ANALYSIS OF EROSION RISK LEVEL IN UPSTREAM OF SEMPOR RESERVOIR

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ABSTRACT

The high rate of erosion in upstream of Sempor reservoir is the main factor of reason for high the deposition in Sempor reservoir, where based on measurement data of sedimentation in Sempor reservoir 1994 that the total catchment volume reduction due to sedimentation was 12.04 million m^3 in the period of 16 years (from 1978 to 1994) or 752,500 m^3/year. It will give bad impact for all parties, including the increased risk of flooding, reduction in irrigated land area and interrupt operation of hydroelectric power. This study aims to determine the erosion risk level in upstream of Sempor reservoir in actual conditions (at the time of the research) based on The Universal Soil Loss Equation (USLE) formula, by applying a Geographical Information System (GIS) Analysis. Three types of maps was used in analysis , i.e. soil, slope, and land cover maps. The results showed that the rate of erosion in upstream area of Sempor reservoir was in the level IV of erosion risk level, which was 225.24 tons/ha/year or 12.51 mm/year. It is necessary to immediately improve land use as an effort to reduce high erosion rates so that all existing sectors can run well upstream and downstream of the Sempor reservoir.

Keywords: *Erosion, GIS, Sedimentation, Sempor reservoir, USLE.*

A. INTRODUCTION

In terms of location, Sempor Reservoir is located in Sempor village, Sempor sub-district, Kebumen district, Central Java, Indonesia. The reservoir which was inaugurated its use on March 1th 1978, is a surface water source for various community activities, both for irrigation, domestic, industry, and for hydropower in Kebumen district. Based on physical data from the Department of Public Works in the South Kedu Multipurpose Project, Sempor reservoir has a volume or maximum capacity of 52,000,000 m^3 at the beginning of construction, while data from the final report on sedimentation measurement work of Sempor and Wadaslintang reservoir in 1994, the total storage capacity of the Sempor reservoir decreased by only around 39,960,000 m^3. Because of the decrease in reservoir capacity as a result of accumulation of sediment volume, it must be prevented as early as possible so that the risk of flooding, reduction in irrigated land area and interrupt operation of hydroelectric power can be avoided. Considering that the catchment area (DTA) is an ecosystem consisting of upstream, central, and downstream areas that have biophysical linkages, then to reduce the rate of sedimentation that enters the reservoir can be achieved by reducing the rate of erosion in the upstream area by applying land use in accordance with conservation principle.

Soil erosion is a complex process that physically takes place by the movement of soil particles from a given site. Soil erosion can affect soil quality and induce soil deterioration by the loss of topsoil that is enriched with organic matter. Therefore, the soil erosion can cause a reduction of crop productivity. Factors which are considered as the main causes of soil erosion are climate, soil type, topography, vegetation and human activities. In the areas where climate, soil type and topography are similar, differences in soil erosion rates are commonly related to land use or land cover (Del Mar López et al. 1998). Since soil erosion generally occurs when the soil is displaced by rain and transported from the specific area, therefore rainfall is considered as the driving factor of soil erosion. However, the factor that significantly affects the soil displacement by rain is land cover or vegetation cover. The reduction of vegetation cover can increase soil erosion. This relationship is a reason why vegetation cover and land use have been widely included in soil erosion studies (Komas et al. 1997; Del Mar López et al. 1998; Szilassi et al. 2006; Zhou et al. 2008; Solaimani et al. 2009; Su et al. 2010).

Erosion Risk Level (ERL) is a maximum amount of soil lost estimation that will happen on a land, where the crop management and soil conservation does not change at that time (Herawati, 2010). Quantitatively, Universal Soil Loss Equation (USLE) formula by Wischmeier and Smith (1978) is a suitable empirical model for estimating soil erosion by water as a function of six factors, i.e. the rainfall and runoff erosivity factor, the soil erodibility factor, the slope length factor, the slope steepness index, the land cover/management factor and the soil conservation factor.

The objective of this study is to assess and determine the erosion risk level in upstream of Sempor reservoir in actual conditions (at the time of the research). Knowing the erosion rate that occurs in an area is an important thing (first step) to be able to find out the amount of transported soil and as a problem solving steps (A'yunin, 2008).

