm occupancy Index	20	%	>50	bad	5
				30-50	moderate	3
				<30	good	1
3	Vegetation coverage index	20	%	<30	bad	5
				30-50	moderate	3
				>50	good	1
4	Sediment delivery ratio	20	-	>0.50	bad	5
				0.25-0.50	moderate	3
				<0.25	good	1
5	Land slope	20	%	>45	bad	5
				15-45	moderate	3
				0-15	good	1

**WF= Weighting Factor*

Weighting factor was reflecting the grade impact toward assessment result. Among of those parameters, the weighting factor was same (20%). Total scores of parameters obtained by enumerating each parameter score (obtained from WF x Score). General condition of degradation level was assigned from the total scores of parameters where the range was 1-5 as shown in the Table 2.

***TABLE 2.** DEGRADATION LEVEL CATEGORY OF WATERSHED*

No	Level category	Range of scores
1	Heavy	3.5-5.0
2	Moderate	2.0-<3.5
3	Light	0.0-<2.0

The use of weighting factor for scoring represents the complexity of watershed components [5], [20], where each of it has different contribution in forming of watershed output such as water inflow and sedimentation.

2.2. Parameters values calculation

Parameter values calculated using software Arc GIS 10.1. For soil erosion, USLE method (1) supported by GIS was selected for the calculation.

$$A = R\ K\ LS\ C\ P \tag{1}$$

Where A is predicted soil loss (ton/ha/yr), R is rainfall factor (MJ mm ha^{-1} h^{-1} yr^{-1}), K is a soil erodibility factor (t h MJ^{-1} mm^{-1}), LS is a topographic factor (dimensionless), C is a cropping and management factor (dimensionless) and P is a conservation practice factor (dimensionless) [21]. Value of K, LS, C and P factor were obtained from soil type map, DEM, and land use map of the watershed using 1: 40.000 topographic scale and 30 m grid map resolution (pixel). Meanwhile, the rainfall data for R factor value calculation was collected from two rainfall stations in the watershed. Farm land occupancy index and vegetation coverage index calculated from land use and land cover (lulc) map of watershed using GIS. Land slope average calculated from DEM of watershed and for sediment delivery ratio (ratio of sediment yield toward soil erosion), sediment yield (bed load type) was calculated using Meyer-Peter and Muller's (MPM) method (2).

$$\mathbf{Q_b}^{2/3} = \mathbf{L}\left(\frac{\gamma_w \left(\frac{Ks}{Kr}\right)^{3/2} RS - 0{,}047\ (\gamma s - \gamma w) d}{0{,}25 \left(\frac{\gamma w}{g}\right)^{1/3}}\right) \div \left(\frac{1}{\gamma s - \gamma w}\right)\left(\frac{1}{1-e}\right) \tag{2}$$

Where L is river width (m), γw is bulk density of water (ton/m^3), γs is bulk density of sediment (ton/m^3), R is hidraulic radius (m), S is river base slope (%), d is diameter of median, g is acceleration of gravity (m/s^2), Q_b is volume of sediment (m^3/s), e is porosity (0.35), and Ks/Kr is ripple factor [22].

3. RESULTS AND DISCUSSION

3.1. Soil erosion estimation

Rainfall erosivity (R) calculated by using Bols equation (2) which is developed for tropical region of Indonesia [20].

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

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). Rainfall data for R calculation was collected from two nearby rainfall station namely Wadaslintang and Limbangan where the R value of those station was 3,190 and 3,483 respectively. Value of K factor determined using references K value of Lenvain in 1975 and Bols in 1979 which is investigated for tropical region of Indonesia based on soil type [23], [24]. K factor value for two types soil in tritis watershed was 0.4 (latosolic reddish brown soil type), and was 0.26 (latosolic red yellow soil type). The watershed was dominated by soil type of latosolic red yellow. The soil map obtained from main office of Serayu Opak River, Ministry of Public Works, Indonesia issued in 2009. LS factor was determined from 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% as proposed by Wood and Dent in 1983 [23]. DEM generated from Indonesian Earth Surface Map (RBI) in 2016. C and P were calculated as CP factor where the values were achieved based on land use type and land cover map (lulc). Lulc map generated from Indonesian Earth Surface Map (RBI) in 2016. There are three types of lulc in the watershed and the value was 0.43 for farm land, 0.01 for vegetation and 0.2 for settlement determined based on CP value for tropical region of Indonesia [25]. Based on those values, the average of soil erosion was achieved. The watershed dominated by area with soil erosion value about 0-15 ton/ha/year (Fig. 2).

