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TOWARD A FULLY AND ABSOLUTELY RASTER-BASED EROSION MODELING BY USING RS AND GIS*)

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ABSTRACT

The erosion map data is one of important data used in planning conservation of degraded land. Generally, erosion data is predicted using a model because to gain actual erosion requires much resource (timely, costly and labour intensive). USLE (Universal Soil Loss Equation) is one of existing erosion models applied worlwide, including Indonesia. Nevertheless, erosion analysis conducted is based on analysis using vector-based maps. This method involves simplification, either algorithms or procedures, and subject to subjectivity, so the result has high uncertainty. This article deals with the idea to build a fully raster-based erosion modeling. Steps required to obtain raster-based data was highlighted as from the beginning up to the model validation to get an absolute model. The integration of remote sensing and GIS was inevitably used for the analysis.

Keywords: erosion modeling, fully raster-based, remote sensing, GIS

INTRODUCTION

Degraded land is one of environmental problems that must be quickly overcome. Indication of the occurrence of land degradation can be disclosed by investigating watershed condition. In Indonesia, the number of critical (*highly eroded*) watershed has been increasing. In 1984 there were 22 watersheds in critical condition, increasing to 29 in 1992, 39 in 1994, 42 in 1998, 58 in 2000, 60 in 2002, 65 in 2004 and 72 in 2007 [*Utomo,* 1989; *Kartodihardjo,* 2008]. Planning to conserve degraded land requires good and accurate data, one of them is the erosion map.

Generally, erosion data is predicted using a model because to gain actual erosion requires much resource (timely, costly and labour intensive). USLE is one of existing erosion model applied worlwide, including Indonesia. Nevertheless, erosion analysis conducted is based on analysis by using vector-based maps. This method involves simplification, either algorithms or procedures, and subject to subjectivity, so the result has high uncertainty [*Eweg et al,* 1998]. For example, slope data when used to compute erosion caused high *margin error*, i.e. ca. 70 % (for *slope* < 9 %) and ca. 25 % (for *slope* > 9 %), while rainfall data caused error ca. 52 %.

With the technological advance in *Remote Sensing* (*RS*) and GIS the uncertainty can be minimized, that is by applying a fully raster-based erosion modeling. This is in line with a statement from a previous study [*Fistikoglu and Harmancioglu,* 2002] reading that erosion modeling estimated by using USLE will be more reliable when the analysis is conducted using small raster-based data. because initially USLE was developed at small area.Raster-based erosion modeling can be applied objectively (using established algorithms and mathematical formulae) without requiring simplification. By using GIS technology, slope data can be analyzed more accurately and faster by utilizing *Digital Elevation Model*. By using remotely sensed data C Factor can be derived through the analysis of vegetation index.

USLE is applied worldwide because this model is easily managed and relatively simple. It also requires relatively less amount of input or parameters than the other more complex erosion modelings do. In Indonesia, its application started in 1972 by Soil Research Agency in Bogor [*Guluda,* 1996], meanwhile Department (Ministry as of 2009) of Forestry has applied USLE, which has been adopted nationalwide [*Departemen Kehutanan*, 1998], to assess degraded land. Morgan and Nearing have proven that USLE has higher accuracy than RUSLE (*Revised USLE*) does and has more complex model of WEPP (*Water Erosion Prediction Project*) [*Wainwright and Mulligan,* 2002]. USLE erosion modeling is predicted to use equation as follows [*Wischmeier and Smith*, 1978] :

$A = R\,K\,L\,S\,C\,P$ .... (1)

where A: mean annual soil erosion rate (ton/hectare/year), R: rainfall erosivity factor (*R* factor) (*MJ mm/ha/h/year)*, *K*: soil erodability factor (*K* factor) (t*on hectare/MJ/mm*), *LS*: slope length and steepness factor (*LS factor*) (dimensionless), *C*: cover and management factor (*C facto*r) (dimensionless), *P*: support practice factor (P factor) (dimensionless).

To determine whether land is degraded or not, a guideline has been published through the decree No. 041/Kpts/V/1998 dated 21 April 1998 issued by Directorate General of Reboisation and Land Rehabilitation, under Indonesia's Department of Forestry. The determination of the degree of degraded land is started by calculating erosion using USLE. All input data are vector-based thematic maps. For application to GIS environment, maps depicting factors R, K, L, S, C and P are digitized and edited.

There are some reasons for fully raster-based erosion modeling to be applied :

1. Analysis of vector-based erosion modeling is done qualitatively and subjectively through the simplification of algorithms and procedures that leads to high *uncertainty* [*Eweg et al.,* 1998].
2. Erosion estimated by using USLE will be more reliable when its analysis adopts small raster because initially USLE was developed in small areas [*Fistikoglu and Harmancioglu,* 2002].
3. Analysis of raster-based erosion modeling is conducted more objectively based on a clearly quantitative algorithm [*Aronoff*, 1989], [*Hadmoko*, 2007).
4. The role of photographically, remotely-sensed data (as one input for vector-based erosion modeling) has been replaced by that of digitally raster-based remotely-sensed data.
5. With the advance in GIS technology, LS factor can be derived from DEM analysis which is already in raster format. Using DEM the variation in shape and its slope angle can be known better [*Evans,* 2002]. *[Mathier et al* 1989] also identifies that slope gradient and its length are important variables controling the study of erosion.
6. Philosophically, a model should be revised when there is a new technological finding that makes revision is possible [*Turban and Aronson,* 1998], in this case, vector-based erosion modeling to become raster-based erosion modeling by using RS and GIS techniques.

