

Absolute Accuracy of the Erosion Model of DEM-NDVI and its Modification

Sulistyo, B.,¹ Gunawan, T.,² Hartono,² Danoedoro, P.² and Listyaningrum, N.²

¹Faculty of Agriculture, University of Bengkulu, Kandang Limun, Bengkulu 38371, Indonesia
E-mail: bambangsulistyounib@gmail.com

²Faculty of Geography, University of Gadjah Mada, Bulaksumur, Yogyakarta 55281, Indonesia
E-mail: totokgunawan@yahoo.com, hartonogeografi@geo.ugm.ac.id, projo.danoedoro@yahoo.com
noviyanti.listyaningrum@mail.ugm.ac.id

Abstract

The research aims at studying the absolute accuracy of the erosion model of DEM-NDVI and its modification (DEM-MSAVI, DEM-SAVI, DEM-TSAVI, and DEM-TVI). Methods applied were by analysing various vegetation indices (NDVI, MSAVI, SAVI, TSAVI, and TVI) of Landsat 7 ETM⁺ data, while Digital Elevation Model was analysed using contour line. Erosion rate within the watershed (E_{model}) then were calculated. The results of E_{model} then were compared to the actual erosion (E_{actual}). The results show that 3 E_{model} (DEM-NDVI, DEM-TSAVI and DEM-TVI) have the high correlation with E_{actual} (the r -value are ≥ 0.80), while 2 E_{model} (DEM-MSAVI and DEM-SAVI) have low correlation, 0.62 and 0.73 respectively. Only E_{model} of DEM-TVI, reached the absolute accuracy of $\geq 80\%$ (ie. 95.47%), while the original model (DEM-NDVI) only 55.39%. The result also revealed that modification resulted in the higher absolute accuracy, as from 55.39% to 69.12% (DEM-MSAVI), to 65.88% (DEM-SAVI), to 64.90% (DEM-TSAVI), and to 95.47% (DEM-TVI).

1. Introduction

One of the global environmental problems that we are facing is the degraded land (Sulistyo, 2011, Bohre and Chaubey 2014, Sulistyo, 2015 and Sulistyo, 2016). Land degradation may be defined as the loss of utility or potential utility or the reduction, loss or change of features or organisms which can be replaced (Barrow, 1991). In Indonesia, degraded land mostly affected by the water erosion due to the high amount and intensity of rainfall (Abdurachman and Sutono, 2002). The rate of degraded land is increasing and increasing while the rate to handle it is very slow. The damage of natural resources in Indonesia is due to all commodities are exploited without regarding well their carrying capacity (Kartodihardjo, 2008). The effort to conserve and rehabilitate the degraded land can be conducted well when objective information and their distribution can be fully identified and mapped (Tarigan, 2012 and Gibbs and Salmon, 2015). One data required to create a map of the degraded land is the erosion data.

Mostly, erosion data is predicted using a model because to obtain actual erosion is timely, costly and labour intensive. Universal Soil Loss Equation (USLE) is one of the existing erosion model applied worldwide (Sulistyo, 2011). USLE requires erosion factors such as rainfall erosivity (R), soil erodibility (K), slope length and steepness (LS), cover and

management (C), and support practice (P) (Wischmeier and Smith, 1978).

However, at some places where the availability data is less and lacking, one start trying to apply the simpler model of erosion called DEM-NDVI (other researchers mention it as E_{30} , NDVI-Slope or Honda model). Honda et al., (1996) and Hazarika and Honda (1999) developed and applied DEM-NDVI to predict soil erosion rate based on DEM and remotely sensed data, especially *Normalized Difference Vegetation Index* (NDVI) at Siwalik Watershed in Nepal and Mae Ao Watershed in Thailand. Those two parameters are correlated to the actual erosion collected in the field, such that erosion rate can be predicted when vegetation density and slope at watershed changes. The method is interesting because it only requires view parameters and it can be applied in hilly areas having a variety of topography. The equations are (Honda et al., 1996 and Hazarika and Honda, 1999):

$$E = E_{30} * (S / S_{30})^{0.9} \quad \text{Equation 1}$$

$$E_{30} = \text{Exp} (((\log E_{30_min} - \log E_{30_max}) / (\text{NDVI}_{max} - \text{NDVI}_{min})) * (\text{NDVI} - \text{NDVI}_{min}) + \log E_{30_max})$$

$$\text{Equation 2}$$

where,

E = the rate of soil erosion (mm/year)

E_{30} = average of soil erosion on the slope of 30°

$E_{30_{\min}}$ = minimum soil erosion on the slope of 30°

$E_{30_{\max}}$ = maximum soil erosion on the slope of 30°

S = slope

S_{30} = tangent of $30^\circ = 0.5774$

$NDVI_{\min}$ = minimum value of NDVI

$NDVI_{\max}$ = maximum value of NDVI

Exp = Exponent

log = logarithmic function

The NDVI can be extracted from satellite data to know the landcover information according to its density, and formulated as (Silleos et al., 2006):

$$NDVI = (NIR - R) / (NIR + R)$$

Equation 3

where NIR is the near infrared band and R is the red band.

Many researcher have applied those erosion model, such as in Indonesia (Arsy, 2008, Gunawan et al., 2011, Wibowo et al., 2012 and Trisakti, 2014), in Sri Lanka (Udayakumara et al., 2010 and Jayawardana et al., 2015) and in India (Bagyaraj et al., 2014). Unfortunately, they applied only to calculate the rate of erosion without any further validation. Therefore, the result is only got the relative accuracy. Only Trisakti (2014) has conducted validation although he didn't measure the actual erosion. He validated the generated soil erosion rates in the watershed by comparing the change of the soil erosion rate to the change of surface runoff coefficient. The results showed that the soil erosion rate in the watershed had an increasing trend, which was consistent with the increasing trend of surface runoff coefficient during 2009-2012 periods.

