Spatial Analysis of Soil Erosion and its Correlation with Landslide Events: Case Study of Cipongkor, West Bandung District

Denny LUMBAN RAJA, Adang SAPUTRA, Johannes ANHORN, Indonesia

Keywords: Soil Erosion, Landslide, Remote Sensing, Geographic Information System, RUSLE

SUMMARY

There is a high potential for landslide hazards in the study area of Cipongkor, West Bandung District, Indonesia. Landslide occur due to the combination of many factors and various triggering events, one of those factors is extensive soil erosion leading to lower slope stability. The objective of this study is to estimate annual soil loss and create a soil erosion potential map using Remote Sensing (RS) and Geographic Information Systems (GIS) based on the Revised Universal Soil Loss Equation (RUSLE). The four basic factors used in RUSLE are Rainfall Index (R), Soil Erodibility Index (K), Topography Index (LS), and Land Cover Index (CP)The data are obtained from various national and international sources, e.g. USGS (SRTM), BIG - Geospatial Information Agency of Indonesia (Landuse) and BMKG – Agency for Meteorology, Climatology, and Geophysics (annual rainfall). Index values were computed and represented as vector layers for further processing of RUSLE using a GIS environment. As a result the study area was categorized into five zones of soil erosion potential namely very high-, high-, moderate-, low-, and very low- soil erosion potential. The results showed that 45% (4115 ha) of the study area is facing very high soil erosion risk and 16% (1485 ha) has high soil erosion risk, while 14% (1243 ha) has moderate soil erosion risk. The area of low soil erosion risk is only 2% (168 ha) and very low soil erosion risk is 22% (2032 ha). The very high soil erosion risk zones are mainly located on the northwest, west, and southwest parts of the study area. High soil erosion potential is observed in combination with high LS values (up to 35%). This study also compares the soil erosion potential with the occurrence of landslides by using the landslide location areas from field survey data. The comparison shows that the area with high soil erosion potential have also higher risk of landslide occurrence. This research demonstrates that RS and GIS technologies are effective tools in modelling soil erosion potential and creating soil erosion potential maps, thus helping to implement soil conservation, landslide mitigation and watershed management measures in Cipongkor. Further researcher is necessary to characterize and understand the relationship between soil erosion potential and the occurrence of landslides in the study area.

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1. INTRODUCTION

Soil erosion in Indonesia is one of the most serious environmental degradation problems the country faces (Kusumandari and Mitchell 1997). West Java Province in Indonesia is the region with the most frequent landslide occurrence, especially during the rainy season (Hirnawan, 1998). In the study area, the intensity of rainfall, the morphology of mountains and valleys with moderate to steep slopes, as well as landuse change due to terrain utilization are factors that modify terrain characteristic. Also human activities including overgrazing, overcropping and deforestation are potential triggers or accelerate the erosion process. Erosion may further cause landslides, damaging villages and infrastructure around.

Soil erosion is a common geological hazard in tropical regions and has major negative impacts in areas where it occurs (Alfan, Triandanu & Muslim 2015). Particularly, in mountain areas the erosion from unstable and loose geological material leads to gully erosion and mass movement of soil and rocks (Lee 2004). Assessing the spatial distribution of areas susceptible to erosion risk is very important for landuse planning strategies and agricultural management (Mati et al. 2000).

The Universal Soil Loss Equation (USLE) is the most widely applied empirical models for assessing the rill erosion, developed by Wischmeier and Smith (1978). The Revised Universal Soil Loss Equation (RUSLE) model in conjunction with Remote Sensing and Geographic Information System technology is used to predict the annual soil loss in this study area. RUSLE is considered the alternative improved version of the proto USLE model (Renard et al. 1991).

This study employs the RUSLE, combined with RS and GIS technologies to: 1) estimate the potential soil loss from areas of Cipongkor, 2) produce soil erosion zone, and 3) identify areas of critical soil erosion conditions. The study helps the local government and community formulating appropriate soil conservation and land management plans.

2. THE STUDY AREA

The study area is located in Cipongkor Subdistrict, West Bandung District Indonesia (Figure 1). Geographically, the study area is located in the northwestern part of West Java Province and lies between $6^{o}53'00''$ S to $7^{o}00'00''$ S and $107^{o}18'$E – $107^{o}26'00''$E comprising of 14 villages, in 2 watersheds and 16 sub-watersheds. This study area is part of the geological map of Sindangbarang and Bandarwaru quardrangle scale 1:100.000 (Koesmono & Suwarna 1996).