B. MATERIALS AND METHODS

a. Study Area

The study was performed in water catchment area of Sempor reservoir, in Sempor village, Sempor sub-district, Kebumen district, Central Java, Indonesia. Precisely located about 7 km from north of Gombong city. Geographically, on the east and north are hills and to the west and south are lowlands consisting of housing and rice fields.

b. Research Methods

Ideally the prediction method must meet the requirements, the model must be reliable, can be used in general, easy to use, using minimum data, comprehensive in terms of the factors used and can follow (sensitive) to changes that occur in the watershed such as soil conservation practices(Morgan, 1992). One of the erosion prediction models that is widely used is the USLE method.

c. Data Analysis

To facilitate process of analysis and data checking, it is necessary to make the smallest mapping called as the Land Unit Map (Land Unit). Land Unit Map is carried out by overlaying of several maps (overlay maps by GIS application, arc view 3.2.) namely land use digital map, soil types digital map and slope digital map, then numbering is given to each Land Unit in order to analyze Erosion rate by using the general equation of the maximum soil loss formula developed by (Wichmeir and Smith. 1978). The equation is:

A = R.K.LS.CP …………………… 1)

Where, A : the computed spatial average soil loss and temporal average soil loss per unit area (ton ha−1 yr−1),

R : rainfall erosivity factor (MJ mm ha−1h−1yr−1),

K : soil erodibility factor (Mg h MJ−1 mm−1),

LS : slope length and steepness factor,

C : cover management factor, and

P : the conservation practice factor.

Rainfall Erosivity Factor (R)

Rainfall erosivity is the basic and important factor in the assessment of soil erosion in the USLE model (Elangovan and Seetharaman, 2011). Calculation method for rainfall erosivity depends on the type of rainfall data availability. It is recommended to use the Bols equation if there is a certain amount of data, namely the average monthly rainfall, the number of rainy days in a given month, and the maximum daily average rainfall in a particular month. Bols (1978) based on his research in Java and Madura Island, he got the following equation:

$$EI_{30} = 6{,}119\, Pb^{1{,}211} \cdot N^{-0{,}474} \cdot P_{max}^{0{,}526} \quad \text{………………………2)}$$

Dimana, EI_{30} : monthly rain erosion index (KJ/ha)

Pb : monthly rainfall (cm)

N : number of rainy days per month (days)

Pmax : maximum rain daily (24 hours) in the month concerned (cm)

Annual EI30 is the accumulated monthly EI30 amount

Soil Erodibility Factor (K)

Soil erodibility factor represents the vulnerability of soil or surface material to erosion, transportability of the sediment, and the amount and rate of runoff given a particular rainfall input, as measured under standard condition .

The following are some erodibility rates according to the type of soil and the main material that composes it.

Table 1. Soil erodibility factor rates (K)

Jenis klasifikasi tanah	Nilai K rata-rata (metrik)
Red latosol	0,12
Yellowish red latosol	0,26
Brown latosol	0,23
Latosol	0,31
Regosol	0,12 – 0,16
Regosol	0,29
Regosol	0,31
Gley humic	0,13
Gley humic	0,26
Gley humic	0,20
Lithosol	0,16
Lithosol	0,29
Grumosol	0,21
Gray Hydromorf	0,20

(source: Asdak, 2007)

Topographic Factor (LS)

Slope steepness and length are critical factors controlling overland flow and erosion (Bryan and Poesen 1989). On sloping land, there is usually net transport of soil downslope because displaced soil can travel further downhill than uphill due to gravity and slope angle. Huang et al. (1999) found that slopes < 5 percent resulted in net sediment deposition during simulated rain events in a laboratory experiment. On relatively flat surfaces, raindrop splash causes essentially no net soil loss because displaced particles are replaced by nearby soil particles that were displaced by raindrop impacts (Troeh et al. 1999).

Table 2**.** LS factor

Slope level	Slope	LS
I	0-8%	0,4
II	8-15%	1,4
III	15-25%	3,1
IV	25-40%	6,8
V	>40%	9,5

(Source: Department of Forestry, 1998)

Land Cover and Supporting Conservation Practice Factor (CP)

The following is an estimate of the CP factor values for various types of land use in Java.