Silleos et al., (2006) have published the development of modification as from the original of NDVI to other vegetation indices. Some other vegetation indices equations are:

$$TVI = \sqrt{((NIR - R)/(NIR +)) + 0.5}$$

Equation 4

$$SAVI = (NIR - R) * (1 + 0.5) / (NIR + R + 0.5)$$

Equation 5

$$TSAVI = \gamma (NIR - \gamma R - b) / (\gamma NIR + R + \gamma b + X (1 + \gamma^2))$$

Equation 6

$$MSAVI = NIR + c - \sqrt{((NIR + c)^2 - 2(NIR - R))}$$

Equation 7

where:

X = noise soil, i.e. 0.08

γ = slope of soil line, i.e. 1.05

b = coefficient value, i.e. 0.044

c = coefficient value to reduce the variation of soil calibration, i.e. 0.5

NDVI is a vegetation index most widely applied in modeling. De Jong (1994), De Jong et al., (1999), Lin et al., (2002, 2006), Van der Knijff et al., (2002), Suriyaprasit (2008), Karaburun (2010) and Sulisty (2016) utilized NDVI to map C factor as one input for erosion modeling, by using regression analysis between NDVI values with the value of C factor measured in the field. McFarland and van Riper (2013) used NDVI to create habitat models to predict breeding birds on the San Pedro River in Arizona. Leon et al., (2012) applied NDVI on modeling of post-wildfire vegetation response as a function of environmental conditions and pre-fire restoration treatments. Onyango (2015) employed NDVI to map grassland and biomass estimation in The Masai Mara Ecosystem, Kenya. While, Usman et al., (2013), arranged model relationship between NDVI and climatic variables using Geographically Weighted Regression.

Although it is not as much as the use of NDVI in modeling, the utilisation of vegetation indices other than NDVI, also has already widely applied in modeling. Kandwal et al., (2009) used twenty-nine different vegetation indices in discriminating invasive species of 'Lantana' and they found that SAVI is the most favorable. Sulisty et al., (2011) used 10 (ten, apart from NDVI) vegetation indices of remotely-sensed data, namely ARVI, MSAVI, TVI, VIF, TSAVI, SAVI, EVI, RVI, DVI and PVI for C factor mapping derived from remotely sensed data, and found that vegetation indices that account for soil background (SAVI, MSAVI and TSAVI) resulted in relatively higher accuracy compared to those vegetation indices neglecting soil background. A similar conclusion has also been gained when Sulisty et al., (2013) applied vegetation indices to model the percentage of canopy cover. Amiri et al., (2012) used vegetation indices to identify invasive species in Vazroud Rangelands, Iran, and they concluded that NDVI, RVI, TVI and NRVI were the most suitable indices for the discrimination of *Cirsium arvense* species, while the best indices for

the *Stachys byzanthine* species were DVI, NDVI, PVI 1, PVI 2, RVI and WDVI. Of all the indices analysed, DVI and WDVI were able to discriminate both species but with varying degrees of separation. The latest one, Sulisty (2017) applied various vegetation indices of satellite Landsat Thematic Mapper to delineate the outer boundary of coral reef area in Enggano Island, the District of North Bengkulu, Bengkulu Province, Indonesia. The research revealed that the accuracy of NDVI was only 66.42%, while SAVI, TSAVI, MSAVI and TVI were 73.33%, 74.22%, 77.32 % and 77.33% respectively.

The research was aim at studying the absolute accuracy of erosion model of DEM-NDVI and its modification. Absolute accuracy is a measure to know how accurate the results of erosion model when it is compared to the actual erosion. While its modification means that utilisation of other vegetation indices and not just the NDVI, i.e. DEM-MSAVI, DEM-SAVI, DEM-TSAVI, and DEM-TVI.

2. Study Area

This research is the part (and continuation) of grand research dealing with the fully raster-based degraded land modeling, such that data, hardware, software, research area and methods were partly similar to those research previously done (Sulisty et al., 2009, Sulisty, 2011, Sulisty et al., 2011, Sulisty et al., 2013, Sulisty, 2015 and Sulisty, 2016). Research area was located in Merawu watershed lies between 109.69° – 109.84° E and 7.17° – 7.37° S, administratively located in Banjarnegara district, Central Java Province,

Indonesia, covers ± 22.734 hectares. Among the watersheds in the area, Merawu watershed resulted in the most of the sediment yield to Sudirman Reservoir (11 mm/year) (PT. Indonesia Power, 2009) Figure 1.

3. Data and Methods

Data required for this research were: topographical map; monthly data/report on sediment yield in watershed outlet during 17 months (March 2004 to May 2006); remotely-sensed data of Landsat 7 ETM⁺ recorded on 21 May 2003 and on 20 June 2006; other data and reports which support the activity. To analyse those data, two GIS softwares were used: ILWIS version 3.4 and Arc/View version 3.5. Meanwhile, some hardwares were also required consisting: equipment used for field work such as: binoculars, compass, GPS, and digital camera. Flow diagram of the study is presented in Figure 2. The research steps consisting of:

1. Analysis of Landsat 7 ETM⁺ data. Analysis of Landsat 7 ETM⁺ data can be broken down into two parts, those are rectification (correction) and restoration. Some errors that must be corrected are geometric and radiometric or atmospheric. Radiometric correction is done using simple radiometric correction based on subtraction of minimum values of the histogram for each band. Then, conversion from reflectance value into the radiance value is applied by considering L_{Max} dan L_{Min} that can be obtained in the metadata. Geometric correction is done by relating pair of coordinates derived from image and topographic map.