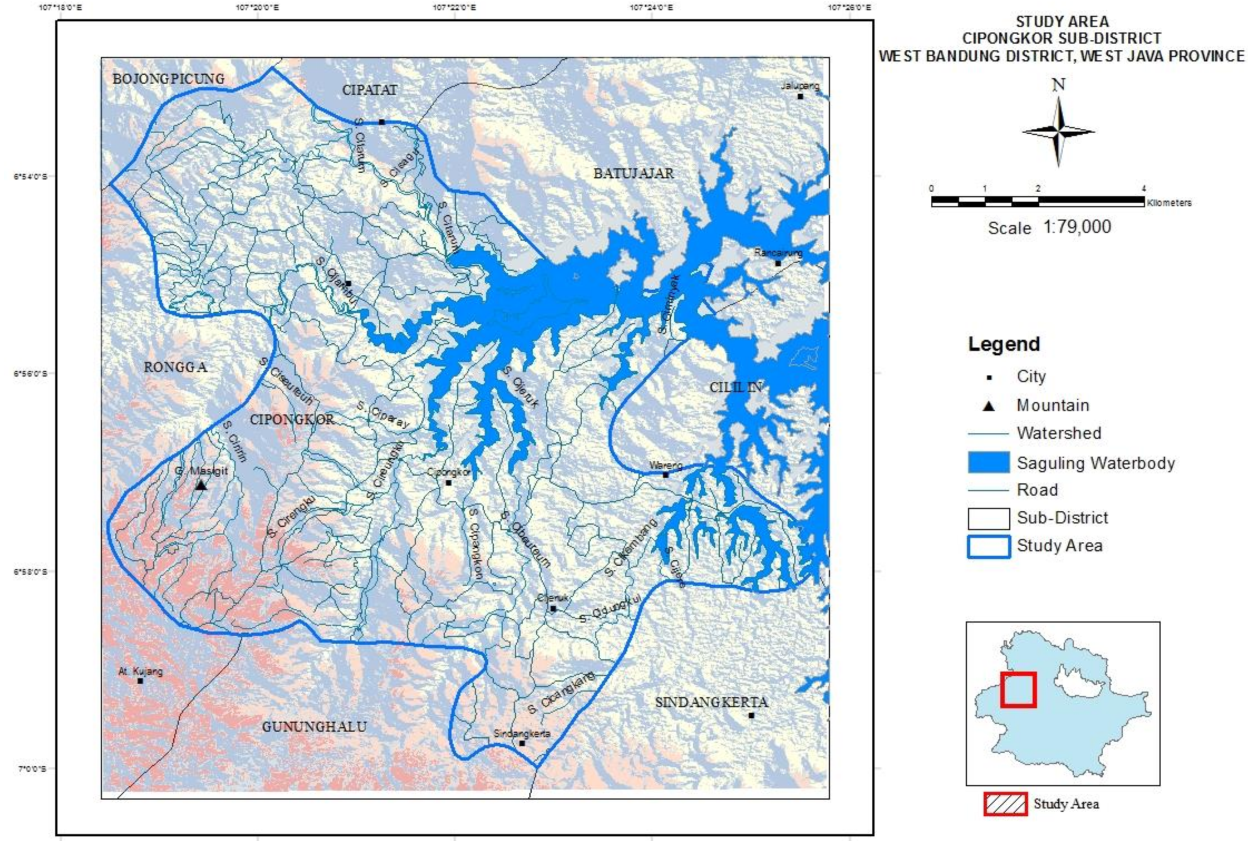

Figure 1. Study Area

3. DATA AND METHODOLOGY

3.1 Data

The input data for the soil erosion potential assessment are a Digital Elevation Model (DEM) from SRTM (USGS), Landsat satellite imagery data, topographic base map, annual rainfall map, geological map (Koesmono & Suwarna 1993). All datasets are saved as separate layers in the GIS database and transferred to vector files for further processing.

3.2 Methodology

Three main steps are employed in this research: preparatory desktop study, fieldwork, and laboratorium analysis. Preparation includes literature study, morphological analysis using topography map, DEM SRTM and Landsat analysis, and analysis of the regional geological map. The fieldwork consists of data collection, outcrop analysis, and landuse. Laboratorium analysis consist of processing data in an GIS- and remote sensing environment to analyze relation between rainfall factors, geological factors, landuse and erosion factors to determine the potential erosion zones of study area.

