

The effect of choosing three different C factor formulae derived from NDVI on a fully raster-based erosion modelling

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Abstract. The research was aimed at studying the effect of choosing three different C factor formulae derived from NDVI on a fully raster-based erosion modelling of The USLE using remote sensing data and GIS technique. Methods applied was by analysing all factors affecting erosion such that all data were in the form of raster. Those data were R, K, LS, C and P factors. Monthly R factor was evaluated based on formula developed by Abdurachman. K factor was determined using modified formula used by Ministry of Forestry based on soil samples taken in the field. LS factor was derived from Digital Elevation Model. Three C factors used were all derived from NDVI and developed by Suriyaprasit (non-linear) and by Sulisty (linear and non-linear). P factor was derived from the combination between slope data and landcover classification interpreted from Landsat 7 ETM⁺. Another analysis was the creation of map of Bulk Density used to convert erosion unit. To know the model accuracy, model validation was done by applying statistical analysis and by comparing E_{model} with E_{actual} . A threshold value of ≥ 0.80 or $\geq 80\%$ was chosen to justify. The research result showed that all E_{model} using three formulae of C factors have coefficient of correlation value of > 0.8 . The results of analysis of variance showed that there was significantly difference between E_{model} and E_{actual} when using C factor formula developed by Suriyaprasit and Sulisty (non-linear). Among the three formulae, only E_{model} using C factor formula developed by Sulisty (linear) reached the accuracy of 81.13% while the other only 56.02% as developed by Sulisty (non-linear) and 4.70% as developed by Suriyaprasit, respectively.

1. Introduction

Degraded land is one of the global environmental problems that must be overcome [1] [2]. Number of degraded land is increasing from year to year, while the rate of improvement can not cope with the pace of the damage. Destruction of Natural Resources in Indonesia occurred because all commodities of natural resources being exploited without regard to the carrying capacity [3]. Planning to conserve degraded land requires good and accurate data, one of them is the availability of erosion map.

Generally, erosion data is predicted using a model because to gain actual erosion requires much resources (timely, costly and labour intensive). USLE is one of the existing erosion model applied worldwide, including Indonesia [4]. Nevertheless, so far 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 [5].

With the technological advance in Remote Sensing (RS) and Geographical Information System (GIS) these uncertainties can be minimized, that is by applying a fully raster-based erosion modelling [6]. This is in a line with Fistikoglu and Harmancioglu who state that erosion modelling which is estimated using USLE will be more *reliable* when the analysis is conducted using small raster-based



data because initially USLE is developed at small areas [7]. Raster-based erosion modelling can be conducted objectively, using established algorithms and mathematical formulae, and no simplification is needed [8]. Slope data can be analyzed more accurately and more faster by utilizing *Digital Elevation Model* (DEM) in a GIS environment, while C factor can be derived through the analysis of vegetation index of remote sensing data [4].

USLE is applied worldwide because this model is easily managed, relatively simple and the number of required parameters is relatively less as compared to other more complex erosion modelling [4]. In Indonesia, its usage has been started since 1972 by Soil Research Agency in Bogor, meanwhile Ministry of Forestry also applies USLE to assess degraded land and has been adopted national wide [10]. Morgan and Nearing has proven that USLE has higher accuracy compared to RUSLE (*Revised USLE*) and the more complex model of WEPP (*Water Erosion Prediction Project*) [9]. USLE erosion model is predicted using equation as follows [11]:

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

where

A = mean annual soil erosion rate (ton/hectare/year)

R = rainfall erosivity factor (R factor) (MJ mm/ha/h/year)

K = soil erodibility factor (K factor) (ton hectare/MJ/mm)

LS = slope length and steepness factor (LS factor) (dimensionless)

C = cover and management factor (C factor) (dimensionless)

P = support practice factor (P factor) (dimensionless)

A fully raster-based erosion modelling is an erosion modelling using data input that are all in raster format, not in raster format as a result of *Vector to Raster Conversion* algorithm [4]. From 5 parameters, LS, C and P are factors that can be directly as data input using raster format, while R and K factors can have raster format through spatial interpolation available in almost all GIS software. Spatial interpolation is the process of using points with known values to estimate values at other points [12].