Table 3**.** CP factor

Conservation and Plant Management	CP value
Forest:	
a. undisturbed	0,01
b. without understorey, with litter	0,05
c. without understorey and litter	0,5
Shrubbery:	
a. undisturbed	0,01
b. some grasses	0,1
Farm:	
a. Agroforest	0,02
b. Garden-yard	0,2
Plantation:	
a. Full covered land	0,01
b. Partially covered land	0,07
Grassland:	
a. Full covered land	0,01
b. Partially covered land; overgrown with reeds	0,02
c. Reeds; burning once a year	0,06
d. Lemongrass	0,65
Agricultural crops:	
a. Tubers	0,51
b. Grains	0,51
c. Nuts	0,36
d. Mixture	0,43
e. Irrigated rice	0,02
Cultivation:	
a. 1 year of planting-1 year of recovery without planting	0,28
b. 1 year of planting-2 year of recovery without planting	0,19
Agriculture with conservation:	
a. Mulch	0,14
b. Terrace	0,04
c. Contour cropping	0,14

(Source: Abdurachman et al., 2005; Ambar and Syafrudin, 1979)

Overlay Analysis

Overlay analysis is operation in GIS for superimposing the multiple layer of datasets that representing different themes together for analyzing or identifying relationship of each layer. Overlay analysis represent the composite map by the combination of different attribute and geometry of datasets or entity. Overlay is the operations of comparing variables among multiple coverages. In the overlay analysis new spatial data sets are created by merging data from two or more input data layers. Overlay analysis is one of the most common and powerful GIS technique.

In this research, there are three maps that will be overlayed, i.e. soil types digital map,

slope digital map and land use digital map. The procedure can be seen as shown below
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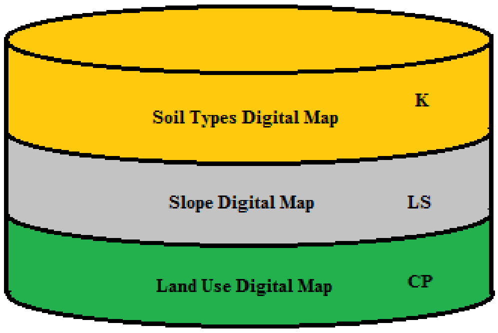

Erosion Risk Level. The following is classification of erosion risk level which is determined based on the guidelines from Department of forestry (1998)

Table 4. The classification of erosion risk level

Erosion risk level	Soil loss (ton/ha/year)	Remark
I	< 15	Very light
II	15 – 60	Light
III	60 – 180	Moderate
IV	180 – 480	Heavy
V	> 480	Very heavy

Source: (Department of Forestry, 1998)

C. RESULTS AND DISCUSSION

a. Rainfall Erosivity Factor (R)

In determining the monthly rainfall erosivity factor, a number of related data were needed (from rain observer: Sempor station, Sampang station, Kedungwringin station managed by the Meteorology, Climatology and Geophysics Agency), including:

1. Monthly rainfall (cm) during 11 years for each rainfall station (2001-2011).
2. Number of rainy days per month (average for 11 years).
3. The maximum daily rainfall (through 24 hours) in each month (average for 11 years).

By using equation 2, the average monthly erosivity value for the last 11 years (2001-2011) can be seen in Table 5 below:

Table 5. Rainfall erosivity in water catchment are of Sempor reservoir

Month	Erosivity (KJ/ha)								
	SAMPANG			KEDUNGWRINGIN			SEMPOR		
	Average (2001-2011)	Average +StDev	Average -StDev	Average (2001-2011)	Average +StDev	Average -StDev	Average (2001-2011)	Average +StDev	Average -StDev
January	539,43	788,13	309,66	578,81	897,25	289,17	519,59	829,70	239,88
February	458,79	684,34	251,54	538,47	820,87	280,45	470,97	651,51	301,92
March	445,89	592,45	307,37	566,84	757,63	386,75	404,19	566,70	252,51
April	309,52	468,27	164,18	346,34	519,85	187,16	230,09	324,64	141,98
May	185,19	365,92	33,74	215,63	437,35	31,99	149,32	284,80	34,14
June	57,82	133,15	0,19	92,62	233,92	0,00	75,43	183,59	0,00
July	82,86	224,02	0,00	92,56	266,09	0,00	78,27	224,84	0,00
August	36,93	160,93	0,00	14,06	62,34	0,00	9,42	38,19	0,00
September	64,23	243,41	0,00	56,86	235,81	0,00	66,20	256,22	0,00
October	481,15	962,21	80,16	537,77	1038,43	114,20	508,39	1118,06	24,94
November	666,63	1031,76	334,40	697,71	1066,97	360,61	680,96	989,04	395,92
December	498,52	705,61	305,68	548,03	840,50	281,24	482,40	671,82	305,32

b. Soil Erodibility Factor (K)