In order to assess erosion risk for Cipongkor the RUSLE equation was used. Six major factors are used to calculate the soil loss in the study area, where each factor is the numerical estimate of a specific condition that affects the severity of soil erosion at a particular location. It computes the average annual soil loss for a given plot as the product of six major factors (Wischmeier & Smith 1978), as shown in equation (1):

$$A = R * K * LS * C * P \quad \text{……………………………………………………….. (1)}$$

Where:

A : represents the potential long term average annual soil loss in tons per hectare (ton/ha/yr);
R : rainfall–runoff erosivity factor (mm/yr);
K : soil erodibility factor (ton/ha);
LS : slope length–steepness factor (dimensionless);
C : crop management factor (dimensionless);
P : is the land management practice factor (dimensionless).

The RUSLE model has several advantages: 1) it is easy to implement and understand from a functional perspective, 2) is compatible with Geographic Information System (GIS), and 3) the data requirements to implement the model are not too complex or unattainable especially in a developing country (Millward & Mersey 1999)

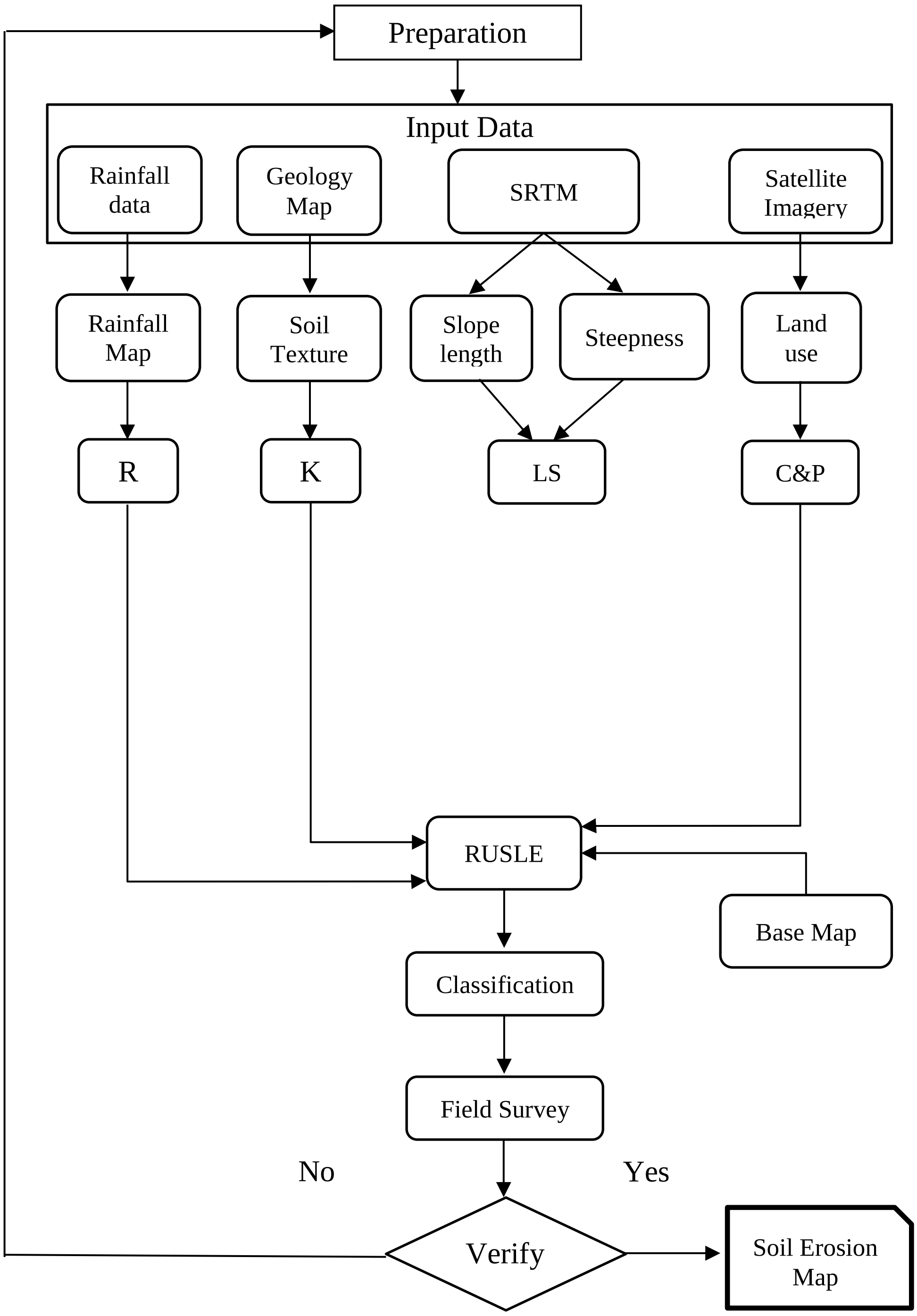

Figure 2. Flow chart of methodology

3.2.1 Rainfall index (R)

The contribution of rainfall to erosion is strongly dependening on rainfall intensity and distribution.