Of the 5 factors in the formula of USLE, the C factor is the factor most difficult to determine at a very large region [13]. This expresses influence of vegetation upon soil erosion, ranging from 1 to 0, where higher values indicate no cover effect hence more erosion while lower C means a very strong cover effect resulting in no erosion. In practice, a C factor is determined by using existing C factor which is the result of research at different location from the location where the erosion will be calculated [14]. C factor information obtained is then assigned to the landuse map which was previously prepared. This method produces a constant of C factor on a relatively wide area, and do not reflect the variation of vegetation [15]. This will certainly have an impact on the calculation of erosion. By using remotely sensed digital data, C factor can be derived through the analysis of vegetation index called Normalized Different Vegetation Index (NDVI).

The research was aimed to study the effect of choosing three different C factor formulae derived from NDVI on a fully raster-based erosion modelling in Merawu watershed, Banjarnegara, Central Java.

2. Materials and Methods

Data required for fully raster-based erosion modelling were: topographical map, landform map, monthly data/report on sediment yield in watershed outlet during 24 months (June 2004 to 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 to May 2006) recorded in Merawu watershed and surroundings, other data and reports which support the activity. To analyze and handle these data various GIS software were used: ILWIS (*Integrated Land and Water Information System*) version 3.4 and Arc/View version 3.5. Meanwhile, some hard wares were also required consisting of drafting tablet, equipment used for

field work such as: binoculars, compass, hagameter, soil munsell color, tape, ring sample, auger, *Global Positioning System* (GPS), and digital camera.

Research area was located in Merawu watershed lies between 109°41'24" – 109°50'24" E and 7°10'12" – 7°22'12" S and administratively located in Banjarnegara district, Central Java Province (Figure 1). Merawu watershed covers ± 22.734 hectares with 3 main rivers flowing through the area from north to south that are: Merawu, Urang and Penaraban rivers. Among the watersheds in the area, Merawu watershed resulted the most of sediment yield to Sudirman Reservoir (11 mm yr⁻¹) [16].

Methods were applied by analysing factors affecting erosion in GIS environment using 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.

Diagrammatically, a fully raster-based erosion modelling is presented in Figure 2.

Monthly rainfall data which recorded between June 2004 and May 2006 (from 8 rainfall stations located within and surrounding of Merawu watershed) was computed to get R factor based on formula developed by Abdurachman [17] as follow:

$$R_m = (Q^{2.263} * P_m^{0.678}) / (40.056 * D^{0.349}) \quad (2)$$

where:

- R_m = monthly average of rain erosivity index (EI_{30})
- Q = monthly average of rainfall (cm/month)
- P_m = maximum daily rainfall average (cm)
- D = monthly average of the number of rainfall days

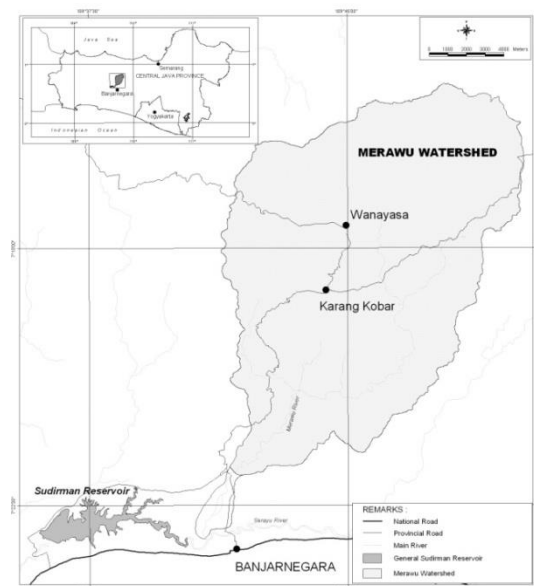


Figure 1. Location of the study.