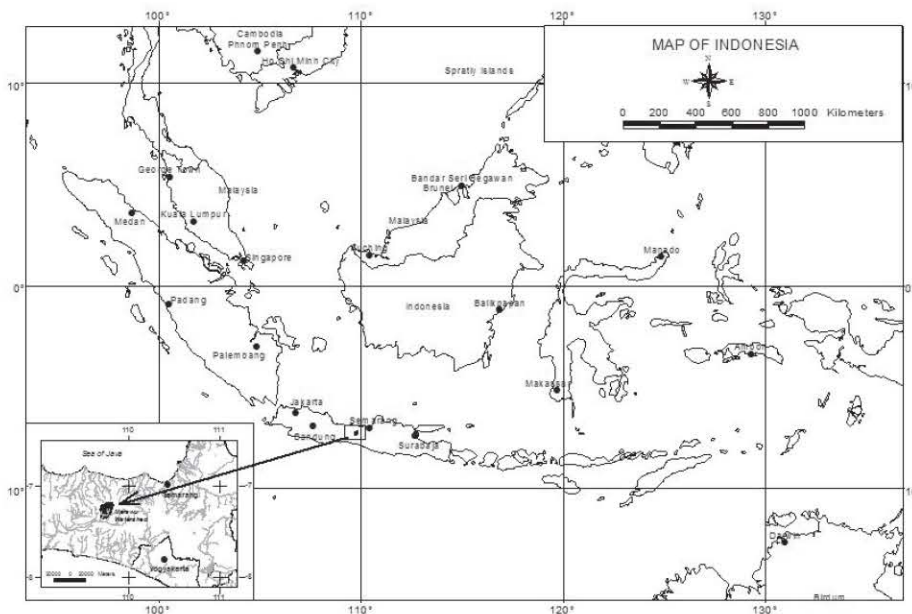


Figure 1: Location of the study

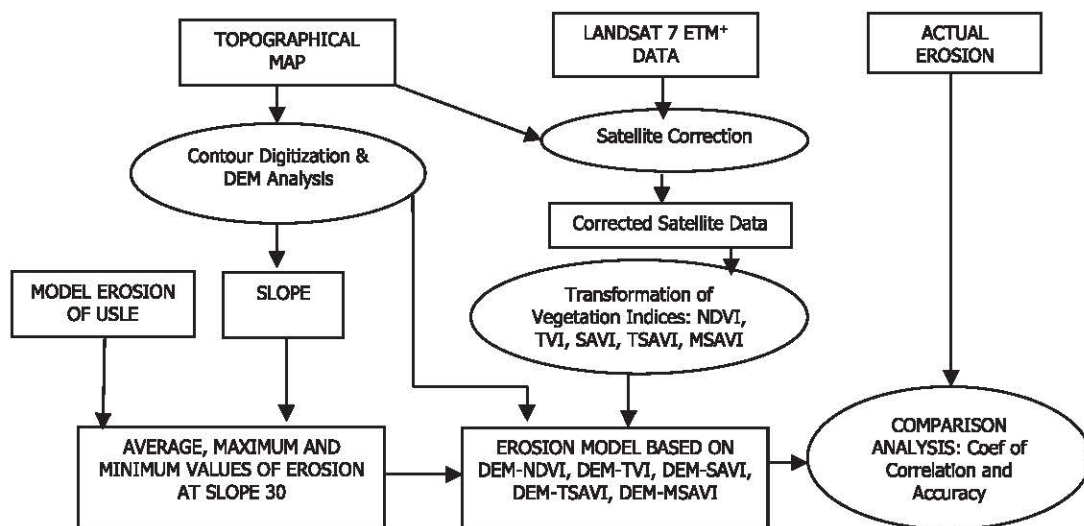


Figure 2: Flow diagram of the study

2. Determination of multiplication / correction factor used to compute monthly vegetation indices. To calculate and interpolate monthly vegetation index, multiplication / correction factor are required because we use only 2 images, while to do the analyses we need monthly data in between the two. This research used multiplication / correction factor as resulted by Sulisty et al., (2009), with little modification needed, as presented in Table 1.

Table 1: Multiplication / Correction factors for computing monthly vegetation indices (modified from Sulisty et al., 2009)

No	Month	Multiplication / Correction Factor
1	May-06	0.996302
2	April-06	0.992604
3	March-06	0.988906
4	Sept-05	0.966717
5	August-05	0.963019
6	July-05	0.959321
7	June-05	0.955623
8	May-05	0.951925
9	April-05	0.948227
10	March-05	0.944529
11	Sept-04	0.922341
12	August-04	0.918643
13	July-04	0.914944
14	June-04	0.911246
15	May-04	0.907548
16	April-04	0.903850
17	March-04	0.900152

3. Analysis of monthly vegetation indices can be calculated by applying the equations (3), (4), (5), (6) and (7).

4. DEM and Slope Analysis. DEM Analysis is initiated by performing rasterization of contour lines, followed by height interpolation and finally produce DEM. From DEM data then can be derived slope gradient data (S).

5. As input, the value of the average rate of erosion, their maximum and their minimum value at the slope of 30° (E_{30_max} and E_{30_min}) were used data resulted from previous research using model erosion of USLE (Sulisty et al., 2009).

6. Calculate the erosion model of DEM-NDVI by using equation (2) and then also calculate the erosion using modified model as follow:

Erosion Model of DEM-TVI:

$$E_{30} = \text{Exp} \left(\frac{(\log E_{30_min} - \log E_{30_max})}{(TVI_{max} - TVI_{min})} * (TVI - TVI_{min}) + \log E_{30_max} \right)$$

Equation 8

Erosion Model of DEM-SAVI:

$$E_{30} = \text{Exp} \left(\frac{(\log E_{30_min} - \log E_{30_max})}{(SAVI_{max} - SAVI_{min})} * (SAVI - SAVI_{min}) + \log E_{30_max} \right)$$

Equation 9

Erosion Model of DEM-TSAVI:

$$E_{30} = \text{Exp} \left(\frac{(\log E_{30_min} - \log E_{30_max})}{(TSAVI_{max} - TSAVI_{min})} * (TSAVI - TSAVI_{min}) + \log E_{30_max} \right)$$

Equation 10

Erosion Model of DEM-MSAVI:

$$E_{30} = \text{Exp} \left(\frac{(\log E_{30_min} - \log E_{30_max})}{(MSAVI_{max} - MSAVI_{min})} * (MSAVI - MSAVI_{min}) + \log E_{30_max} \right)$$

Equation 11

7. Comparison Analysis among E_{model} and E_{actual} .
By using coefficient of correlation analysis as (Gordon et al., 1992):

$$r = \frac{(n \sum xy - (\sum x)(\sum y))}{\left[(n \sum x^2 - (\sum x)^2) (n \sum y^2 - (\sum y)^2) \right]^{0.5}}$$

Equation 12

where:

r = coefficient of correlation

n = number of population (17)

y = dependent variable, i.e. the actual erosion (E_{actual})

x = independent variable, i.e. the predicted erosion using model (E_{model})

By using a direct comparison to get the absolute accuracy:

$$\text{Absolute Accuracy (\%)} = 100 - \left(\frac{\text{Absolute Difference}}{\text{Average}} \right) \times 100\%$$

Equation 13

$$\text{Absolute Difference} = |E_{model} - E_{actual}|$$

$$\text{Average} = 0.5 \times (E_{model} + E_{actual})$$

The average overall of accuracy is calculated by summing up all accuracies divided by the number of samples. E_{model} is said to be "good" when its coefficient of correlation (r) is ≥ 0.8 and its absolute accuracy is $\geq 80\%$.