Rainfall index is an average annual value, calculated as a summation of event-based energy-intensity values (EI_{30}) for a location divided by the number of years over which the data were collected. EI_{30} is defined as the product of kinetic energy of rainfall and the maximum contiguous 30 minutes rainfall intensity during the rainfall event. Based on Ambar (1986), the equation to compute erosivity values for each discretized polygons using GIS is:

$$EI_{30} = 0{,}41\ R^{1{,}09} \quad (2)$$

Where:

R : is the annualy rainfall (mm).

3.2.2 Soil Erodibility index (K)

Soil erodibility relates to the sensitivity of soil types to erosion. The erodibility factor (K) is represented by the relationship between the soil loss and the rainfall erosivity, when such data are derived individually for each rainfall event (Mannigel et al. 2002). In this work, the K-factor was derived from the geological data available. The erodibility factor (K) of various types of soils was arranged in Table 1 and is based on predefined values from the Ministry of Forestry (1985).

Table 1. Soil erodibility index

No	Soil Texture	K
1.	Clay	0,02
2.	*Loam* clay	0,04
3.	*Loam* sand	0,30
4.	Sillty	0,20
5.	Sandy	0,70

3.2.3 Topography index (LS)

The topography index (LS) (or slope length and steepness factor) comprises of two elements: The slope length/flow length (L) represents the effect of slope length on erosion, while the slope gradient (S) is a slope steepness factor expressed as slope angle degree or percent (Arsyad, 2010). The spatial analyst toolkit of the GIS software is used to generate raster layers of slope gradient (degrees), and using the hydrology toolkit, flow direction and flow accumulation rasters are calculated. The LS factor is calculated based on the following equation recommended by Griffin, M., et.al. (1988):

$$LS = Pow\left([Flow\ Acc]x\ \frac{resolution}{22.1,\ 0.6}\right) x\ Pow\left(\frac{(Sin[slope\ gradient]x0.001745)}{0.09,\ 1.3}\right) \ldots (3)$$

Where:

Pow : power function in ArcGIS® spatial analyst.

Flow Acc : is the flow accumulation

Slope Gradient : is the slope degree

Table 2. Slope gradient and resulting Slope Length Index (LS) according to Ministry of Forestry (1986)

No	Slope (%)	LS
1.	0 – 5	0,25
2.	5 – 15	1,20
3.	15 - 35	4,25
4.	35 - 50	7,50
5.	> 50	12,0

3.2.4 Vegetation Cover index (C)

Land use prevailing in Cipongkor mainly includes, settlements, forests, thicket, garden (horticulture), paddy fields, mixed garden, and dry fields (Table 3). These land use features were classified based on their effects on erosion using conversion values from the Ministry of Forestry (1998), the canopy cover (how much precipitation would reach the ground) and vegetation cover.

Table 3. Cover crop and vegetation cover index (Ministry of Forestry, 1985).

No	**Class name**	**CP**
1.	Settlement	0,60
2.	Mixed Garden	0,30
3.	Paddy Field	0,05
4.	Dry fields	0,75
5.	Garden	0,40
6.	Forest	0,03

3.2.5 Land Management Practice index (P)

The land management practice factor (P) considers particular soil conservation practices implemented in the study area. P factor relates strongly with land conservation. It is the ratio of soil erosion with land management practices (e.g. terracing, advanced cropping patterns) to soil erosion without land management under otherwise identical circumstances. For this case study the P factor is considered 1. Because there is so far no soil conservation practice in place and land managementis generally poor.

3.2.6 Calculation of Erosion Risk with RUSLE

The various factors are put into equation (1) using GIS software and classified into 5 different erosion level classes: very high, high, moderate, low and very low, as shown in table 4. The classification is based on governmental recommendations from the Ministry of Forestry (1998).

Table 4. The classification of erosion risk level (Ministry of Forestry 1998)

No	Soil loss (ton/ha/th)	Class of Erosion	Erosion Level
1.	< 15	I	Very high
2.	16 – 60	II	High
3.	60 – 180	III	Moderate
4.	180 – 480	IV	Low
5.	> 480	V	Very low

4. RESULTS AND DISCUSSIONS

Remote sensing data, GIS and the RUSLE erosion model has been integrated to estimate the level and spatial distribution of soil erosion in the study area. Four different erosion risk factors including rainfall erosivity (R), soil erodibility (K), slope length and steepness (LS), land cover management and soil conservation (CP) are calculated.