Upstream area of Sempor Reservoir was dominated by two types of soil, i.e. Podsolik soil and Latosol soil. Digital map and the percentage and erodibility factors of both types of soil can be seen in figure 2 and Table 8 below:

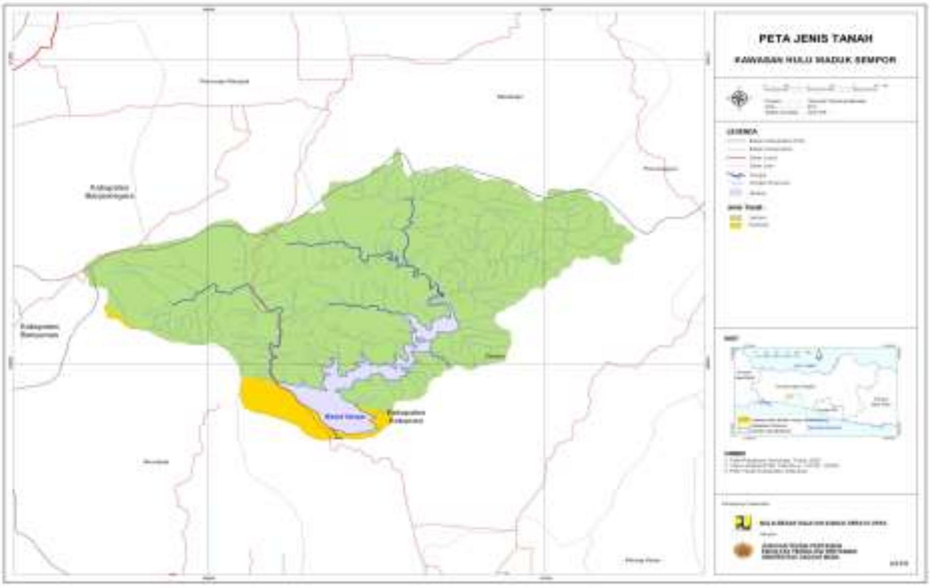

Figure 2. Soil type digital map

Table 6. Soil erodibility factor in water catchment area of Sempor reservoir

Type of soil	Soil erodibility factor (K)	Area (Ha)	Persentage (%)
Podsolik	0,40	180,29	4,33
Latosol	0,36	3980,22	95,67
Total Land Area		4160,51	100,00

c. Topographic Factor (LS)

The potential of erosion will increase in line with the increase in surface slope and the length of the slope (more runoff causes greater depth of surface flow, and therefore the velocity becomes higher).

Based on the slope digital map (Figure 3), water catchment area of Sempor reservoir has three slope range, and LS factor for each slope range can be seen in Table 9 below:

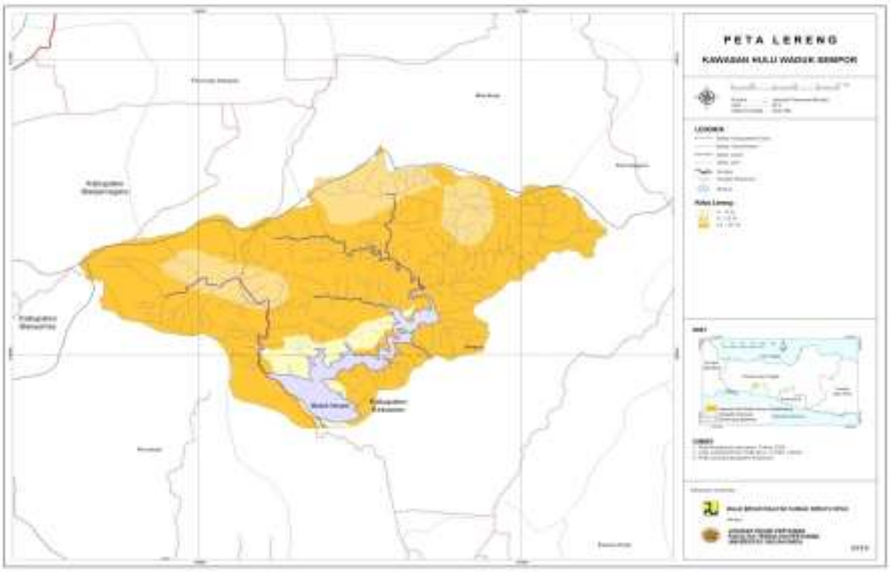

Figure 3. Slope digital map

Table 7. Slope steepness and length factor in water catchment area of Sempor reservoir

Slope range	LS factor	Area (Ha)	Persentage (%)
0-8 %	0,4	216,66	5,21
8-15 %	1,4	723,14	17,38
15-25 %	3,1	3220,70	77,41
Total Land Area		4160,51	100

d. Land Cover and Supporting Conservation Practice Factor (CP)

Based on the land use digital map (Figure 4), water catchment area of Sempor reservoir has eight land use types, and CP factor for each land use type can be seen in Table 10 below:

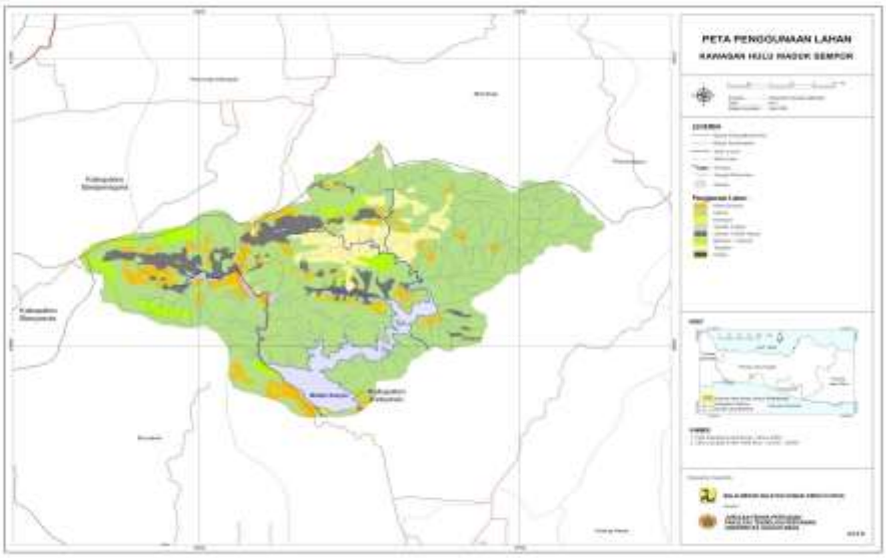

Figure 4. Land use digital map

Table 8. CP factor for each land use type in water catchment area of Sempor reservoir

Land use type	CP value	Area (Ha)	Persentage (%)
Shrubbery	0,1	152,86	3,67
Forest	0,01	0,50	0,01
Farm	0,02	3082,62	74,09
Settlement	0,2	276,58	6,65
Grass	0,02	11,16	0,27
Irrigated rice fields	0,02	27,51	0,66
Rainfed rice fields	0,02	299,00	7,19
Moor	0,28	310,28	7,46
Total Land Area		4160,51	100

e. Overlay Analysis

After the calculation of each parameter required to examine the soil erosion, the overlay method has been used in GIS to find out average annual soil loss. There are 183 land units with various characteristics produced through overlaying analysis. As an example, the following table shows five land units produced by overlaying analysis with arc view GIS application.

Table 9. Land units in water catchment area of Sempor reservoir

Land Unit	Area (Ha)	Name of Station	Soil Type	Slope	Land Use Type
1	8,89	Sampang	Podsolic	15 - 25 %	Farm
2	39,81	Sampang	Latosol	8 - 15 %	Rainfed rice fields
3	25,87	Kedung Wringin	Latosol	15 - 25 %	Shrubbery
4	202,27	Kedung Wringin	Latosol	15 - 25 %	Moor
5	37,49	Sempor	Podsolic	15 - 25 %	Settlement

The erosion rate in upstream of Sempor reservoir can be calculated using all of 183 land units above. The average of erosion rate in water catchment area of Sempor reservoir can be seen in Table 12 below.