4. Results and Discussion

4.1 The Result of Monthly Vegetation Indices

There were eighty-five (85) map of monthly vegetation indices resulted after applying the equations (3), (4), (5), (6) and (7). Five maps of them, for the month of June 2006, are presented in Figure 3, Figure 4, Figure 5, Figure 6 and Figure 7, while their area for each vegetation index in the study area are presented in Table 2. From Table 2 it can be inferred that the area of each interval class of vegetation index value is different according to vegetation index used. It is also true for their distribution, though it is very difficult to clearly differentiate due to the limited scale. From the maps we can see that high vegetation index value dominates in Batur district, suggesting that this area is fully used for intensively agricultural activities. High vegetation index value also sporadically occurred in all areas. List of the minimum and maximum values for each vegetation index is presented in Table 3. These values will be used as one of the inputs to calculate erosion.

4.2 The Result of DEM and Slope

Interpolated contour, commonly referred to as an elevation image as a base for DEM data, in the Merawu catchment comprises elevation between 298.94 m and 2,200.00 meters above sea level. More than half of the Merawu catchment located at an elevation higher than 1,059.33 meters above sea level. The total area of the Merawu catchment according to its elevation are presented in Table 4.

Table 2: Area of vegetation index value in Merawu catchment (in hectares)

No	Vegetation Index	Interval class of vegetation index value					Total
		-0.31 – 0.02	0.02 – 0.36	0.36 – 0.69	0.69 – 1.03	1.03 – 1.36	
1	MSAVI	3.24	329.76	3,870.63	18,527.85	0.00	22,731.48
2	NDVI	6.84	1,329.57	11,293.38	10,101.69	0.00	22,731.48
3	SAVI	5.94	432.18	2,289.15	9,783.27	10,220.94	22,731.48
4	TSAVI	12.96	1,430.46	11,401.56	9,886.50	0.00	22,731.48
5	TVI	0.00	0.00	0.99	5,146.92	17,583.57	22,731.48

Table 3: The minimum and maximum values for each vegetation index

	NDVI	MSAVI	SAVI	TSAVI	TVI
Maximum Value Index	1.000	0.950	1.357	0.904	1.185
Minimum Value Index	-0.160	-0.305	-0.199	-0.165	0.606