The rainfall erosivity factors (R) waz found to be in the range of 1500-3000 mm/year (Figure 4) with the highest values (2500-3000 mm/year) prevail in the western part of the study area and the lowest values (1500-2000 mm/year) occuring in the east.

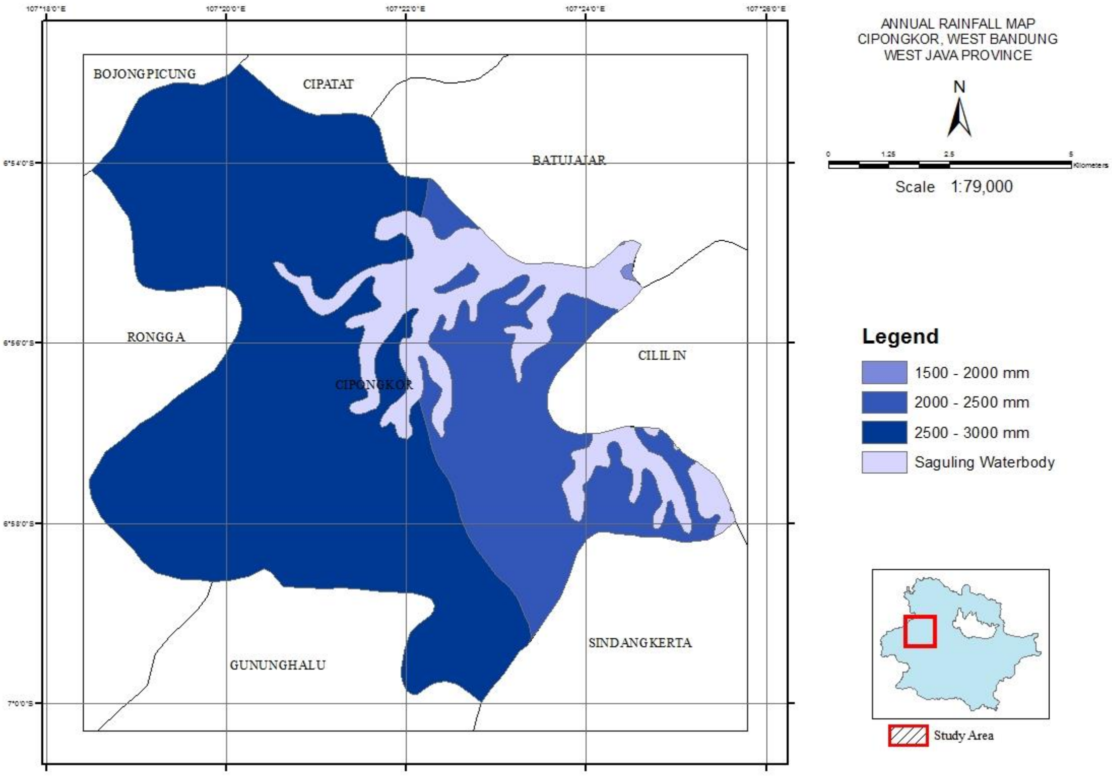

Figure 4. Spatial distribution of rainfall erosivity index (R)

Soil erodibility index (K) is derived from the geologic map (Ministry of Forestry 1985). The results of the geological rock unit conversion into erodibility is shown in (Figure 5). The study area are dominated by Tuff formations.