The result of R factor then was plotted on a map for each station according to its position, digitised, transformed and spatially interpolated using *Moving Average* technique to gain map of R factor of the study area.

Soil erodibility factor (K factor) was determined using formula as follow:

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

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

Thirty soil samples, distributed evenly according to the landform, were taken in the field. The result of K computation for each sample then was plotted according to its position, digitised, transformed and spatially interpolated using *Kriging* technique to gain map of K factor of the study area. To apply spatial interpolation using *Kriging* technique it needs information about *sill*, *nugget* and *range* values that can be obtained by executing *spatial correlation* analysis.

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

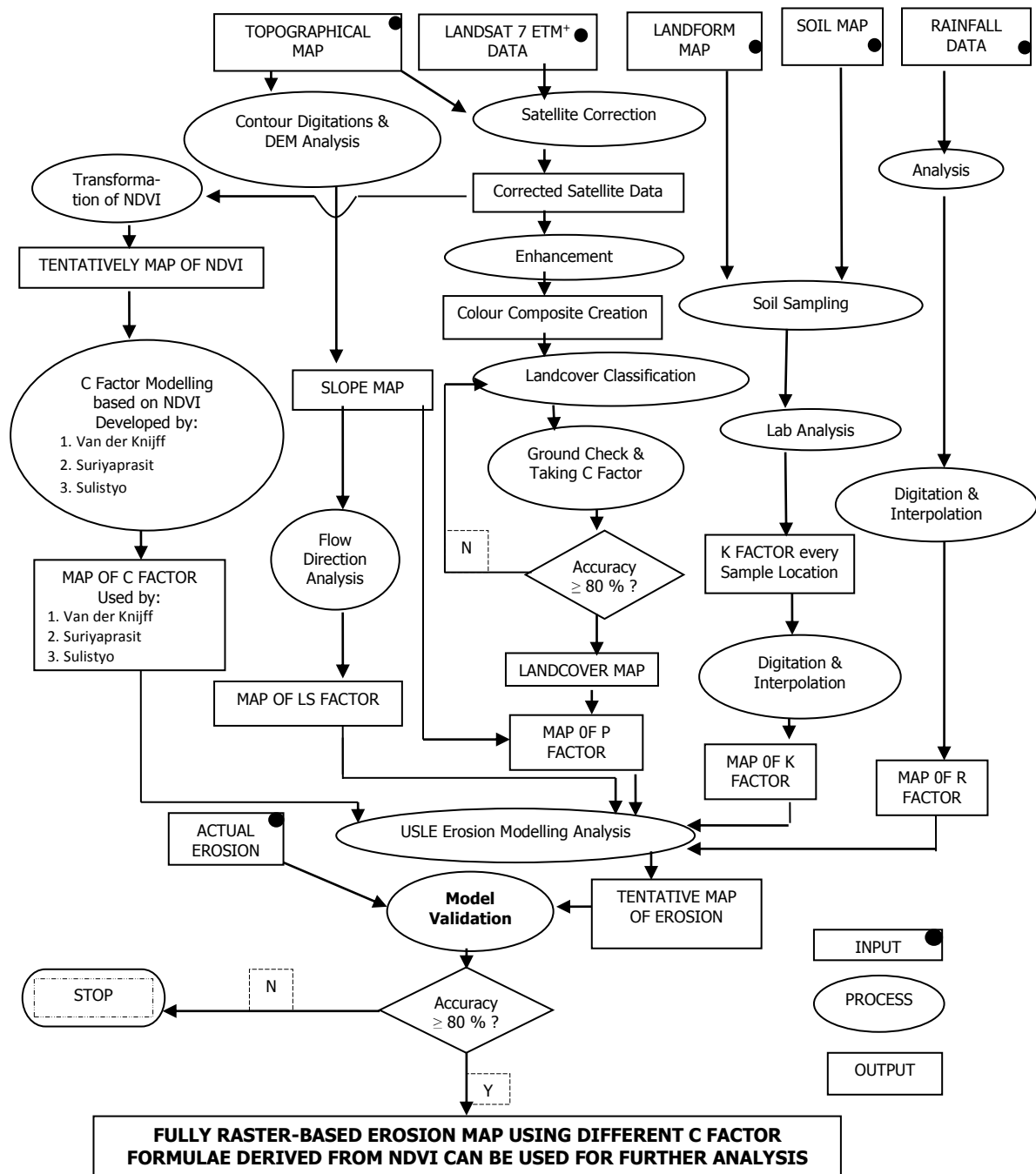


Figure 2. Diagram flow of the study

Slope length and steepness factor (LS factor) for slope < 20% is computed using the formula of Schwab *et al.* [17]:

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

while for slope > 20% LS factor is computed using the formula of Goldman *et al.* [17]:

$$LS = [(65,41 \times s^2) / (s^2 + 10.000) + (4,56 \times s) / (s^2 + 10.000)^{0,5} + 0,065] [(L_a/2,21)^m] \quad (5)$$

where L_a is actual slope length (in meters), s is slope (in %) and m is a constant value which is dependt on the slope, those are $m = 0.1$ if $s \leq 1\%$; $m = 0.3$ if $s > 1\%$ and if $s \leq 3\%$; $m = 0.4$ if $s > 3\%$ and if $s < 5\%$; and $m = 0.5$ if $s \geq 5\%$.

Cover and management factor (C factor) was derived from NDVI and formulated as follow:
Developed by Sulisty [4]:

(a) *Linear equation*

$$C = 0.6 - 0.77 \text{ NDVI} \quad (6)$$

(b) *Non-Linear equation*

$$C = 5.77 * \exp\{-5.62 * \text{NDVI}\} \quad (7)$$