A fully raster-based erosion modeling is an erosion modeling using data input that are all in raster format, not in the one as a result of *Vector to Raster Conversion* algorithm. From 5 (or 6, if LS factor is assumed to be L factor and S factor) parameters, LS, C and P are factors that can serve directly as data input using raster format, while R and K factors can have raster format through spatial interpolation available at almost all GIS software. Spatial interpolation is a process of using points with known values to estimate values at other points [*Chang*, 2008]. By using spatial interpolation one can convert point/location data (eg. rainfall station; location of soil sampling used to generate soil erodibility or bulk density) to areal data with raster format.

Some improvement may be made when applying a fully raster-based erosion modeling compared to those vector-based erosion modeling as presented in Table 1.

The research aims to analyze a fully raster-based erosion modeling by using RS and GIS (The Case in Merawu Watershed, Banjarnegara, Central Java).

Geographically, the research area is located at Merawu watershed lying between 109°41'24" – 110°50'24" E and 7°10'12" – 7°22'12" S, administratively located in Banjarnegara district, Central Java Province. Merawu watershed covers ca. 22,734 hectars with three main rivers flowing through the area from north to south, those are : Merawu, Urang and Penaraban rivers. Among the watersheds in the area, Merawu watershed has detached the most of sediment yield to Sudirman Reservoir (11 mm/year). Sudirman Reservoir is one source for electrical power in Central Java. See Fig. 1.

Table 1. Some improvement when applying a fully raster-based erosion modeling compared to those vector-based erosion modeling

No	Item Evaluated	Weakness of vector-based	Improvements when applying a fully raster-based
1	Data Format	Vector	Raster
2	Land unit Elimination for area < 1 cm^2	Required	Not Required
3	in creating Map of R (rain erosivity), after each rainfall stasion is calculated its R	No clear explanation in the way how much interval of interpolation have to be determined	Applying Spatial Interpolation technique
4	Slope Analysis	Interpreted and produced manually by using contour lines information of topographical map	Interpreted and produced digitally by using DEM Analysis
5	Slope Classification	0 – 3 %, 3 – 8 %, 8 – 15 %, 15 – 25 %, 25 – 40 % and > 40 %	Slope Classification is not required, directly use the result of DEM Analysis

6	Measurment of L factor	based on an assumtion of the existing drainage density, and then by taking slope class into consideration, simplification is made	L is directly computed based on *Flow Direction* derived from DEM Analysis
7	Determination of L factor	Simplified according to Slope classification	Directly computed using available algorithm
8	Determination of LS factor	Simplified according to Slope classification	Directly computed using available algorithm
9	Creation of K factor map	Based on landform or soil map. One unit be assigned one value	Applying Spatial Interpolation technique. One pixel automatically assigned one value
10	Determination of C factor	Based on the existing value in table (although originated from different location). No Validation required	Apply modeling by correlating various vegetation indices derived from remotely-sensed data to the field data. Validation required
11	Determination of P factor	Based on the existing value in table (although originated from different location).	Based on DEM Analysis combined with land cover data derived from remotely-sensed data.

Source: Result of Analysis, 2010

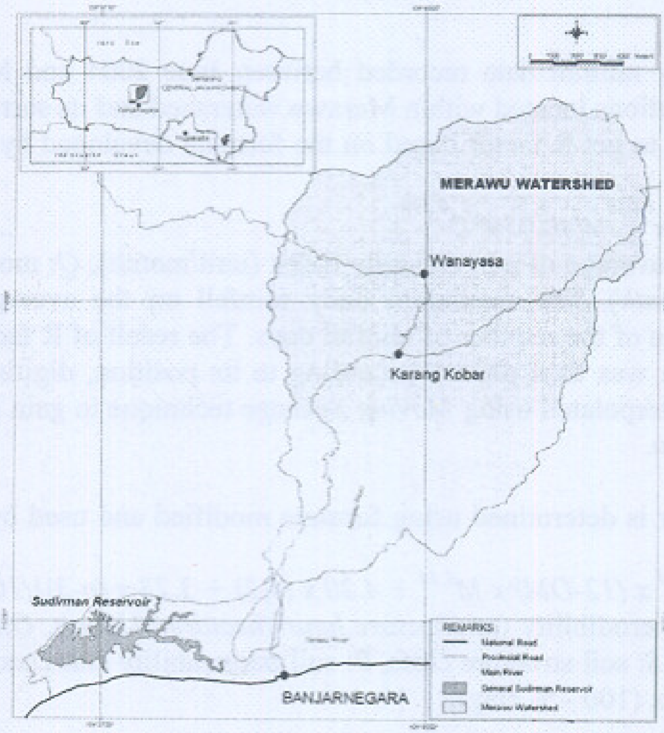


Figure 1. Location of the Study

THE METHODS

Data required for fully raster-based erosion modeling are: topographical map; landform map, monthly data/report on sediment yield at watershed outlet during 24 months (June 2004 till May 2006), remotely-sensed data of Landsat 7 ETM^+ recorded on 21 May 2003 and on 20 June 2006, rainfall data during 24 months (June 2004 till May 2006) recorded at Merawu Watershed and its surroundings, other data and reports which support the activity. To analyse and handle these data various types of GIS Software were used : *ILWIS* (*Integrated Land and Water Information System*) version 3.4, Arc/Info version 3.5, Arc/View version 3.5. Meanwhile, some hardwares are also required such as Laptop and PC/Window computer, digitizing tablet, laboratorium/office equipment consisting of : drafting tablet, equipments used for field work such as: binoculars, compass, hagameter, soil munsell color, tape, ring sample, auger, *Global Positioning System* (GPS), digital camera, and others that support the activity.