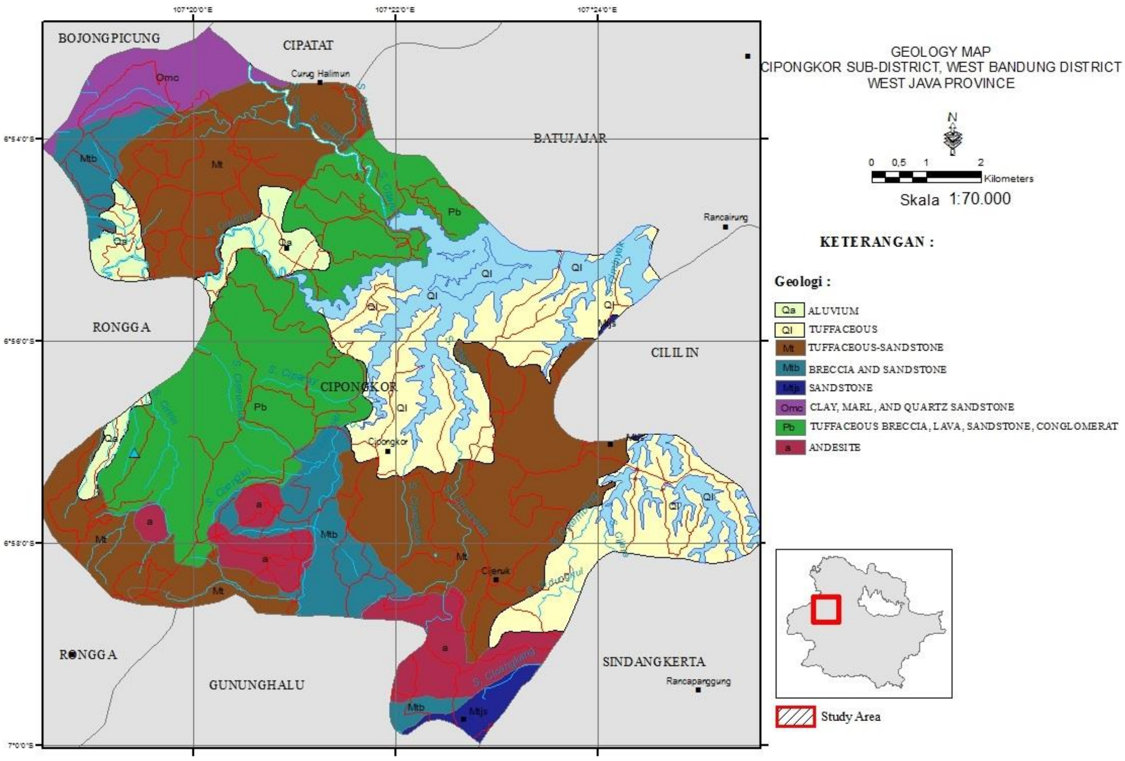

Figure 5. Geologic Map

The topography index and slope length and steepness (LS) was classified using the criteria of the Ministry of Forestry (1986). Results are represented in Figure 6 below.

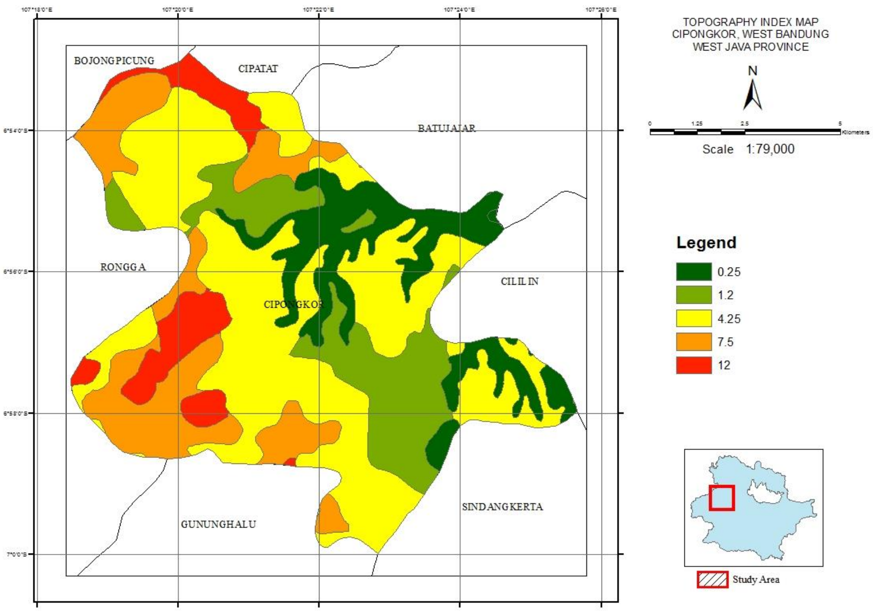

Figure 6. Topography Index

The soil conservation values (CP) are obtained based on the type of land use. Figure 7 presents the landuse map of the study area. The values are classified based on criteria from the Ministry of Forestry (1985).