Developed by Suriyaprasit [19]:

$$C = 0.227 * \exp\{-7.337 * \text{NDVI}\} \quad (8)$$

NDVI is formulated as:

$$\text{NDVI} = (\text{NIR} - \text{R}) / (\text{NIR} + \text{R}) \quad [9]$$

where NIR and R indicate channel or band of Landsat 7 ETM⁺ which are near infrared and visible red respectively.

Landcover change analysis was done using two satellite 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 a line with the months of rain erosivity.

Generally, for the shake of ease and practicality, support practice factor (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 Digital Elevation Model and landcover classification interpreted from Landsat 7 ETM⁺ using criteria developed by Abdurachman *et al.* [20] as shown in Table 1.

Table 1. P factor value based on Abdurachman

No.	Landcover	P factor
1	Agricultural Area with Slope $\leq 8\%$	0.50
2	Agricultural Area with Slope between $\geq 8\%$ and 20%	0.75
3	Agricultural Area with Slope $\geq 20\%$	0.90
4	Shrub, Secondary Forest and Forested Area	1.00

Another analysis supporting the research activity was the creation of bulk density map which was generated through plotting bulk density data according to its position, digitised, transformed and spatially interpolated using *Kriging* technique. Map of bulk density was used to convert erosion unit as from a Mg ha⁻¹ month⁻¹ to mm month⁻¹ [21].

After whole data were analysed, then erosion can be calculated. The result of erosion using USLE is assumed only to gain *sheet* and *rill erosion*. In order to get total erosion in a watershed (*gross erosion*), other erosion such as *gully erosion* and *channel erosion* are determined according to the result of previous research done by Piest *et al.* and Seyhan [18] stated that *gully erosion* was one-fifth (1/5) of the total sediment occurred, while *channel erosion* was about 10% of *sheet* and *rill erosion*.