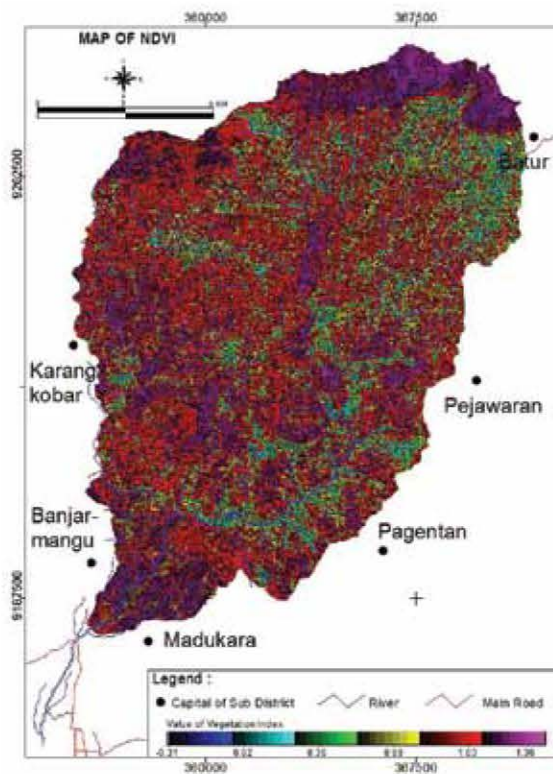


Figure 3: Map of NDVI

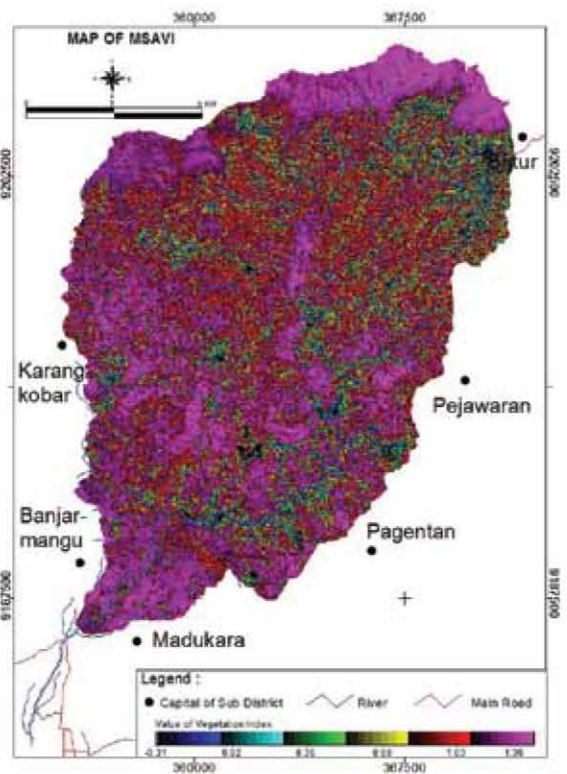


Figure 4: Map of MSAVI

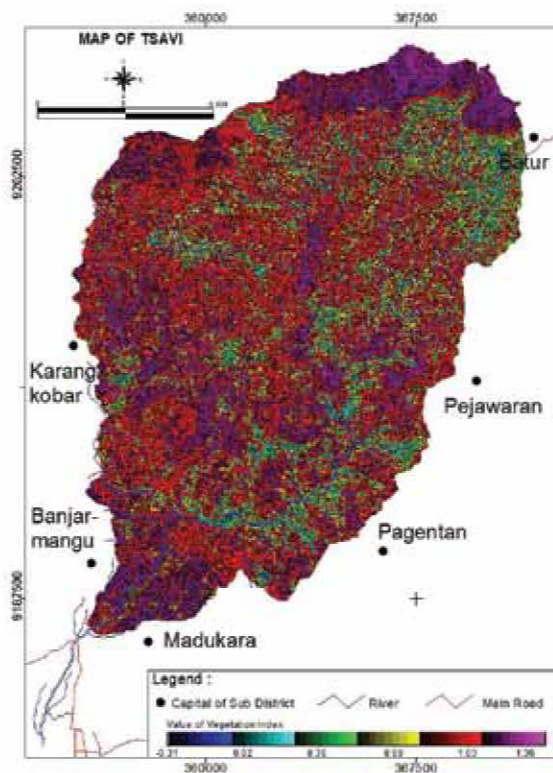


Figure 5: Map of TSAVI

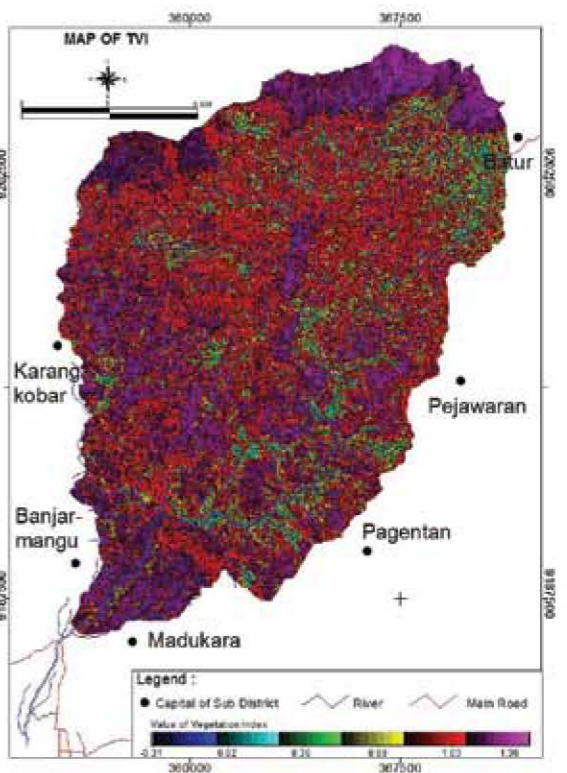


Figure 6: Map of TVI

Table 4: Area of elevation value in Merawu catchment

No	Elevation (m asl)	Hectare	%
1.	298.94 - 679.00	2,812.59	12.37
2.	679.00 - 1,059.33	7,056.63	31.04
3.	1,059.33 - 1,439.56	8,016.84	35.27
4.	1,439.56 - 1,819.44	4,085.73	17.97
5.	1,819.44 – 2,200.00	759.69	3.34
		22,731.48	100.00

Table 5: Area of slope in Merawu catchment

No	Slope Interval (%)	Hectare	%
1.	Slope ≤ 8%	3,689,73	16.2
2.	8% < Slope < 15%	4,229,91	18.6
3.	15% ≤ Slope < 25%	5,423,58	23.9
4.	25% ≤ Slope < 40%	4,647,24	20.4
5.	≥ 40%	4,741,02	20.9
		22,731.48	100.00