Methods were applied by analysing factors affecting erosion in GIS environment using the fully raster-based format. The pixel size for the study was 30 m by 30 m to account for the spatial resolution of Landsat 7 ETM^+ which was 30 m by 30 m.

Monthly rainfall data recorded between June 2004 and May 2006 (from eight rainfall stations located within Merawu watershed and its surrounding area) were computed to get R factor based on the formula developed by [*Abdurachman*, 1989] as :

$$R = (Q^{2.263} * Pm^{0.678})/(40.056*D^{0.349}) \quad \text{...................... (2)}$$

Where *R* is the average of rain erosivity index (unit/month), *Q*: monthly average of rainfall (*cm/month*), *Pm*: maximum daily rainfall on the average (cm) and D: monthly average of the number of rainfall days. The result of R factor computation for each station was then plotted according to its position, digitised, transformed and spatially interpolated using *Moving Average* technique to gain Map of R Factor of the study area.

K factor is determined using formula modified and used by Department of Forestry as :

$$K = \{2.17 \times 10^{-4} \times (12\text{-}OM) \times M^{1.14} + 4.20 \times (s\text{-}2) + 3.23 \times (p\text{-}3)\}/100 \quad \text{...............(3)}$$

where *K* is soil erodibility (*ton.hectare.hour/(hectare.MJ.mm*), *OM*: percentage of organic matter, *S*: soil structure class, P: soil permeability class and M: (% silt + % very fine sand) x (100 - % clay).

Thirty soil samples, distributed evenly according to the landform, were taken in the field. The result of computation for each sample was then plotted according to its position, digitised, transformed and spatially interpolated using *Kriging* technique to gain Map of K Factor of the study area.

S Factor derives directly from DEM which L Factor can also derives from by taking flow direction from each pixel into consideration. Slope distance for each pixel is 30 meters long for flow direction to the South, West, North and East, and 42.43 meters long for flow direction to Southeast, Southwest, Northwest and Northeast.

LS Factor for slope < 22 % is computed using simplified formula of Wischmeier and Smith :

$LS = \sqrt{(L_a) \times (1.38 + 0.965\, s + 0.138\, s^2)/100}$ ....(4)

while for slope ≥ 22 % it is computed using the formula of Gregory :

$LS = (L_a/2.21)^{0.5} \times 34.7046 \times Cos\,(s_d)^{1.503} \times \{0.5 \times Sin\,(s_d)^{1.249} + Sin\,(s_d)^{2.249}\}$ ......(5)

where L_a *is actual slope length (in meters), s: slope (in %/100) and* s_d *: slope (in degree).*

C Factor derived from the regression analysis using equation [*Kazmier,* 1995] as

$Y = a + b\,X$ ....(6)

where Y is C Factor measured directly on the field, X: various vegetation indices of Landsat 7 ETM^+ (recorded on 20 June 2006), a: is intercept and b: slope direction of the regression line.

The C factor was estimated in the field (C_f) using prior land use (PLU), canopy cover assessed for different cover types (CC), and surface cover (SC) following the method explained for RUSLE [*Renard et al.*, 1997] in: [*Suriyaprasit,* 2008] as follows:

C_f = SC CC PLU SR ....(7)

Vegetation Index is a mathematical combination of satellite bands, which have been found to be sensitive indicators of the presence and condition of green vegetation. It is based on the reflectance properties of vegetation in comparison with water on the one hand and bare soil on the other hand. Vegetated areas have high reflectance in the near infrared and low reflectance in the visible red [*Lillesand and Kiefer,* 2004].

In this study, 11 (eleven) vegetation indices were used, those are :

Normalized Difference Vegetation Index :

$NDVI = (IMD-M)/(IMD+M)$ ....(8)

Ratio Vegetation Index :

$RVI = IMD/M$ ....(9)

Soil Adjusted Vegetation Index :

$SAVI = (IMD-M)*(1+0.5)/(IMD+M+0.5)$ ....(10)

Transformed Soil Adjusted Vegetation Index :

$TSAVI = 1.05(IMD-1.05M-0.044) / (1.05IMD+M+1.05*0.044+0.08(1+1.05^2)$...(11)

Modified Soil Adjusted Vegetation Index :

$MSAVI = IMD+0.5-Sqrt((IMD+0.5)^2-2(IMD-M))$ ....(12)

Perpendicular Vegetation Index :

$PVI = (IMD-1.05M-0.044)/Sqrt(1.05^2+1)$ ....(13)

Transformed Vegetation Index :

$TVI = Sqrt(((IMD-M)/(IMD+M))+0.5)$ ....(14)

Atmospherically Resistance Vegetation Index :

$ARVI = (IMD-B)/(IMD+B)$ ....(15)

Enhanced Vegetation Index :

$EVI = 2.5(IMD-M)/(1+IMD+6M+7.5B)$ ....(16)

Vegetation Index Faster:

$VIF = (IMD)/((M)+(IMD))$ ....(17)

Difference Vegetation Index :

$DVI = 2.4*((IMD)-(M))$ ....(18)

where IMD, M and B indicate channel or band of Landsat 7 ETM^+ which are near infrared, visible red and blue respectively.