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, in Mg ha⁻¹ month⁻¹. By

multiplying (and then summing them up for the whole Merawu watershed) pixel value of map of erosion from USLE (A) with pixel area ($900 \text{ m}^2 = 0.09 \text{ hectare}$) and divide it by bulk density, watershed area ($22,734 \text{ ha} = 227,340,000 \text{ m}^2$) and constant number of 10 will result real soil loss in a watershed ($A_{\text{watershed}}$) in mm month^{-1} .

$$A_{\text{watershed}} = (A \times 0.09 / \text{bulk density} / 227,340,000 / 10)_{1-n} \quad (10)$$

However, USLE is assumed only to gain *sheet* and *rill erosion*. In order to get total erosion in a watershed (*gross erosion*), other erosion such as *gully erosion* and *channel erosion* are determined according to the result of previous research done by Piest *et al.* and Seyhan [18] who stated that *gully erosion* was one-fifth ($1/5$) of the total sediment occurred, while *channel erosion* was about 10% of *sheet* and *rill erosion*.

$$E = (A + G + C) \quad [11]$$

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

A fully raster-based erosion modelling is a new model in which it needs model validation. Comparison between erosion as a result of modelling (E_{model}) with actual erosion (E_{actual}) can be done using statistical analysis (ANOVA or Correlation Analysis) or direct comparison (subtracted 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 was supplied by PT Indonesia Power which regularly monitor sediment yield in outlet of Merawu watershed.

3. Results and Discussion

3.1. Map of R Factor

Eight rainfall stations located within and surrounding of Merawu watershed were used for the study to compute R factor. Example of the pattern of some R factor as a result of spatial interpolation using *Moving Average* technique is presented in Figure 3.

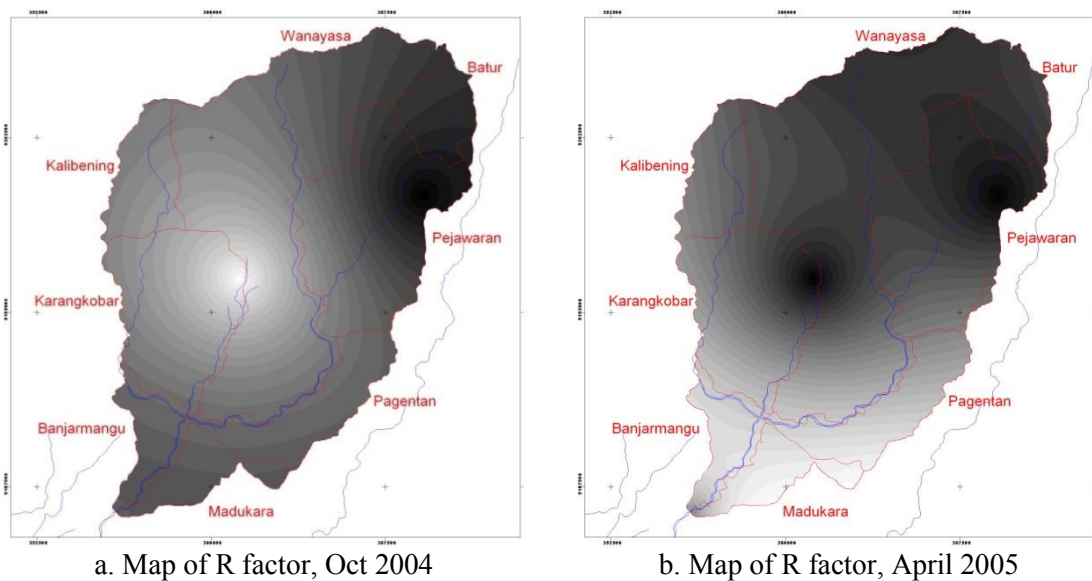


Figure 3. The pattern of some R factors of Merawu watershed

3.2. Map of K Factor and Map of Bulk Density

To apply spatial interpolation using *Kriging* technique, to get map of K factor and map of Bulk Density, it needs information about *sill*, *nugget* and *range* values that can be obtained by executing *spatial correlation* analysis. 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*. While to map the distribution of bulk density the values of 0.025; 0.150 and 8.500 were chosen as *sill*, *nugget* and *range*. The result of map of K factor map of bulk density is shown in Figure 4. Merawu watershed has soil erodibility in average of 0.29 (minimum: 0.08 and maximum: 0.54), while their bulk density average is 1.60 (minimum 1.03 and maximum 2.16).