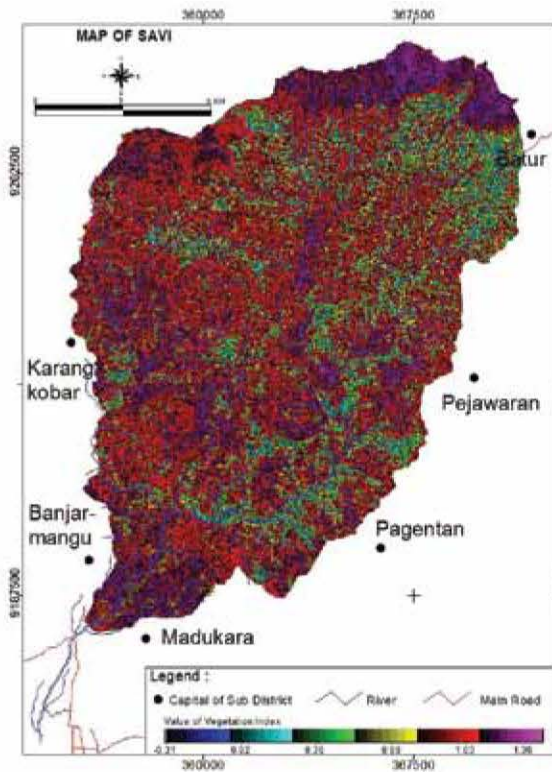


Figure 7: Map of SAVI

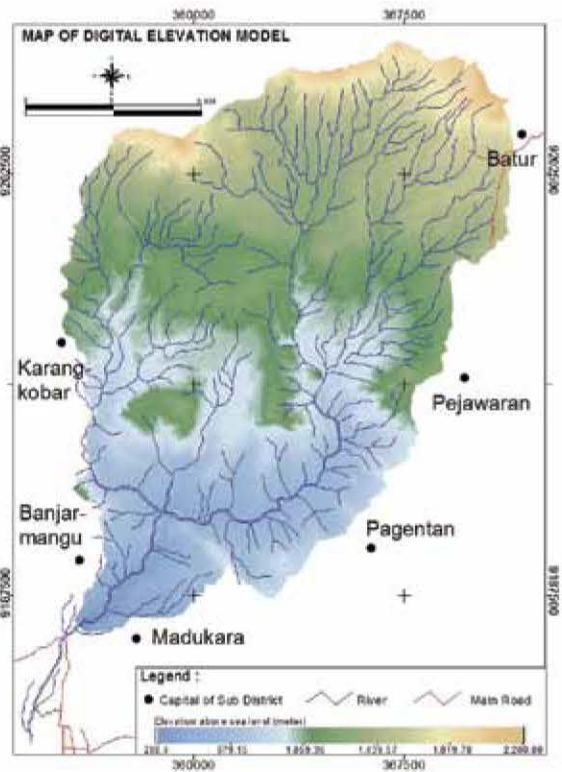


Figure 8: Map of DEM

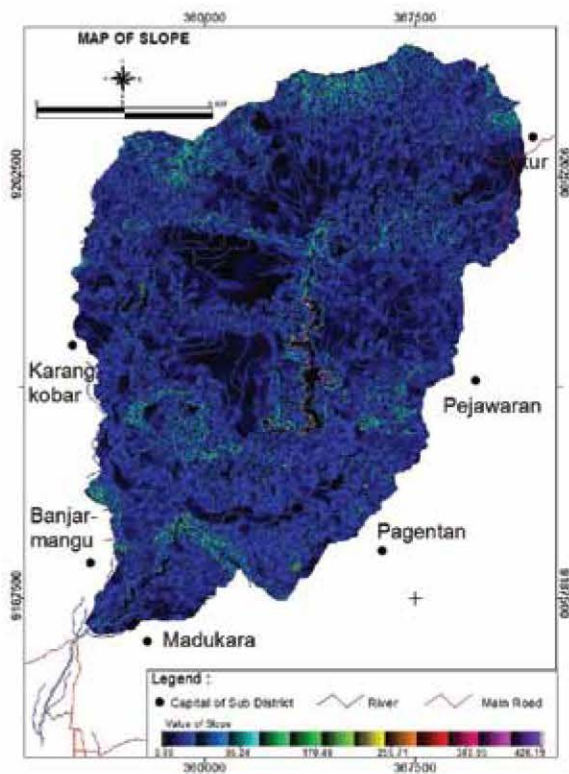


Figure 9: Map of slope

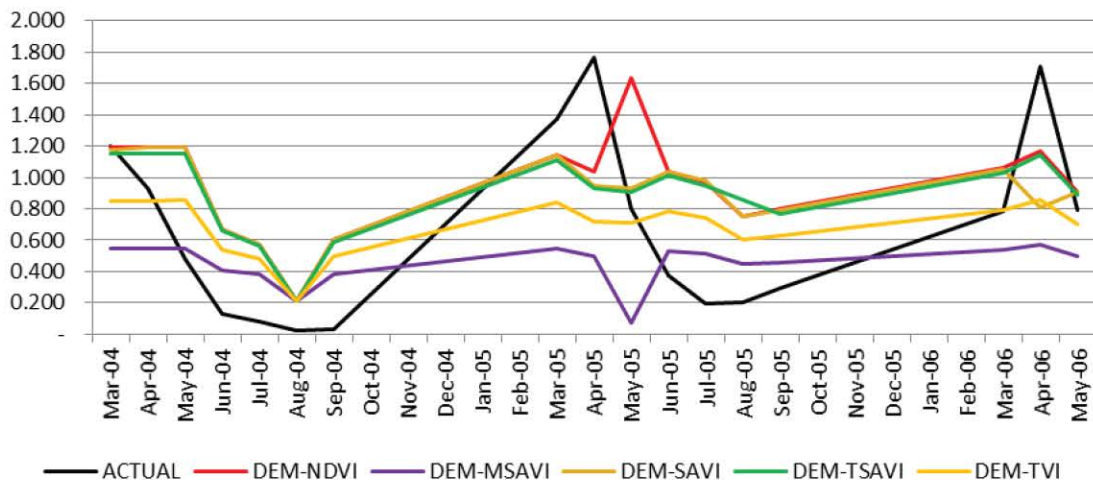


Figure 10: The actual, estimated erosion and the result of comparison analysis

The slopes along with the slope length are the two main characteristics of the topography that affect erosion (Suripin, 2004). The steeper slopes and, in addition, the more in length, the greater the speed of runoff and erosion. When we connect this fact with a bare slope, then this is the easiest to erosion terms of the topography, because the speed of the water flow over the surface can easily erode the topsoil.

One of the results derived from DEM is the image of the slope (S). After reclassifying into 5 classes, the total area of the Merawu catchment

according to the slope is presented in Table 5. Table 5 shows that the Merawu catchment only had flat areas (<8%) covering an area of 3,690 hectares (16.2%), while the rest is a region with undulating, hilly and even steeper, so that the Merawu catchment, when viewed from the slope aspect, has a great chance of erosion. Maps of DEM and Map of Slope within the location of the study are presented in Figure 8 and Figure 9.

4.3 The Absolute Accuracy of DEM-NDVI and Its Modification

The results of the actual erosion (E_{actual}), erosion model of DEM-NDVI, DEM-MSAVI, DEM-SAVI, DEM-TSAVI, and DEM-TVI (E_{model}), and the comparison analysis is presented in Table 6, while its graphical form is in Figure 10.

Table 6 and Figure 10 show that all erosion models using 3 vegetation indices (DEM-NDVI, DEM-TSAVI and DEM-TVI) had the high correlation with E_{actual} (the value of coefficient of correlation is ≥ 0.80), while DEM-MSAVI and DEM-SAVI have low correlation, 0.62 and 0.73 respectively. In terms of their absolute accuracy, only erosion model of DEM-TVI, reached the threshold value of $\geq 80\%$, which was 95.47%, while the original model (DEM-NDVI) only got 55.39%. The result of the absolute accuracy also revealed that modification of vegetation index as from its original (NDVI) to its modification (SAVI, MSAVI, TSAVI and TVI) resulted in higher absolute accuracy, as from 55.39% to 69.12% (MSAVI), to 65.88% (SAVI), to 64.90% (TSAVI), and to 95.47% (TVI). The results from this study indicate that the use of modeling by utilising non-NDVI has a tendency to produce a better accuracy compared with just using NDVI. These results are in line with results from other studies that utilise non-NDVI in modeling (Kandwal et al., 2009, Sulisty, 2011, Sulisty et al., 2011, Amiri et al., 2012, Sulisty et al., 2013 and Sulisty, 2017).

The low in their absolute accuracy may happen because the model has neglected the real other factors of occurrence of the erosion; those are climate (rainfall), soil type and management. Those factors have already considered on the erosion model of USLE but not in the erosion model of DEM-NDVI and its modification. Erosion model of DEM-NDVI was originally developed at the small size of the watershed, around 1.000 hectares, where the effect of variety on rainfall and soil type can be assumed as similar. In the other hand, Merawu Watershed has the area around ± 22.734 hectares, where variety in rainfall and soil type can't be assumed as similar. Erosion model of DEM-NDVI estimates average annual sediment yield, while in this research erosion was determined in every month.

The most interesting result is the very high in absolute accuracy of erosion model of DEM-TVI (95.47%), meaning that E_{model} is almost similar to E_{actual} . The most reasonable explanation is by reminding the reason behind the modification of the equation as from NDVI to TVI that is by introducing the Normal distribution rather than the Poisson distribution (Deering et al., 1975). Then, the possibility to apply DEM-TVI to other locations may be considered. However, it must be realised that a model will be very suitable to be developed in accordance with the conditions of the location where the model is developed. Other necessary validation and modifications are needed if the model is applied to other locations.