From the regression analysis some statistical tests should be conducted, such as linierity test, coefficient of correlation and regression test. In this study, a threshold of the correlation coefficient value of $\geq$ 0.80 ($r \geq 0.80$) is chosen for criteria to decide which vegetation indices that sould be chosen to determine the final C factor.

Landcover change analysis is done using two satellites, Landsat 7 ETM^+ (recorded on 20 June 2006 and 21 May 2003) to know the rate of changes to justify the correction factor used for computing monthly C factor for 24 months in line with the months of rain erosivity.

P Factor was derived from the combination between slope data from DEM and landcover classification interpreted from Landsat 7 ETM^+ using criteria developed by [*Abdurachman* ,1985] as showed in Table 2.

Table 2. P Factor value based on Abdurachman

No.	Landcover	P Factor
1	Agricultural Area with Slope ≤ 8 %	0.50
2	Agricultural Area with Slope between ≥ 8 % and 20 %	0.75
3	Agricultural Area with Slope ≥ 20 %	0.90
4	Shrub, Secondary Forest and Forested Area	1.00

Sources: [*Abdurachman et al, 1985*]

Another analysis supporting the research activity was the creation of Map of Bulk Density which was generated through plotting bulk density data according to its position, digitised, transformed and spatially interpolated using *Kriging* technique. Map of Bulk Density is used to convert erosion unit as from ton/hectare/month to mm/month [*Arsyad,* 2000].

After the whole data were analysed, then erosion can be calculated. The result of erosion using USLE was assumed only to gain *sheet* and *rill erosion.* To get total erosion in a watershed (*gross erosion*), other erosions such as gulley erosion and channel erosion were determined according to the result of previous researches done by [*Piestet al.,* 1975 and *Seyhan*, 1976] stating that gulley erosion is one-fifth (1/5) of the total sediment that occured, while channel erosion is about 10 % of sheet and rill erosion.

A fully raster-based erosion modeling is a new model which requires model validation. The comparison of erosion as a result of modeling (E_{model}) and actual erosion (E_{actual}) can be made by using statistical analysis (ANAVA or Correlation Analysis) or direct comparison (substracted E_{model} from E_{actual}). A threshold value of ≥ 0.8 or ≥ 80 % is chosen to determine whether or not a model is accepted or refused. Actual erosion data for this study were suplied by PT Indonesia Power which regularly monitors sediment yield at outlet of Merawu watershed.

Diagrametrically, a fully raster-based erosion modeling is presented in Fig. 2.

RESULTS AND DISCUSSIONS

The Result of Map of R Factor

Eight rainfall stations located within Merawu watershed and its surroundings were used for the study to compute R Factor as presented in Table 3. To map R factor in raster format needs spatial interpolation using *Moving Average* technique. A better spatial interpolation technique, such as *Kriging* was not possible to apply because of the limited number of rainfall stations available. Spatial interpolation using *Moving Average* can be done after plotting R factor for each rainfall station according to its position, then digitised and transformed. Example of the pattern of some R factors are showed in Fig. 3.

The Result of Map of K Factor and Map of Bulk Density

To map K factor in a raster format needs spatial interpolation using *Kriging* technique. This step can be taken after plotting 30 K factor data for each sample location according to its position, then the data are digitised and transformed.

Meanwhile, to apply spatial interpolation using *Kriging* technique requires information about sill, nugget and range values that can be obtained by executing spatial correlation analysis. Choosing different sill, nugget and range values will result different maps. The best sill, nugget and range values can be gained merely after some trial and error by investigating every resulted map. After some trial and error, finally to map K Factor the values of 0.000, 0.013, and 8.000 were chosen as sill, nugget and range. The result of Map of K Factor is demonstrated in Fig. 4.