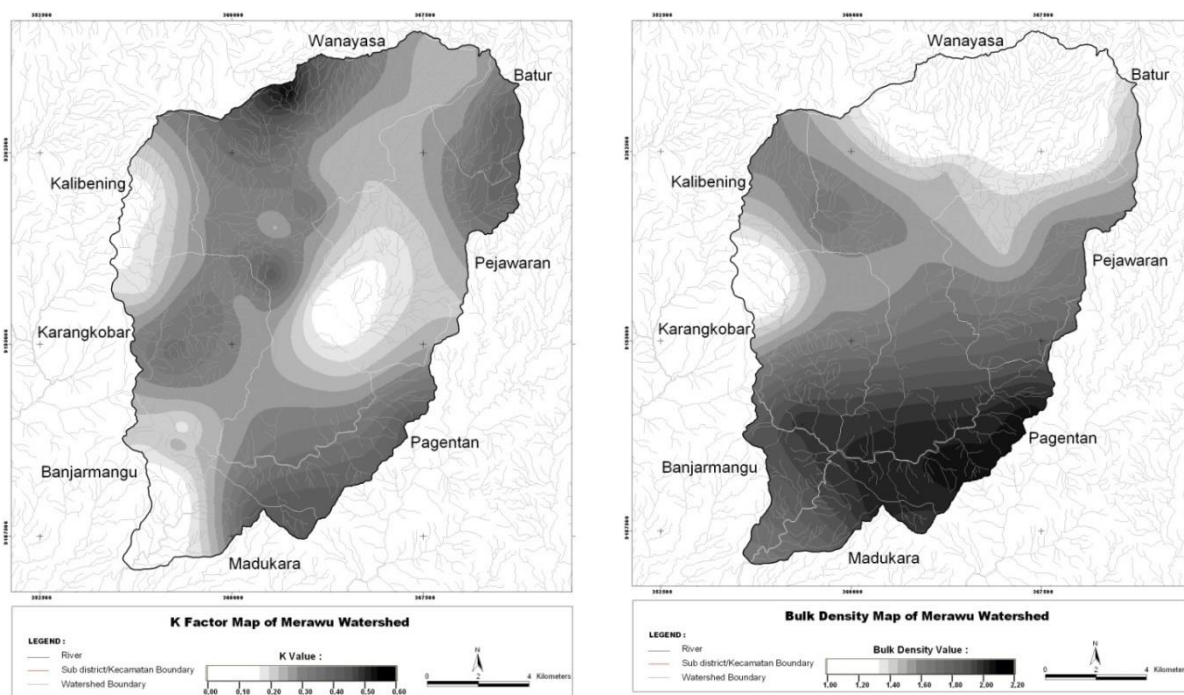


Figure 4. Map of K factor (left) and Map of bulk density (right) of Merawu watershed

3.3. Map of LS Factor

The area of LS factor is presented in Table 2, while its distribution is shown in Figure 5. From Table 3 it can be inferred that Merawu watershed was dominated by LS factor < 20 with average covering area of 16,465 ha, while the rest area had LS factor > 20.