Table 10. Erosion rate in actual condition in upstream of Sempor reservoir

Kondisi Aktual (*existing condition*)							
No	Bulan	Rainfall (average)		Rainfall (average+StDev)		Rainfall (average-StDev)	
		Erosion (ton/ha)	Erosion (mm)	Erosion (ton/ha)	Erosion (mm)	Erosion (ton/ha)	Erosion (mm)
1	January	30,95	1,72	47,24	2,62	16,09	0,89
2	February	27,95	1,55	41,98	2,33	15,08	0,84
3	March	28,26	1,57	37,85	2,1	19,22	1,07
4	April	17,85	0,99	26,75	1,49	9,68	0,54
5	May	11,01	0,61	22,06	1,23	1,81	0,1
6	June	4,4	0,24	10,83	0,60	0	0
7	July	4,86	0,27	13,72	0,76	0	0
8	August	1,17	0,06	5,1	0,28	0	0
9	September	3,32	0,18	13,27	0,74	0	0
10	October	28,53	1,58	56,41	3,13	5,22	0,29
11	November	37,9	2,11	57,9	3,22	19,64	1,09
12	December	29,03	1,61	43,1	2,39	16,11	0,89
Annual Erosion		**225,24**	**12,51**	**376,23**	**20,90**	**102,85**	**5,71**
Erosion Risk Level		**Heavy**		**Heavy**		**Moderate**	
**) weight of soil mass = 1,8 ton/m*^{3}							

The result of average annual soil loss represents that, totally 4160.51 Ha area (upstream of Sempor reservoir) comes under very heavy category. This condition was caused by decreasing the area of forest (land conversion) in upstream of Sempor reservoir.

Total of forest area was only about 0,01% certainly bring a negative impact to the environment. Land areas covered by plant biomass, living or dead, are more protected and experience relatively little soil erosion because raindrop is dissipated by the biomass layer and the topsoil is held by the biomass (Agriculture California, 2002; SWAG, 2002). For example, in Utah and Montana, as the amount of ground cover decreased from 100% to less than 1%, erosion rates increased approximately 200 times (Trimble and Mendel, 1995).In forested areas, a minimum of 60% forest cover is necessary to prevent serious soil erosion and landslides (Singh and Kaur, 1989; Haigh et al., 1995; Forest Conservation Act, 2002). The extensive removal of forest for crops and pastures is followed by extensive soil erosion.

In another case, 74,09 % farming area was also a reason why the erosion rate in upstream of Sempor reservoir was very high. Agricultural fields commonly experience more erosion than forests mainly due to a lack of ground cover and greater amounts of exposed mineral soil. Additionally, agricultural soils tend to be more compacted than forest soils because of farm machinery traffic. Compaction collapses macropores and results in lower infiltration rates, more runoff, and greater erosion. Further, tillage (i.e., disturbing the topsoil to prepare a seed bed and provide weed control) can reduce surface residues, soil macroporosity, and aggregrate stability, thereby increasing erosion potential. Reduced tillage or no-till can help reduce erosion rates by allowing more surface residue and macropores to develop through increased soil biological activity. Since the surface of agricultural fields is irregular and has microtopography, the area is commonly drained by concentrated overland flow and rills (Pankau et al. 2012).

Onclusion

As sediment is the most common water pollutant worldwide, it is important to understand the dominant factors influencing erosion rates to help minimize sediment delivery to surface water bodies and protect aquatic biota. In humid climates, precipitation intensity, soil moisture, slope steepness, slope length, vegetation, and soil organisms interact to determine a watershed’s vulnerability to erosion. The area with smaller land cover obviously showed the higher risk of soil erosion than the larger land cover did. Land managers and owners can limit erosion by following two simple tenants: 1) maintain as much ground cover as possible during land management activities (farming, timber harvesting) and 2) rapidly establish ground cover following periods of active land management. Practicing these two rules will provide low-cost, effective, and long-term erosion control that will help keep working landscapes productive.

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