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Erosion Prediction Model using Fractional Vegetation Cover

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ABSTRACTS

The purpose of this study was to create an erosion prediction model in Serang Watershed, Indonesia. The erosion model used two input data, namely the slope derivied from Digital Elevation Model (DEM) data, and Fractional Vegetation Cover (FVC) from SPOT images. Assessment of the model was carried out using questionnaires and interviews with several experts by presenting the results of the model and its supporting data. Based on the DEM data, the level of slope steepness in the study area is very varied namely; flat (52.77%), sloping (7.62%), and rather steep to very steep (39.59%). Vegetation density according to the FVC results is dominated by medium density. The results of the analysis of the two input models can provide predictions of the level of erosion with an accuracy of 67.92%. Evaluation of the model was done by experts with conclusions that the method was very flexible and can be adapted to similar watersheds elsewhere.

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INTRODUCTION

Erosion modeling is one way to predict the amount of erosion that occurs in a particular area. Different spatial erosion models have different levels of accuracy depending on available data and regional characteristics. However, each region has different geographical characteristics, thus the dominant factors influencing the erosion will vary from place to place. Erosion is a complex and dynamic phenomenon requiring intense observation and detailed measurements to understand the eroded soil. Thus, in order to evaluate the factors that influence erosion in a place, it is necessary to simplify erosion prediction through modeling.

Several previous studies have shown that vegetation and topographic factors are more dominant for erosion (Kamaludin *et al.*, 2013; Wang *et al.*, 2015). Vegetation describes the condition of land cover and land use, which in this study uses the FVC approach. Some previous studies have used FVC to describe surface vegetation (Vrieling, *et al.*, 2006; Zhang *et al.*, 2019). Other researchers stated that the erosion risk was most significant in areas with steep slopes, high erodibility, and low vegetation cover (Kefi *et al.*, 2011). This study used an integrated approach that's remote sensing and geographic information systems. Remote sensing has become the solution to various spatial problems (Arif *et al.*, 2013; Pradesh, 2017; Silva *et al.* 2018; Wang *et al.*, 2003). To produce accurate models, methods and predictive results need to be calibrated and in this study, the model was evaluated by the expert as a replacement for the actual erosion measurement in the field. Calibration with actual erosion calculations in the field is rarely done because it takes a longer time and it's expensive. Expert judgments are required to ensure or verify the quality of the resulting model (Rosqvist, 2003). Sonneveld *et al.* (2001) used expert knowledge to assess qualitative erosion of various types of land use. Hence, this assessment is fairer than quantitative evaluation which tends to be subjective.

In this research, the evaluation of the factors that influence the erosion was done qualitatively by looking at the spatial pattern between the erosion prediction map generated and the spatial pattern of each input used. This approach was expected to be a quick solution for model calibration so that the dominant factors influencing erosion could be identified and conservation efforts are done immediately. The purpose of this study was to create an erosion prediction model using two input data, namely vegetation and slope. The model is expected to be an alternative model that can be applied to different areas with limited data.

2. MATERIALS AND METHODS

2.1. Study Area

The research was undertaken in Serang Watershed which is situated between Progo and Bogowonto Watersheds in Kulon Progo Regency, Yogyakarta Special province, Indonesia. Geographically, it is located at 7°43'40" S - 7°55'30" S and 110°03'49" E - 110°13'50" E. Based on statistical data of Serayu Opak Progo River Basin Management Office in 2009, critical land area in Serang District was 2,030.98 ha (9.03%), somewhat critical 6,450.51 ha (28.66%), potential to be critical 12,411.77 ha (55.15%), and not critical 1,610.38 ha (7.16%). This means that Serang watershed was in a critical condition that could trigger land degradation, erosion, and landslides.

2.2. Data

The data used in this study was SPOT 5 (*Satellite Pour l'Observation de la Terre*) Images Copyright 24 October 2014. These images had 10 m spatial resolution in multispectral mode. The digital elevation model (DEM) was obtained from Indonesian topographical map at a scale of 1:25.000).