Table 2. Area of Merawu watershed according to its LS factor

No	LS factor	Area
1	$0 < LS < 20$	16,468
2	$20 \leq LS < 40$	3,437
3	$40 \leq LS < 60$	1,680
4	$60 \leq LS \leq 80$	1,150
Total		22,734

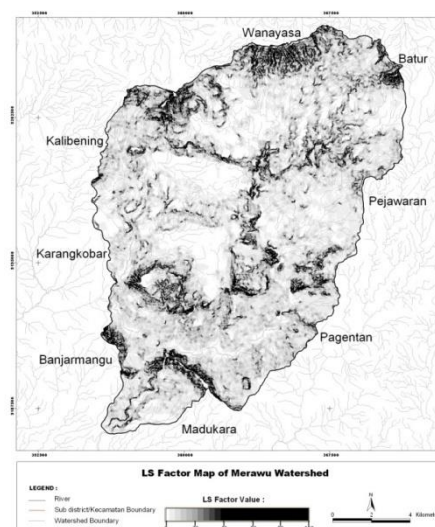


Figure 5. Map of LS factor of Merawu watershed

3.4. Map of C Factor

The area of C factor developed by Suriyaprasit and Sulistyo (linear and non-linear) is shown in Table 3, while its distribution, especially which is developed by Sulistyo, is presented in Figure 6.

To interpolate C factor every month in accordance with the months used in computing R factor, analysis of landcover change was done. This analysis was used by overlaying NDVI recorded on 20 June 2006 on NDVI recorded on 21 May 2003. The result shows that the total number of unchange pixel is 218,947 (86.69%). This means that the pixel changed is 13.31% during 36 months, or it can be concluded that the rate of change is $0.3698\% \text{ mo}^{-1}$. This value is used for interpolating monthly C factor between May 2006 and June 2004.

3.5. Map of P Factor

The result of P factor is presented in Table 6, while its distribution is shown in Figure 7.

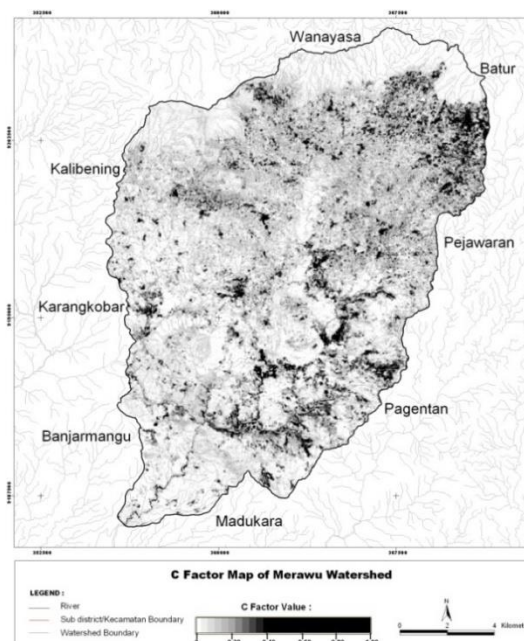


Figure 6. Map of C factor derived from NDVI as developed by Sulistyo

Table 3. The area of C factor in Merawu watershed (hectare)

No.	Interval class of C factor	Developed by:		
		Sulistyo (non-linear)	Suriyaprasit	Sulistyo (linear)
1.	0 - 0.1	15,109	22,672	12,988
2.	0.1 - 0.2	4523	55	5,804
3.	0.2 - 0.3	1265	6	2,291
4.	0.3 - 0.4	627	0	1,116
5.	0.4 - 1.0	1,206	0	535
Total		22,734	22,734	22,734

Table 4. The area of P factor in Merawu watershed

No	Landcover	Area (Ha)	Area (%)
1.	Agricultural Areas with P factor = 0.50	2,760	12.14
2.	Agricultural Areas with P factor = 0.75	5,604	24.65
3.	Agricultural Areas with P factor = 0.90	6,824	30.01
4.	Non Agricultural Areas with P factor = 1	7,548	33.2
Total		22,734	100,00

From table 4 it can be inferred that Merawu watershed is dominated by agricultural area with P factor < 1 covering 15,186 ha (66.8%), while the rest is non agricultural area with P factor = 1 covering 7,548 ha (33.2%).