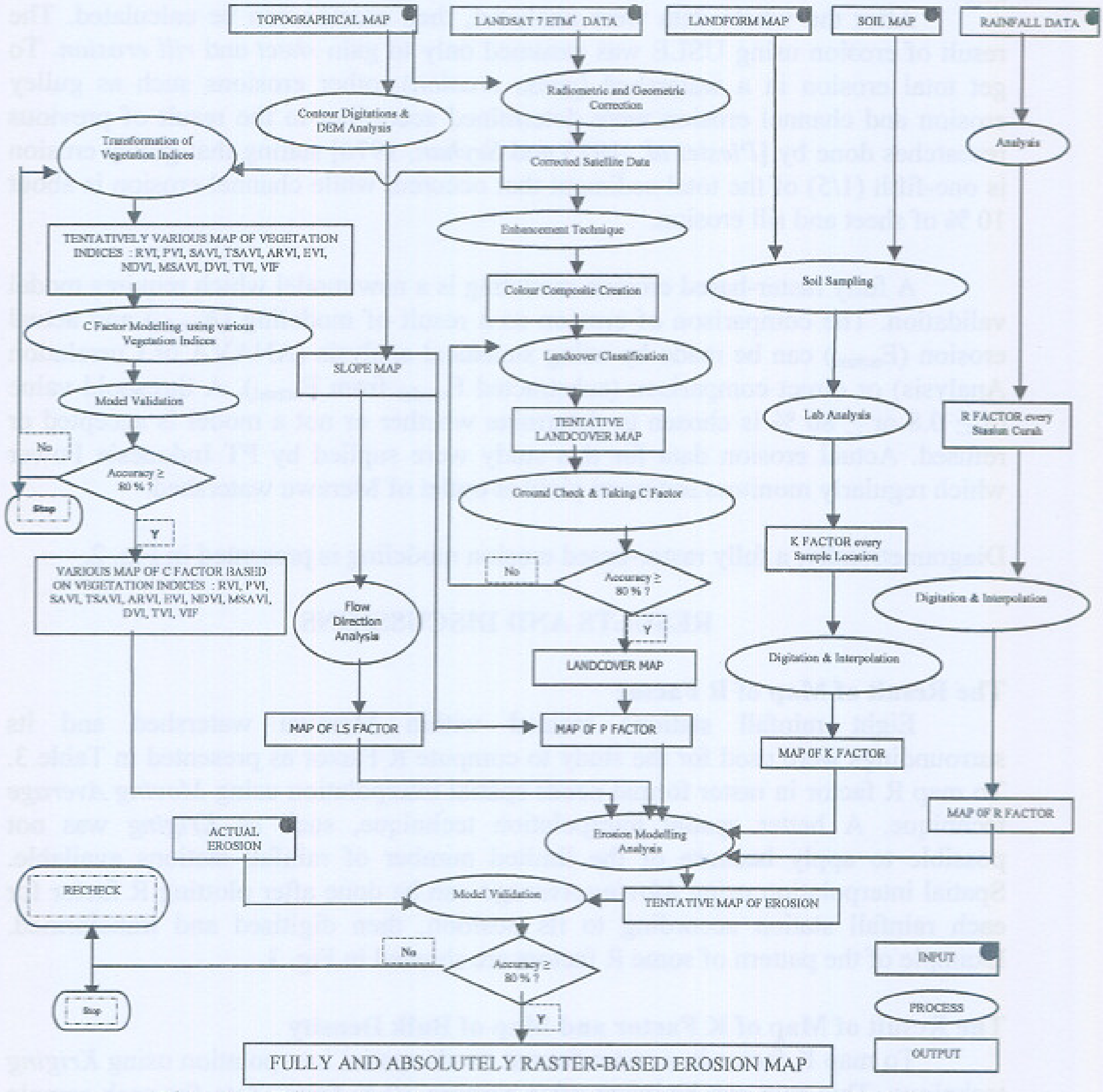


Figure 2. Diagram showing a fully raster-based erosion modeling

Remarks :

RVI: Ratio Vegetation Index, PVI: Perpendicular Vegetation Index, SAVI: Soil Adjusted Vegetation Index, TSAVI : Transformed Soil Adjusted Vegetation Index, ARVI: Atmosphere Resistance Vegetation Index, EVI: Enhanched Vegetation Index, DVI: Difference Vegetation Index, TVI: Transformed Vegetation Index, VIF: Vegetation Index Faster

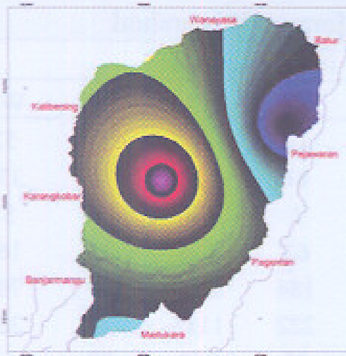
Table 3. Rain Erosivity at Merawu Watershed

No.	Month	Rainfall station :							
		BN	CL	GA	KR	LI	PE	WA	PA
1	May-06	21	44	46	12	16	9	52	16
2	Apr-06	410	396	132	81	159	2	374	4
3	Mar-06	65	54	13	1	40	1	51	429
4	Feb-06	868	205	35	62	136	31	164	2803
5	Jan-06	527	809	95	184	298	10	747	844
6	Dec-05	436	1082	428	222	1185	22	282	1922
7	Nov-05	53	323	128	35	235	28	41	198
8	Oct-05	33	197	78	26	414	0	104	308
9	Sep-05	19	60	10	1	41	0	12	0
10	Aug-05	25	41	1	0	25	0	26	0
11	Jul-05	13	8	6	3	379	0	8	0
12	Jun-05	46	15	19	44	414	0	41	2
13	May-05	3	118	51	6	158	1	5	30
14	Apr-05	220	52	204	3	117	4	211	106
15	Mar-05	142	114	127	59	758	4	44	51
16	Feb-05	201	56	252	14	544	3	31	90
17	Jan-05	310	209	322	4	67	28	154	364
18	Dec-04	956	989	209	1009	249	338	431	411
19	Nov-04	443	323	213	240	1198	11	361	8
20	Oct-04	0	5	1	13	4	0	2	0
21	Sep-04	0	0	5	3	1	0	0	0
22	Aug-04	0	0	0	0	0	0	0	0
23	Jul-04	10	5	1	0	6	0	6	0
24	Jun-04	6	0	0	0	44	0	0	10

Source: Result of Analysis, (2010)

Remarks:
BN : Banjarnegara, CL: Clangap, GA: Garung, KR: Karangkobar, LI: Limbangan, PE: Pejawaran, WA: Wanadadi, and PA: Paninggaran.