Table 6: The actual, estimated erosion, and the result of comparison analysis

No	Month	E_{actual} (mm/month)	E_{model} (mm/ month) using DEM-				
			NDVI	MSAVI	SAVI	TSAVI	TVI
1	May-06	0.794	0.910	0.500	0.910	0.890	0.700
2	Apr-06	1.707	1.170	0.570	0.810	1.140	0.860
3	Mar-06	0.780	1.060	0.540	1.050	1.030	0.790
4	Sep-05	0.289	0.800	0.460	0.790	0.770	0.630
5	August-05	0.207	0.750	0.450	0.750	0.860	0.600
6	Jul-05	0.191	0.970	0.510	0.980	0.950	0.740
7	Jun-05	0.374	1.040	0.530	1.040	1.010	0.780
8	May-05	0.800	1.630	0.070	0.930	0.910	0.710
9	Apr-05	1.764	1.040	0.500	0.950	0.930	0.720
10	Mar-05	1.370	1.140	0.550	1.140	1.110	0.840
11	Sep-04	0.029	0.600	0.380	0.600	0.590	0.500
12	August-04	0.024	0.210	0.210	0.210	0.210	0.210
13	Jul-04	0.082	0.570	0.380	0.570	0.560	0.480
14	Jun-04	0.130	0.670	0.410	0.670	0.660	0.540
15	May-04	0.485	1.190	0.550	1.190	1.150	0.860
16	Apr-04	0.930	1.190	0.550	1.190	1.150	0.850
17	Mar-04	1.198	1.190	0.550	1.180	1.150	0.850
A.	Average	0.656	0.949	0.454	0.880	0.886	0.686
B.	Coef of Correlation		0.80	0.62	0.73	0.81	0.81
C.	Absolute Accuracy (%)		55.39	69.12	65.88	64.90	95.47

5. Conclusions

All E_{model} using 3 vegetation indices (DEM-NDVI, DEM-TSAVI and DEM-TVI) have the high correlation with E_{actual} (the value of the coefficient of correlation are ≥ 0.80), while DEM-MSAVI and DEM-SAVI have low correlation, 0.62 and 0.73 respectively.

In term of their absolute accuracy, only erosion model of DEM-TVI, reached the threshold value of $\geq 80\%$, which was 95.47%, while the original model (DEM-NDVI) only got 55.39%. The result of absolute accuracy also revealed that modification of vegetation index as from its original (DEM-NDVI) to its modification resulted in higher absolute accuracy, as from 55.39% to 69.12% (DEM-MSAVI), to 65.88% (DEM-SAVI), to 64.90% (DEM-TSAVI), and to 95.47% (DEM-TVI).

Acknowledgment

The authors would like to thank Director General of Higher Education, Ministry of Research, Technology and Higher Education, The Republic of Indonesia for providing a grant that supports the financial for this study.

References

- Abdurachman, A. and Sutono, 2002, Soil Erosion Control Technology, Research and Development of Soil and Agro-climate, (Bogor, Indonesia: the Agency for Agricultural Research and Development).
- Amiri, M., Solaimani, K., Tamartash, R. and Miryaghoubzadeh, M., 2012, Identification of Invasive Species using Remote Sensing and Vegetation Indices, (Case Study: Vazroud Rangelands, Iran), *Journal of Rangeland Science*, 3, 59-70.
- Arsy, R. F., 2008, Utilization of Digital ASTER Imagery for Estimating and Mapping of Soil Erosion at Oyo Watershed, DIY, *Thesis*, Faculty of Geography, University of Gadjah Mada, Yogyakarta, Indonesia.
- Bagyaraj, M., Ramkumar, T., Venkatramanan, S., Chung, S. Y. and Gurugnanam, B., 2014, Assessment of Soil Erosion Probability in Kodaikanal, India using GIS and Remote Sensing, *Disaster Advances*, 7, 36-49.
- Barrow, C. J., 1991, *Land Degradation*, (Melbourne, Australia: Cambridge University Press).
- Bohre, P. and Chaubey, O. P., 2014, Restoration of Degraded Lands Through Plantation Forests, *Global Journal of Science Frontier Research*, 14, 18-27.
- De Jong, S. M., 1994, Applications of Reflective Remote Sensing For Land Degradation Studies in a Mediterranean Environment, *PhD Thesis*, Utrecht University, Utrecht, The Netherlands
- De Jong, S. M., Paracchini, M. L., Bertolo F., Folving, S., Megier, J. and De Roo A. P. J., 1999, Regional Assessment of Soil Erosion using the Distributed Model SEMMED and Remotely Sensed Data, *Catena*, 37, 291-308.
- Deering, D. W., Rouse, J. W., Haas, R. H. and Schell, J. A., 1975, Measuring "Forage Production" of Grazing Units From Landsat MSS Data, *Proceedings of the 10th International Symposium on Remote Sensing of Environment*, 2, 1169-1178.
- Gibbs, H. K. and Salmon, J. M., 2015, Mapping the World's Degraded Lands. *Journal of Applied Geography*, 57, 12-21.
- Gordon, N. D., McMohan, T. A. and Finlayson, B. L., 1992, *Stream Hydrology: An Introduction for Ecologist*, (New York: John Wiley & Sons)
- Gunawan, G., Sutjningsih, D. and Soeryantono, H. 2011, Evaluation of Erosion Based On GIS and Remote Sensing For Supporting Integrated Water Resources Conservation Management, Case Study: Manjuntio Watershed, Bengkulu Province-Indonesia, *Dinamika TEKNIK SIPIL*, 8, 208-2011.
- Hazarika, M. K. and Honda, K., 1999, Estimation of Soil Erosion using Remote Sensing and GIS, Its Valuation and Economic Implications on Agricultural Production, In: D.E. Stott, R.H. Mohtar and G.C. Steinhardt (eds). *Sustaining the Global Farm, Selected papers from the 10th International Soil Conservation Organization Meeting held May 24-29, 1999 at Purdue University and the USDA-ARS National Soil Erosion Research Laboratory*.
- Honda, K., Samarakon, L., Ishibashi, A., Mabuchi, Y. and Miyajima, S., 1996, Remote Sensing and GIS Technologies for Denudation Estimation in a Siwalik Watershed of Nepal, *GISdevelopment.net*, ACRS 1996, Water Resources/Hydrology.
- Jayawardana, B. A. Y. B., Udayakumara, E. P. N., Dammalage, T. and Fowze, J. S. M., 2015, Application of GIS and RS Techniques to Identify Farmer's Contribution for Soil Erosion in Upper Mahaweli Catchment, *Proceedings of the First International Symposium on Environmental Management and Planning*.
- Kandwal, R., Jeganathan, C., Tolpekin, V. and Kuswaha, S. P. S., 2009, Discriminating Invasive Species, 'Lantana' using Vegetation Indices, *Journal Indian Society of Remote Sensing*, 37, 275-290.