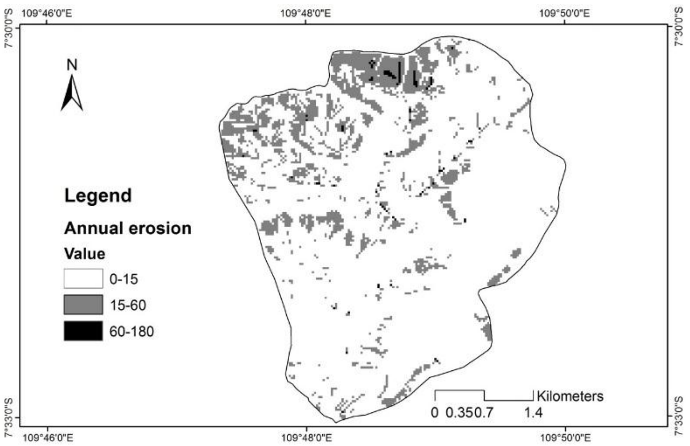

Fig. 2. *Erosion distribution in Tritis watershed*

3.2. Farm land and vegetation coverage index

Farm land occupancy index and vegetation coverage index calculated from lulc. Farm land occupies about 61.9% of total area in form of garden, wet rice field and moor land and vegetation occupies about 17.3% of total area in form of shrub and forest (Table 3 and Fig. 3). Meanwhile, settlement covers more than 20% of watershed area. High land occupancy for farming and settlement indicate that the watershed prone to degradation.

TABLE 3. *LAND USE AND LAND COVER TYPES IN TRISTIS WATERSHED*

Land use and land cover type	Coverage area (%)
Vegetation	17.3
Farm land	61.9
Settlement	20.8

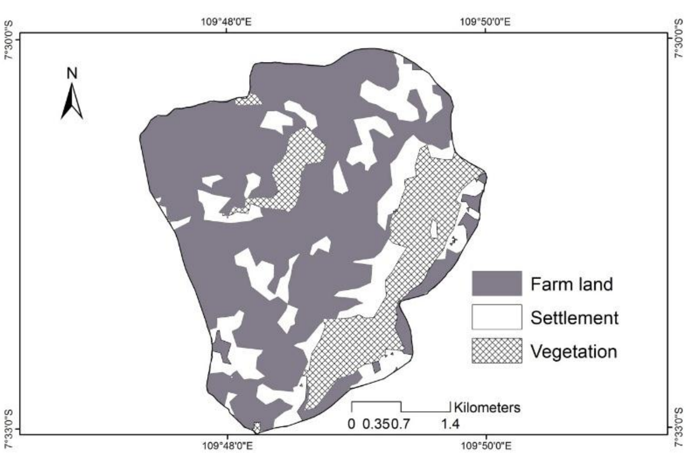

Fig. 3. *Land use types distribution in Tritis watershed*

3.3. Sediment delivery ratio

Sediment delivery ratio (SDR) assessment was conducted by calculating the bed load as main component of sediment which has significant effect on soil deposit in the downstream area. SDR reflects the ability of watershed to move the soil particle from land to rivers. For calculating bed load using MPM method, the water inflow data were required and collected from office Office of Probo river system from 2006-2015. The result of monthly sediment yield calculation in unit m^3 was shown in the Fig. 4

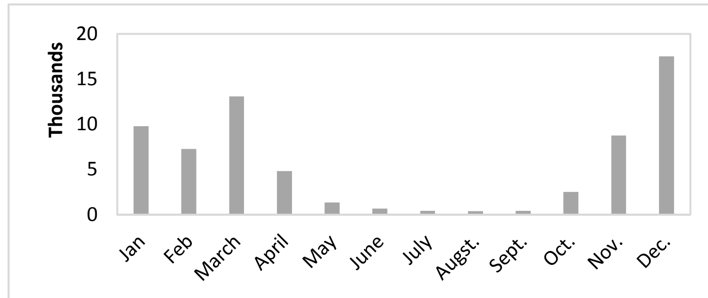

Fig. 4. *Sediment yield in Tritis watershed*

Annual sedimentation yield was 66,853 m^3. SDR value was obtained from the value of sediment yield and soil erosion of Tritis watershed (Fig. 5). Generally the SDR value was between 0-0.25.