Mapping the distribution of bulk density is similar to mapping soil erodibility. After some trial and error, finally to map bulk density the values of 0.025, 0.150 and 8.500 were chosen as sill, nugget and range. The resulted map of bulk density is illustrated in Fig. 5.



a. Map of R Factor, Oct 2004

b. Map of R Factor, April 2005

c. Map of R Factor, August 2005

d. Map of R Factor, April 2006

Figure 3.The Pattern

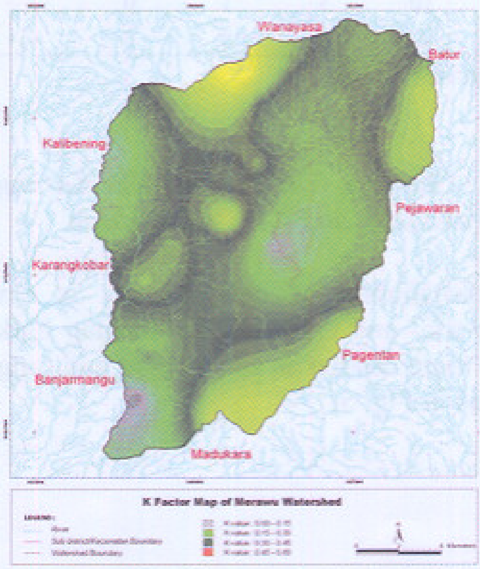


Figure 4. Map of K factor of Merawu Watershed

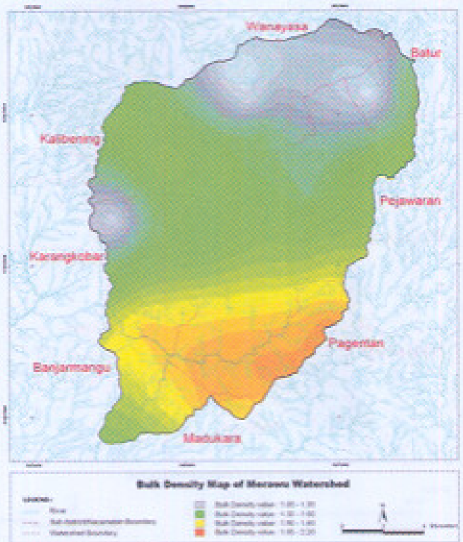


Figure 5. Map of Bulk Density of Merawu Watershed

Globally, Merawu watershed has average soil erodibility of 0.29 (minimum : 0.08 and maximum : 0.54), while their average bulk density is 1.60 (minimum : 1.03 and maximum 2.16).

The Result of Map of LS Factor

Contour interpolation at Merawu watershed resulted from DEM that can generate slope data (S) and flow direction (also means : slope distance for each pixel) in which LS Factor then can be computed using available formulae. The result of LS Factor is presented in Table 4, while its distribution is in Fig. 6. From Table 4 it can be inferred that Merawu watershed has only limited plain area (< 8 %) of about 3,690 hectares (16.2 %), while the rest are undulating, hilly, and even steep areas.

Table 4. Merawu watershed according to its LS Factor

No	LS Factor	Area (Ha)	Area (%)
1	< 20	16,465	72.4
2	20 ≤ LS < 40	3,437	15.1
3	40 ≤ LS < 60	1,680	7.4
4	60 ≤ LS ≤ 80	1,150	5.1
	Total	22.734	100,0

Source : Result of Analysis (2010)

From Table 4 it can be inferred that Merawu watershed is dominated by LS Factor < 20, covering area 16,465 hectares (72.4 %), while the rest is area having LS Factor ≥ 20 covering 6,267 hectares (17.6 %).

Figure 6. Map of LS Factor of Merawu Watershed

The Result of Map of C Factor

Linierly regression analysis was done between C Factor directly measured in the field and the value from various vegetation indices derived from Landsat 7 ETM^{+}. This technique has ever been done by other researcher using only NDVI, some of them are [*De Jong,* 1994; *Lin et al.,* 2002 and *Karaburun,* 2010]. Regression analysis for each vegetation index, coeficient value (a and b), coeficient of correlation (r) and its *standard error* (s) is presented in Table 5.

Table 5. Regression analysis for each vegetation index

No.	Vegetation Index	Linierly regression Model : Y = a + b X				
		a	b	s	r	Remarks
1	MSAVI	0.83	-0.94	0.07	0.82	High
2	TVI	1.82	-1.61	0.07	0.81	High
3	VIF	1.37	-1.55	0.08	0.80	High
4	NDVI	0.60	-0.77	0.08	0.80	High
5	TSAVI	0.58	-0.75	0.08	0.80	High
6	SAVI	0.60	-0.51	0.08	0.80	High
7	ARVI	0.77	-0.91	0.09	0.72	Moderate
8	EVI	0.36	-0.43	0.09	0.70	Moderate
9	RVI	0.35	-0.05	0.10	0.66	Moderate
10	PVI	0.30	-224.36	0.11	0.43	Low
11	DVI	0.29	-62.94	0.11	0.42	Low

Source : Result of Analysis (2010)

Note :

Y = *Estimated C Faktor*

X = *Vegetation Index*

It can be inferred from Table 5 that of 11 vegetation indices under studied, only six (MSAVI, TVI, VIF, NDVI, TSAVI and SAVI) have *high* correlation ($r \geq 0.80$) with C Factor measured directly on the field. These six vegetation indices were used for further erosion analysis, while the rest are left. The area of C Factor can be seen in Table 6, while its distribution is presented in Fig. 7.

From Table 6 it can be concluded that the area of each interval class of C Factor is different depending on vegetation index used. It is also true for their distribution, though it is very difficult to clearly differentiate among them due to the limited scale. The maps show that Batur district is dominated by high C Factor indicating that the area is fully used for intensive agricultural activities. High C Factor also sporadically occurs in all areas.