2.3. Preprocessing

The SPOT 5 image was ortho-rectified to reduce geometric distortions. Geometric correction is done by selecting 60 control points (GCP) with an RMSE value of 0.307928 which means that in reality there is a shift of 0.307928-pixel x = 3.079 meter. The radiometric correction was carried out up to the Top of Atmosphere (ToA) correction stage, namely the conversion of digital number (DN) values into spectral radians and finally spectral reflectance values. The radiometric correction was performed on the full SPOT 5 image scene that covered the study area. From the corrected image, the normalized difference vegetation index (NDVI) transformation was done using the formula used in SPOT, namely:

NDVI = (band 3-band 2)/(band 3+band 2)

The surface vegetation cover density was calculated as a derivative of NDVI transformation, namely Fractional Vegetation Cover (FVC) which was regressed with the results of measurements of vegetation density in the field. The FVC equation was derived using the formula used by (Gutman & Ignatov, 1998).

$$FVC = \left(\frac{NDVI - NDVI_s}{NDVI_v - NDVI_s}\right)$$

where $NDVI_v$ is the maximum NDVI value (NDVI = 1), and the value of $NDVI_s$ is the value of NDVI for bare soil (NDVI = 0).

The second parameter used was the slope. The classification of slope steepness used the classification established by the Indonesian Ministry of Forestry. Slope data was calculated from the DEM using the slope definition of McCool *et al.* (1989).

$$S = \begin{cases} 10.8\, sin\theta + 0.03\,\theta & \theta < 5° \\ 16.8\, sin\theta - 0.5 & 5° \le \theta < 10° \\ 21.9 sin\theta - 0.96 & \theta \ge 10° \end{cases}$$

2.4. Accuracy Assessment

Assessment of the model accuracy was performed on both model inputs and model results by calculating overall accuracy, producer's accuracy, and user's accuracy. The model results were then evaluated using expert judgment. Expert judgments of the results of the model were done by determining some people as respondents taken to be experts with related research conducted. Field data was collected to help experts assess compliance with the model output, and each expert gave a score on the five characteristics of the model presented in the questionnaire. The assessment was done using questionnaire and interview to respondents with exposure to the input data and model results. Experts assessed some characteristics of the model as used by Sonneveld *et al.* (2011):

1. Data requirement (the available input data for the model meets the erosion model data criteria).
2. Flexibility (the ability of the model to be adapted in a similar basin as well as the ability to understand the diverse data patterns so as to construct erosion variables).
3. Erosion control (model results can be used to support land conservation activities).
4. Model output (interpretation of the model results).
5. Validation (the availability of independent data for model validation).

3. RESULTS AND DISCUSSION

3.1. Fractional Vegetation Cover

Surface vegetation cover was obtained based on the percentage of cover in one pixel, through the transformation of FVC derived from the NDVI transformation. NDVI is widely used to obtain vegetation cover (Rahmat *et al.*, 2018; Vrieling *et al.*, 2006). The negative FVC values are caused by the negative vegetation index values, so the negative value is considered to have a value of 0% on the FVC (**Figure 1**)

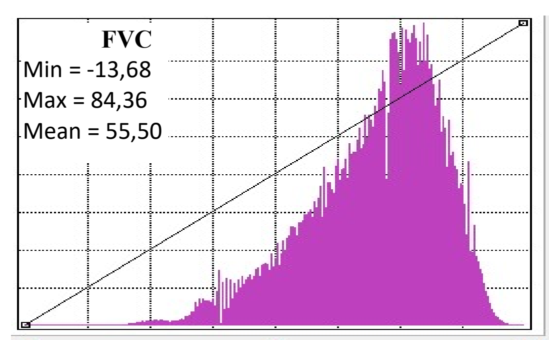

Figure 1. Histogram of FVC

Figure 1 shows that the higher NDVI value results in the better the density of vegetation. Vegetation density in the field was obtained, in which this was measured by canopy cover density. Overall vegetation density in Serang watershed was observed by regression results of measurements of vegetation density in the field with the density of the FVC transformation results. Correlation results are shown in **Figure 2** with the spatial distribution of vegetation density presented in **Figure 3**.

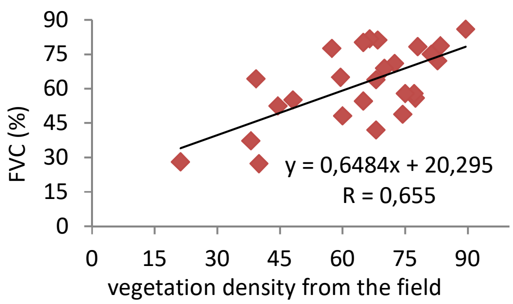

Figure 2. Correlation of vegetation density with FVC

Figure 2 shows that the correlation of FVC with vegetation density from the field is R = 0.655 obtained using the equation y = 0.6484x + 20.295. These results are different from Vrieling *et al.* (2006) who obtained results with a higher correlation.