- Karaburun, A., 2010, Estimation of C factor for Soil Erosion Modeling using NDVI in Buyukcekmece Catchment, *Ozean Journal of Applied Science*, 3, 77-85.
- Kartodihardjo, H., 2008, Management of Natural Resources and Environment, *Seminar on Environment and Natural Resources*, University of Bengkulu, Bengkulu, Indonesia.
- Leon, J. R. R., van Leeuwen, W. J. D. and Casady, G. M., 2012, Using MODIS-NDVI for the Modeling of Post-Wildfire Vegetation Response as a Function of Environmental Conditions and Pre-Fire Restoration Treatments, *Remote Sensing*, 4, 598-621.
- Lin, C. Y., Lin, W. T. and Chou, W. C., 2002, Soil Erosion Prediction and Sediment Yield Estimation: The Taiwan Experience, *Soil and Tillage Research*, 68, 143-152.
- Lin, W. T., Lin, C. Y., Chou, W. C., 2006, Assessment of Vegetation Recovery and Soil Erosion at Landslides Caused by a Catastrophic Earthquake: A Case Study in Central Taiwan. *Ecological Engineering*, 28, 79-89.
- McFarland, T. M. and van Riper, Charles III, 2013, Use of NDVI Habitat Models To Predict Breeding Birds on the San Pedro River, Arizona, *U.S. Geological Survey Open-File Report 2013-1100*. 42.
- Onyango, O. D., 2015, Application of Hyper-Temporal NDVI Data in Grassland Mapping and Biomass Estimation in the Masai Mara Ecosystem, Kenya, *Thesis, Faculty of Geo-Information Science and Earth Observation of the University of Twente*, The Netherlands.
- PT. Indonesia Power, 2009, *Report on Sudirman Hydropower Reservoir Sedimentation*, (Banjarnegara: Unit Bisnis Pembangunan Mrica)
- Silleos, N. G., Alexandridis, T. K., Gitas, I. Z. and Perakis, K., 2006, Vegetation Indices: Advances Made in Biomass Estimation and Vegetation Monitoring in the Last 30 Years, *Geocarto International*, 21, 21-28.
- Sulistyo, B., Gunawan, T., Hartono and Danoedoro, P., 2009, Toward a Fully and Absolutely Raster-Based Erosion Modeling by using RS and GIS, *Indonesian Journal of Geography*, 41, 149-170.
- Sulistyo, B., 2011, The Effect of Choosing Different Contour Interval on a Fully Raster-Based Erosion Modeling (The Case In Merawu Watershed, Banjarnegara, Central Java), *Journal of Tropical Soils*, 16, 258-266.
- Sulistyo, B., Gunawan, T., Hartono and Danoedoro, P., 2011, Pemetaan Faktor C Yang Diturunkan Dari Berbagai Indeks Vegetasi Data Penginderaan Jauh Sebagai Masukan Pemodelan Erosi Di DAS Merawu (C Factor Mapping Derived From Various Vegetation Indices of Remotely Sensed Data As Input For Erosion Modeling In Merawu Catchment), *Jurnal Manusia dan Lingkungan*, 18, 68-78.
- Sulistyo, B., Gunawan, T., Hartono and Danoedoro, P., 2013, Pemodelan Persentase Tajuk Di DAS Merawu Yang Diturunkan Dari Berbagai Indeks Vegetasi Data Penginderaan Jauh (Modeling of Percentage of Canopy in Merawu Catchment Derived from Various Vegetation Indices of Remotely Sensed Data). *Forum Geografi*, 27, 23-32.
- Sulistyo, B., 2015, Kajian Perubahan Tingkat Kekritisn Lahan Sebagai Akibat Proses Eliminasi Unit Lahan: Studi Kasus di Kawasan Pertambangan Danau Mas Hitam, Provinsi Bengkulu (The Study of Land Degradation Level As a result of Land Unit Elimination Process: Case Study in Mining Region of Danau Mas Hitam, Bengkulu Province). *National Seminar on Biodiversity*, University Club, University of Gadjah Mada, Yogyakarta, 828-833.
- Sulistyo, B., 2016, The Effect of Choosing Three Different C Factor Formulae Derived From NDVI on a Fully Raster-Based Erosion Modeling, *2nd International Conference of Indonesian Society for Remote Sensing (ICOIRS)*, Published under licence by IOP Publishing Ltd, IOP Conference Series: Earth and Environmental Science, Vol., 47, No. 1.
- Sulistyo, B., 2017, The Accuracy of the Outer Boundary Delineation of Coral Reef Area Derived From the Analyses of Various Vegetation Indices of Satellite Landsat Thematic Mapper, *Biodiversitas*, 18, 351-358.
- Suripin, 2004, *Pelestarian Sumber Daya Tanah dan Air*, (Yogyakarta, Indonesia: Penerbit ANDI).
- Suriyaprasit, M., 2008, Digital Terrain Analysis and Image Processing for Assessing Erosion Prone Areas, *Thesis, International Institute for Geo-Information Science and Earth Observation (ITC)*, Enschede, The Netherlands
- Tarigan, S. D., 2012, Methods for Delineating Degraded Land at Citarum Watershed, West Java, Indonesia. *Journal of Tropical Soils*, 17, 267-274.

- Trisakti, B., 2014, Soil Erosion Rate Estimation using Landsat and SPOT, *Jurnal Penginderaan Jauh*, 88-101.
- Udayakumara, E. P. N., Shrestha, R. P., Samarakoon, L. and Schmidt-Vogt, D., 2010, People's Perception and Socioeconomic Determinants of Soil Erosion: A Case Study of Samanalawewa Watershed, Sri Lanka, *International Journal of Sediment Research*, 25, 323-339
- Usman, U., Yelwa, S. A., Gulumbe, S. U. and Danbaba, N., 2013, Modelling Relationship between NDVI and Climatic Variables using Geographically Weighted Regression. *Journal of Mathematical Sciences and Applications*, 1, 24-28.
- Van der Knijff, J., Jone, R. J. A. and Montanarella, L., 2002, *Soil Erosion Risk Assessment in Italy*. European Soil Bureau, Joint Research Center of European Commission. EUR 19022EN.
- Wibowo, A., Ismullah, I. H., Dipokusumo, B. S. and Wikantika, K., 2012, Land Degradation Model Based on Vegetation and Erosion Aspects using Remote Sensing Data, *ITB Journal Science*, 44, 19-34.
- Wischmeier, W. H. and Smith, D. D., 1978, *Predicting Rainfall Erosion Losses: A Guide to Conservation Planning*, (USA: USDA Agriculture Handbook No. 37).