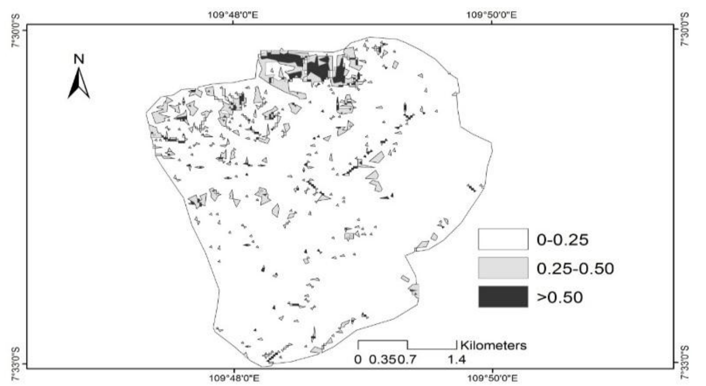

Fig. 5. *Distribution of SDR value in Tritis watershed*

3.4. Land slope

Land slope average obtained from DEM map by using spatial analysis tools. The slopes were reclassified into three class: 0-15%, 15-30% and 30-45%. The result shows that the area of watershed dominated by flat land with slope about 0-15% as shown in the Fig. 6.

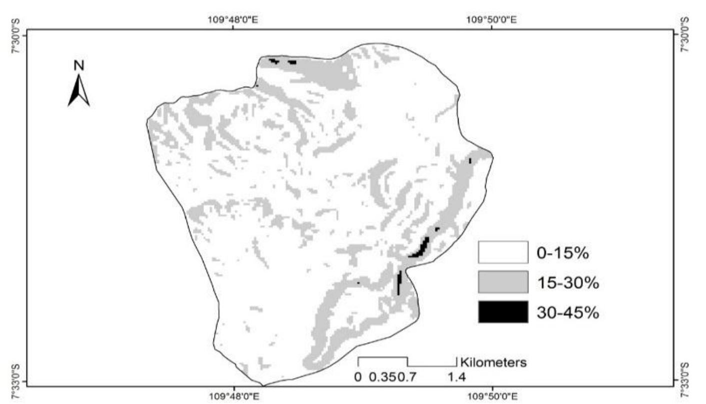

Fig. 6. *Distribution land slope in Tritis watershed*

3.5. Degradation level assessment

Validation of methods used for parameters values calculation in this study was hard. The lack of observed data through direct measurement such as sedimentation has become the main problem. To minimize the error into allowable limit, some value of parameters obtained from reference values of related studies in Indonesia particularly at Java Island. Field survey were also conducted during the study to ensure appropriate value of the parameters as field survey for land use types. The values of parameters were various. For soil erosion, the range value from 0-60 ton/ha/year dominated the area of watershed means that for erosion parameter the value was good (score: 1). The others parameters those were farm land occupancy index and vegetation coverage index, the values were 61.9% (bad) and 17.3% (bad) respectively. Those value have score 5. For sediment delivery ratio and land slope average, the values were good (score 1). Generally the SDR values were between 0-0.25 and for land slope the watershed dominated by area with flat terrain (slope between 0-15%). Total score parameters was 2.6 (Table 4) mean that generally the watershed was in moderate condition. High land occupancy for farming was increasing the potency of land degradation particularly in form of soil erosion and sedimentation. Good land use management need to be applied to reduce farm land and to increase vegetation coverage. Well agricultural practices could apply in the farm land to minimize the effect of land cultivation on land degradation.

TABLE 4. *VALUES OF ASSESSMENT PARAMETERS*

	Parameter	WF	Value	Category	Score	PS
1.	Average soil loss	0.20	0-60	good	1	0.2
2.	Land farm occupancy Index	0.20	61.90%	bad	5	1.0
3.	Vegetation coverage index	0.20	17.30%	bad	5	1.0
4.	Sediment delivery ratio	0.20	0-0.25	good	1	0.2
5.	Land slope	0.20	0-15%	good	1	0.2
					∑	2.6

**WF= Weighting Factor; PS= Parameter Score (WF x Score)*

4. CONCLUSIONS

In general, the Tritis watershed was in moderate condition, owing to the land degradation potency dominated by flat land with slope between 0-15% of watershed were flow. Farming activities contribute a high potency for triggering land degradation in the watershed. Good land use management and agricultural practices are required to control the land degradation in the watershed. GIS had proved a good better ability for degradation level assessment in Tritis watershed. Addition more parameters were recommended for the future studies in the larger watersheds where the problems will be more complex.

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