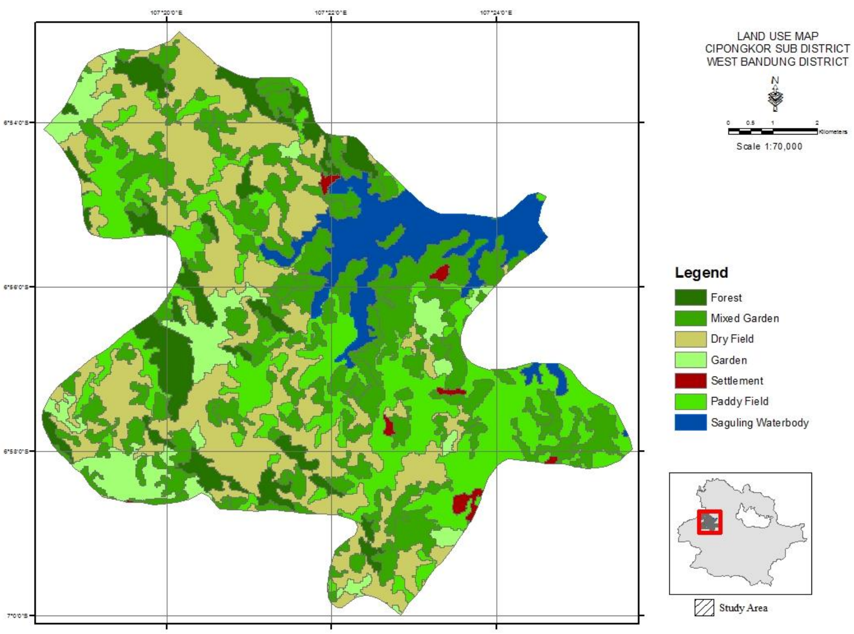

Figure 7. Land Use Map

The final RUSLE values are calculated according to the above mentioned equation using the conversion values of the individual indexes for each attribut. After calculation, the next step is to classify according to the limits of erosion potential.

The following table presents the size and percentage of the study area classified according to the level of soil erosion potential (Table 5).

Table 5. Distribution of Soil Erosion Potential in Cipongkor District

No.	Potential Of Erosion Level	Area (Ha)	Percentage (%)
1	Very Low	2032.3	22,47
2	Low	168.36	1,86
3	Moderate	1242.8	13,74
4	High	1485.3	16,42
5	Very High	4114.7	45,50
	TOTAL	**9043.46**	**100**

The soil erosion potential in the area and surrounding districts has been divided into five zones of soil erosion potential as shown. The soil erosion potential of Cipongkor and surrounding area is dominated by very high levels of erosion potential (41.28 km^2, or 45.50% of the total study area). The very high erosion potential areas are in the northwest, west, and southwest parts of the study area. Villages in North Cipongkor included are: Saguling, Cihea, Barangansiang, Sirnagalih, and Desa Cijambu. While South Cipongkor includes the Desa Cibenda, Cintaasih, Neglasari, Karangsari, Girimukti, Sindangkerta, and Desa Cijenuk. The results are represented in the following map (Figure 8).