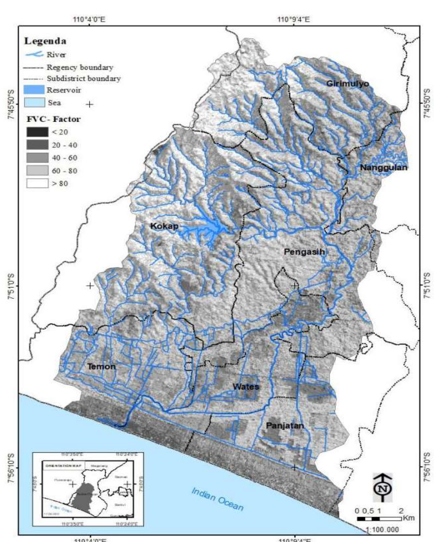

Figure 3. Spatial distribution of FVC

Figure 3 shows that the distribution of vegetation density in the Serang watershed is dominated by medium and high-density classes scattered in the north and west parts of the study area, namely in the Kokap sub-district, part of the Girimulyo sub-district, Pengasih sub-district, and Temon sub-district. In the southern part of the study area, there is low density because it is a coastal area and densely populated. Looking at the spatial distribution of vegetation density, it can be concluded that the vegetation conditions in the Serang water-shed are quite good.

3.2. Slope

The analysis of the DEM produced the slope map presented in **Figure 4**. The results show that the Serang watershed area is dominated by slope class <8% or flat area. Vulnerable areas are found in Kokap sub-district, Girimulyo sub-district, and part of Pengasih sub-district. Areas with flat topography in the study area were Wates, Temon, Panjatan, Pengasih, and Nanggulan districts.

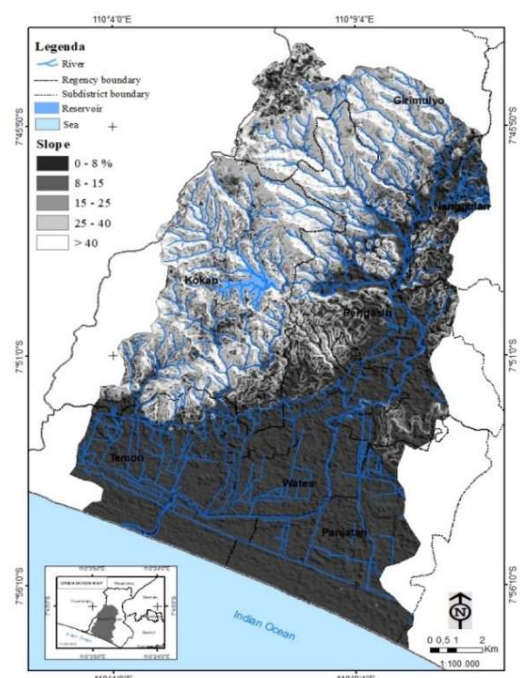

Figure 4. Slope map of Serang watershed

Spatially, **Figure 4** shows that the topography of Serang watershed is dominantly flat in Panjatan sub-district, Wates sub-district, Temon sub-district, part of Pengasih sub-district, and Naggulan sub-district. The north and western parts the study area is dominantly steep to very steep slopes that have the potential for erosion. Arif *et al*. (2017) stated that the most influential factor on erosion in the Serang watershed in addition to erodibility is the topographic factors.

3.2. Assessment of the erosion model

The results of the raster overlaid the two erosion parameters (namely FVC and slope), and they produced an erosion map as shown in **Figure 5**. From the map, 53 samples were taken consisting of 30 data that had been previously validated with field data and 23 prediction results that had not been cross-checked and obtained classification accuracy results as presented in **Table 1**.

Table 1 shows several classes identified that equally affect the level of accuracy, *i.e.* the heavy erosion classes that are justified as very heavy and moderate erosion classes because they exhibit the same erosion appearance in the field. However, the following erosion classes namely very light, light, and very heavy are easier because the boundaries between these erosion classes are very clearly marked (Arif *et al*., 2017). Justification for the erosion classes is very subjective based only on the combination of each of the two erosion parameters and the appearance of erosion encountered in the field, such as channel erosion, trench erosion, or root outcrop.