Table 6. The area of C Factor at Merawu watershed (in hectares)

No.	Vegetation Index	Interval class of C Factor					Total
		0 - 0.1	0.1 - 0.2	0.2 - 0.3	0.3 - 0.4	0.4 - 1.0	
1	MSAVI	13,487	5,466	2,009	945	825	22,731,48
2	NDVI	12,986	5,804	2,291	1,116	535	22,731,48
3	SAVI	12,927	5,862	2,291	1,120	531	22,731,48
4	TSAVI	12,950	5,844	2,281	1,111	545	22,731,48
5	TVI	13,210	5,575	2,212	1,051	684	22,731,48
6	VIF	12,957	5,728	2,384	1,117	545	22,731,48

Source : Result of Analysis (2010)

a. Map of C Factor derived from MSAVI

b. Map of C Factor derived from TVI

c. Map of C Factor derived from VIF

d. Map of C Factor derived from NDVI

e. Map of C Factor derived from TSAVI

f. Map of C Factor derived from SAVI

Figure 6. Map of LS Factor of Merawu Watershed

As a whole, vegetation indices using more complicated formulae resulted in higher correlation coefficient. From six vegetation indices resulting $r \geq 0.80$, vegetation indices considering soil background tend to result higher coefficient of correlation (MSAVI and TSAVI, except SAVI) compared to those vegetation indices which are not considering soil background. On the other hand, vegetation indices using blue channel (ARVI and EVI) resulted lower coefficient of correlation. Blue channel of Landsat 7 ETM^+ usually used for study related to water and not used for study related to vegetation index which are best when using infrared and red channel [*Lillesand et al.,* 2004].

To interpolate C Factor every month in accordance with the months used in computing R factor, landcover change analysis was done. This analysis used by overlaying NDVI recorded on 20 June 2006 on NDVI recorded on 21 May 2003. The result is in the form of table as presented in Table 7.

Table 7. The Result of Change Analysis between NDVI 2003 and NDVI 2006

NDVI 2003	NDVI 2006: Water	0.06 - 0.15	≥ 0.15 - 0.25	≥ 0.25 - 0.35	≥ 0.35 - 0.45	≥ 0.45 - 0.55	≥ 0.55 - 1.00	Σ_{Row}
Water	536	27						563
0.06 - 0.15	81	1,171	3					1,255
≥ 0.15 0.25		614	2,487					3,101
≥ 0.25 - 0.35			1,903	3,127				5,030
≥ 0.35 - 0.45				4,176	3,664			7,840
≥ 0.45 - 0.55					8,003	4,738		12,741
≥ 0.55 - 1.00						18,818	203,224	222,042
C_{olumn}	617	1,812	4,393	7,303	11,667	23,556	203,224	252,572

Source : Result of Analysis (2010)

From Table 7 it can be inferred that the total number of unchange pixel is 218,947 (86.69 %). This means that the change pixel is 13.31 % during 36 months, or it can be concluded that the rate of change is 0.3698 % / month. This value is used for interpolating monthly C Factor between May 2006 and June 2004.

The Result of Map of P Factor

Generally, for the shake of ease and practicality, P Factor is assigned value as 1 for the whole area under studied. In this research P Factor is derived from the combination between slope data from DEM and landcover classification interpreted from Landsat 7 ETM$^+$ using criteria developed by [*Abdurachman,* 1985] as in Table 2. The result is presented in Table 8, while its distribution is in Fig 8.

Table 6. The area of P Factor at Merawu watershed (in hectares)

No	Landcover	Area (Ha)	Area (%)
1	Non Agricultural Area with P Factor = 1	7,548	33.2
2	Agricultural Area with P Factor < 1	15,186	66.8
	J u m l a h	22.734	100,0

Source : Result of Analysis (2010)

From Table 8 it can be concluded that Merawu watershed is dominated by agricultural area with P Factor < 1 covering 15,186 hectares (66.8 %), while the rest is non agricultural area with P Factor = 1, covering 7,548 hectares (33.2 %).

The Result of a Fully Raster-Based Erosion Modeling

Technically, estimated total soil loss (A) of Merawu watershed is the result of multiplication among USLE parameters previously described. Pixel value of Map of Erosion from USLE (A) is soil loss as a result of *rill erosion* and *sheet erosion* for the area of 30 m x 30 m (= 900 m^2), in ton/hectare/month. By multiplying (and then summing them up for the whole Merawu watershed) pixel value of Map of Erosion from USLE (A) with pixel area (900 m^2 = 0.09 hectare) and devide it by bulk density, watershed area (22,734 hectare = 227,340,000 m^2) and constant number of 10 will result real soil loss in a watershed ($A_{watershed}$) in mm/month.

Figure 8. Map of P Factor of Merawu Watershed

$A_{watershed} = (A \times 0.09 / Bulk\ Density / 227,340,000 / 10)_{1-n}$ ....(19)

But, USLE is assumed to gain sheet and rill erosion only. In order to get total erosion in a watershed (gross erosion), other erosions such as gulley erosion and channel erosion are determined according to results of previous researches done by [*Piest et al,* 1975] and [*Seyhan,* 1976] stating that gulley erosion is one-fifth (1/5) of the total sediment that occured, while channel erosion is about 10 % of sheet and rill erosion.