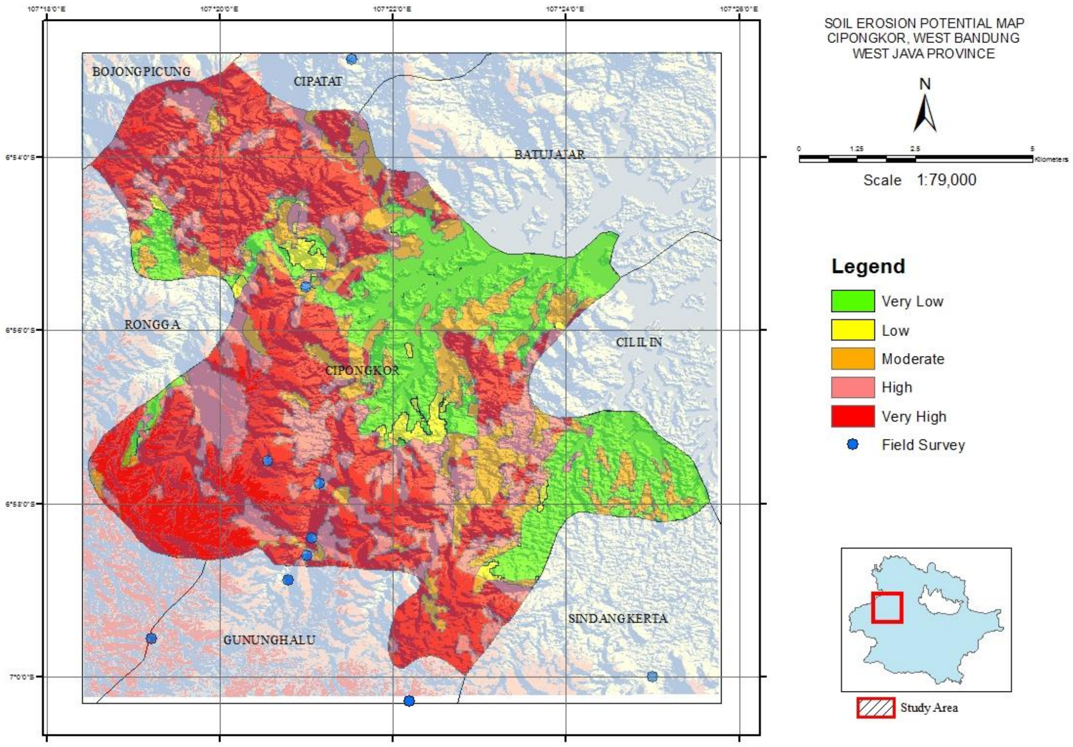

Figure 8. Soil Erosion Potential Map

4.1 Field Survey

The fieldwork is conducted in order to compare the occurrence of landslides in high soil erosion potential areas. The field survey focuses on the location of landslides especially in zones of high to very high soil erosion potential. Those landslide locations are also marked in the final soil erosion potential map (Figure 8).

Based on the presented field observations, erosion occurs in the study area due to natural and human factors. Those include overgrazing, overcropping, and deforestation. Landslides occur in high and very high soil erosion potential zones. Landslides occurs on steep slopes, area with active faults and mostly Tuff formations (Figure 9 and 10).

Table 6. Points of Field Survey

No.	Lat	Long	Location	Geology	Slope
Ero-1	-6.99	107.320	Cilabodas Village	Breksi/Andesit	54°
Ero-2	-7.00	107.369	Cicangkap Girang	Tuffa, Sand	65°
Ero-3	-7.00	107.416	Tugu Batas	Sand	40°
Ero-4	-6.95	107.342	M. Masigit	Andesit	45°
Ero-5	-6.96	107.342	Bojong Haur	Tuffa	36°
Ero-6	-6.97	107.340	Sodong Village	Tuffa	43°
Ero-7	-6.92	107.349	Sagulung Waterbody	Tuffa, Sand	60°
Ero-8	-6.89	107.358	Sagulung Waterbody	Tuffa, Sand	60°
Ero-9	-6.89	107.334	Sagulung Waterbody	Tuffa, Sand	60°

Figure 9. Erosion in the roadside Desa Saguling, Kec. Cipongkor

Figure 10. Massive landslides in the roadside Cipongkor-Saguling

5. CONCLUSIONS

Spatial modeling with GIS to determination the soil erosion potential using index value overlay techniques is capable to give a visual impression of the main factors contributing to soil erosion. Based on the study results most of the surroundings of Cipongkor is dominated by very high soil erosion potential. The areas of high and very high soil erosion potential are the areas of North Cipongkor: Saguling, Cihea, Barangansiang, Sirnagalih, and Cijambu village. While in the south they include the villages of Cibenda, Cintaasih, Neglasari, Karangsari, Girimukti, Sindangkerta, and Cijenuk.

Human activity is one of the main factors affect erosion potential in the study area and it is expected that the study results support the local government in terms of spatial planning, and the implementation of soil conservation methods and/or soil management regulations.

The link between landslides and the soil erosion potential in the study area needs further investigation and analysis. Nevertheless, increasing soil erosion and haphazard human interventions leading to destabilized slopes do aggravate the potential for damaging large scale landslide events.

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BIOGRAPHICAL NOTES

Denny Lumban Raja is a Doctoral candidate of Geological Engineering at Padjadjaran University. He received his Master degree in Geodesy and Geomatic from Bandung Institute of Technology. He is an employee and a teacher for the Ministry of Energy and Mineral Resources since 2005. He has been actively involved in various research projects using remote sensing, GIS, erosion modelling, and information technology.

Adang Saputra received his Master Degree and Doctoral degree from Postgraduate program of Geological Engineering at Padjadjaran University. He is an employee and trainer for the Ministry of Energy and Mineral Resources since 1990 until now. His research interest include Geographic Information System (GIS), Remote Sensing, tectonic geomorphology and erosion modeling.

Johannes Anhorn is working for the German Federal Institute for Geosciences and Natural Resources (BGR, Hannover) in the German Indonesian Development Cooperation Project “Mitigation for Georisks” in Bandung, Indonesia. He holds a Geography Diploma of Heidelberg University (minor Remote Sensing and Political Science), where he is also persueing his PhD. His research focuses on Human-Environmental Interactions in the field of natural hazards and resilience.

CONTACTS

Denny Lumban Raja
Human Resource Development Center for Apparatus
Ministry of Energy and Mineral Resources
Cisitu Lama Road 37
Bandung
INDONESIA

Tel. +6222 2502428
Fax +6222 2506224
Email: denny.lumbanraja@esdm.go.id
Web site: www.ppsdmaparatur.esdm.go.id

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