Tabel 1. Accuracy assessment of erosion classes

Erosion class		*Ground truth*					Total	User's accuracy (%)
		SR	R	S	B	SB		
JST results	**SR**	**2**	1	1			4	50,00
	R	1	**4**				5	80,00
	S	1		**4**	3	2	9	40,00
	B			1	**4**	4	8	44,44
	SB			1	2	**22**	27	88,00
Total sample		4	5	7	9	28	**53**	
Produser's acc. (%)		50	80	57,14	44,44	78,57		
Overall accuracy (%)		67,92						
Kappa		0,53						

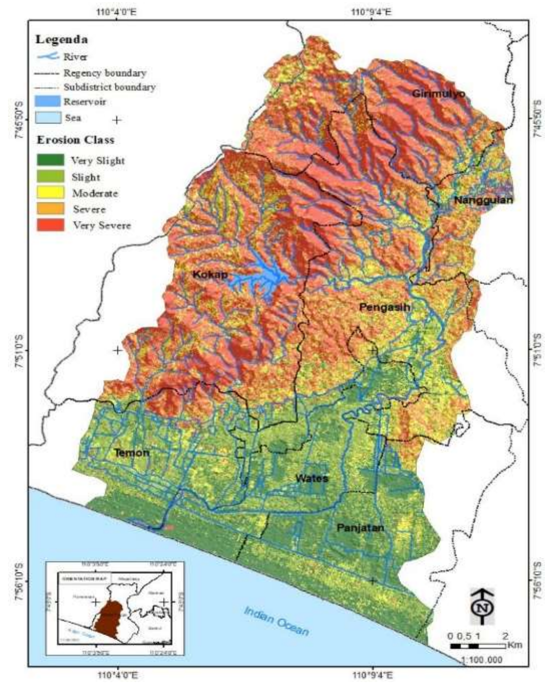

Figure 5. Spatial distribution of erosion in Serang watershed

Figure 5 shows that the distribution of erosion classes in the study site was dominated by the following erosion classes namely very severe erosion spreading across most of the area of Kokap Sub-district, Girimulyo Sub-district, and parts of Pengasih Sub-district. Severe erosion was spreading all over Panjatan Sub-district, Pengasih Sub-district, and was Nanggulan Sub-district. Moderate erosion was spreading across Pengasih Sub-district, parts of Wates Sub-district, and Panjatan Sub-district. Slight erosion and very slight erosion was spreading all over Temon Sub-district and Wates Sub-district. Based on the results of the model (map), each expert gave a score on the five characteristics of the model presented in the questionnaire. The recapitulation of the assessment results is presented in **Figure 6**.

Figure 6 shows the difference in judgments between experts. Assessment becomes highly subjective because of differences in views and database knowledge of each expert.

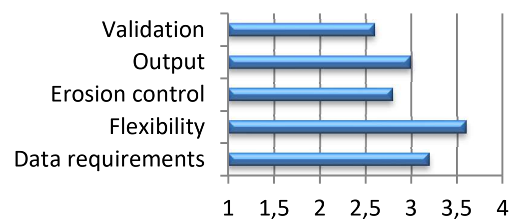

Figure 6. Spatial distribution of erosion in Serang watershed

Expert 1 assessed and recommended the model because it corresponds to the logic of the erosion modeling using parameters corresponding to the equations used in deriving erosion hazard maps. Most experts preferred model as being more acceptable because in the upstream area (Girimulyo subdistrict) with steep slopes relatively severe erosion up to very severe and in Panjatan and Wates subdistricts with flat and steep slopes have very slight and slight erosion. This is supported by (Vrieling *et al.*, 2006) who asserted that very steep slopes have high erosion scores. The steeper the slope is, the more particles are scattered on the slopes and the more is the trigger of splash erosion and erosion by groove (Assouline *et al.,* 2006). The results of this study indicated that the assessment of the erosion rate based on two input factors, namely vegetation and topography, represented the condition of erosion in the field. Thus, the model is considered to be flexible, meaning that it can be adapted to a similar watershed. The model can properly execute the predicted results even if it involves only two input, namely DEM and FVC values. The results of expert judgments showes that some model characteristics (namely flexibility, data requirements, and model output) was rated well by the expert. This means that the input data used to build the model is in accordance with the input data required in the erosion prediction model. The model was very flexible to be adapted to a similar watershed, and the spatial distribution of the model was easily understood and in accordance with other erosion prediction maps ever observed by the experts. The model validation and erosion control were considered sufficient. Raster-based spatial distribution is difficult to apply to land conservation efforts; Thus, erosion control becomes more difficult.

4. CONCLUSION

The use of remote sensing data and geographic information systems is very helpful in making erosion prediction models. Erosion modeling using two input models namely DEM and FVC can be an alternative model in erosion prediction. The accuracy of the erosion prediction results was 67.92%. The experts assessed model as being very flexible so that it can be adapted in other regions with the same characteristics.

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