3.6. Fully Raster-Based Erosion Modelling by Using three different C Factor formulae derived from NDVI

The gross erosion estimated using USLE generated from three different C factor formulae derived from NDVI (E_{model}), actual erosion (E_{actual}) and the result of validation is presented in Table 5.

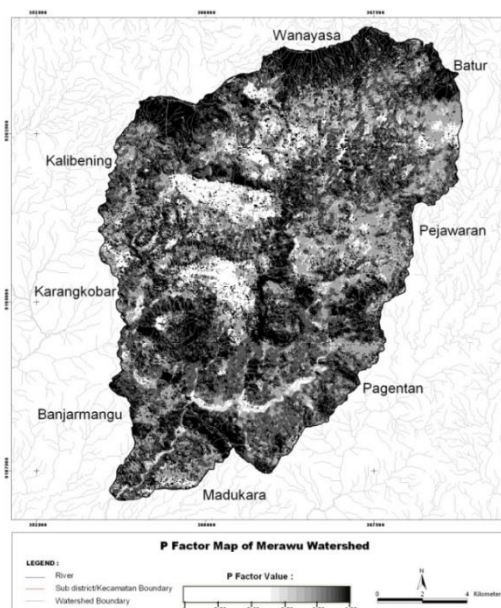


Figure 7. Map of P factor of Merawu watershed

From Table 5 it can be inferred that all E_{model} using three different C Factor formulae derived from NDVI have high coefficient of correlation with E_{actual} ($r = 0.87$). The result of analysis of variance (F test) shows that there was significantly difference between E_{model} and E_{actual} when using C factor formula developed by Suriyaprasit and Sulisty (non-linear), indicated by the $F_{\text{computation}}$ value (26.16 and 4.24 respectively) which was greater then F_{table} (4.06) using degree of freedom 1 and 46 at α 5%. Nevertheless, among the 3 formulae, only E_{model} developed by Sulisty reached the accuracy of 81.13% while the other only 56.02% as developed by Sulisty (non-linear) and 4.70% as developed by Suriyaprasit, respectively. Its mean that model developed by Sulisty (linear) can be used for further analysis (such as for planning purposes, research, or other analysis).

Table 5. Summary of Estimated USLE erosion, Actual Erosion and the result of validation

No	Month	E_{actual} (mm/month)	E_{model} (mm/month)		
			Sulisty (Non-Linear)	Suriyaprasit	Sulisty (Linear)
A.	Average	1.027	2.63	0.05	1.22
B.	Coefficient of Correlation		0.87	0.87	0.87
C.	ANAVA test:	$F_{\text{computation}}$	4.24	26.16	0.24
		F_{table}	4.06	4.06	4.06
D.	Absolute Accuracy (%)		56.02	4.70	81.13

However, it must be realized that a model will be very suitable to be developed in accordance with the conditions of the location where the model is developed. Necessary modifications is needed if the model is applied to another location. The model developed by Suriyaprasit conducted in Thailand. Actually, the model developed by Suriyaprasit similar to the model developed by Sulisty, namely C factor that was derived from the formula after applying regression analysis between NDVI of remote sensing data and C factor measured directly on the field. The difference is that Suriyaprasit only using non-linear model, while Sulisty using both linear and non-linear model. Linear model apparently better than those of non-linear model.

4. Conclusions

All E_{model} using three formulae of C factors have coefficient of correlation value of > 0.8 . The results of analysis of variance showed that there was significantly difference between E_{model} and E_{actual} when using C factor formula developed by Suriyaprasit and Sulisty (non-linear). Among the three formulae, only E_{model} using C factor formula developed by Sulisty (linear) reached the accuracy of 81.13% while the other only 56.02% as developed by Sulisty (non-linear) and 4.70% as developed by Suriyaprasit, respectively.

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