$E = (A + G + C)$ ....(20)

where E is *gross erosion,* A: *sheet* and *rill erosion* resulted from USLE, G: *gulley erosion* and C: *channel erosion*.

The gross erosion estimated using USLE (E_{model}), actual erosion (E_{actual}) and validation result is presented in Table 9.

Table 9. Estimated USLE erosion, Actual Erosion and the result of validation

No	Month	E_{actual} (mm/month)	E_{model} (mm/month) using C Factor derived from :					
			NDVI	MSAVI	SAVI	TSAVI	TVI	VIF
1	May-06	0.794	0.202	0.209	0.203	0.203	0.203	0.202
2	Apr-06	1.707	1.311	1.358	1.320	1.319	1.322	1.316
3	Mar-06	0.780	0.284	0.294	0.286	0.285	0.285	0.284
4	Feb-06	2.030	2.007	2.080	2.022	2.020	2.019	2.012
5	Jan-06	3.075	2.715	2.812	2.734	2.731	2.734	2.723
6	Dec-05	2.702	4.606	4.771	4.637	4.632	4.641	4.620
7	Nov-05	0.879	1.039	1.075	1.045	1.044	1.047	1.042
8	Oct-05	0.564	0.998	1.034	1.004	1.003	1.006	1.001
9	Sep-05	0.289	0.135	0.140	0.136	0.136	0.136	0.135
10	Aug-05	0.207	0.093	0.097	0.094	0.094	0.094	0.094
11	Jul-05	0.191	0.520	0.538	0.523	0.522	0.525	0.522
12	Jun-05	0.374	0.756	0.782	0.761	0.760	0.763	0.758
13	May-05	0.800	0.378	0.392	0.381	0.380	0.382	0.380
14	Apr-05	1.764	0.486	0.503	0.489	0.488	0.490	0.487
15	Mar-05	1.370	1.455	1.506	1.464	1.462	1.468	1.460
16	Feb-05	1.341	1.024	1.061	1.031	1.030	1.034	1.028
17	Jan-05	1.765	0.814	0.843	0.820	0.819	0.820	0.816
18	Dec-04	2.738	7.213	7.448	7.261	7.253	7.257	7.231
19	Nov-04	0.988	3.128	3.237	3.148	3.144	3.154	3.138
20	Oct-04	0.036	0.059	0.061	0.059	0.059	0.059	0.059
21	Sep-04	0.029	0.014	0.015	0.014	0.014	0.014	0.014
22	Aug-04	0.024	0.000	0.000	0.000	0.000	0.000	0.000
23	Jul-04	0.082	0.019	0.019	0.019	0.019	0.019	0.019
24	Jun-04	0.130	0.059	0.061	0.060	0.059	0.060	0.059
A.	Average	1.027	1.221	1.264	1.230	1.228	1.231	1.225
B.	Coefficient of Correlation		0.873	0.873	0.873	0.869	0.873	0.873
C.	ANAVA test :							
1.	$C_{computation}$		0.24	0.33	0.25	0.25	0.26	0.24
2.	F_{table}		4.06	4.06	4.06	4.06	4.06	4.06
D.	Accuracy (%)		81.13	76.98	80.33	80.46	80.24	80.78

Source : Result of Analysis (2010)

From Table 9 it can be inferred that all E_{model} using vegetation indices deriving from Landsat 7 ETM$^+$ to generate C Factor have high correlation with E_{actual} *(r = 0.873)*. The result was supported by analysis result of variance (F test) showing that there was no difference between E_{model} and E_{actual}. This is indicated by the $F_{computation}$ values (varies from 0.23 to 0.33) which are less than F_{table} (4.06) using degree of freedom 1 and 46 at α 5 %. Absolutely, the accuracy of erosion modeling was also high for the various vegetation indices used (> 80 %), except MSAVI (76.98 %). NDVI resulted in the highest accuracy (81.13 %) showing that various vegetation indices considering soil background (SAVI, TSAVI and MSAVI) were unable to increase the accuracy. This is probably due to unability of Landsat 7 ETM$^+$ to record vegetation height information and subsurface cover which are used to determine C Factor.

Those results shows that USLE modeling using fully raster-based data can be used for further analysis, such as for planning purposes, research or other analysis. One possible thing causing difference between E_{model} and E_{actual} is in collecting waterlevel to analyse E_{actual} which took place only three times a day, namely at 07:00, 12:00 and 17:00 such that actual waterlevel fluctuation was unrecorded as in reality.

CONCLUSIONS

From 11 vegetation indices used in the study to get C Factor, only six meet the criteria (r ≥ 0.80), i.e. MSAVI, TVI, VIF, NDVI, TSAVI and SAVI.

All E_{models} using six vegetation indices deriving from Landsat 7 ETM$^+$ to generate C Factor have high correlation with E_{actual} *(r = 0.873)*. These results were supported by the result of variance analysis (F test) showing that there were no difference between E_{model} and E_{actual}, as indicated by the $F_{computation}$ values (varies from 0.23 to 0.33) which were less than F_{table} (4.06) using degree of freedom 1 and 46 at α 5 %. Absolutely, the erosion modeling accuracy was also high for various vegetation indices used (> 80 %), except MSAVI (76.98 %). NDVI resulted in the highest accuracy (81.13 %) showing that various vegetation indices considering soil background (SAVI, TSAVI and MSAVI) were unable to increase the accuracy. Those results show that USLE modeling using fully raster-based data is able for used for further analysis, such as for planning purposes, research or other analysis.

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