ASEAN Engineering Journal

Full Paper

PREDICTION OF EROSION IN HILLY AREAS OF KHILAU SUB-SUB WATERSHED USING THE RUSLE METHOD

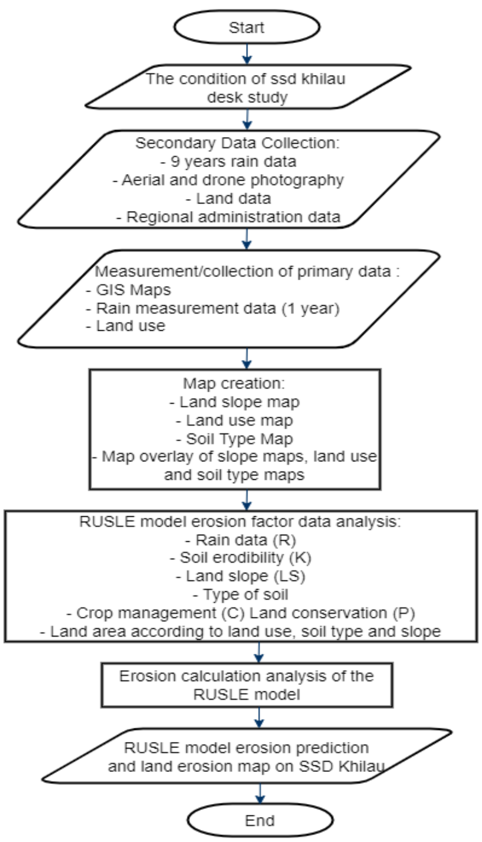
Yuda Romdania*, Ahmad Herison

Faculty of Engineering, Lampung University, 35141, Bandar Lampung City, Lampung, Indonesia

Article history
Received
23 September 2022
Received in revised form
04 May 2023
Accepted
27 May 2023
Published online
31 August 2023

*Corresponding author
yuda.romdania@eng.unila.ac.id

Graphical abstract



Abstract

Soil erosion poses an environmental threat to the sustainability and productivity of the land in the Khilau Sub-Sub Watershed, Bulok Sub-Watershed, Sekampung Watershed, Pesawaran Regency. The research aimed to predict soil erosion by implementing the RUSLE model on the Khilau Sub-Sub-Watershed, combined with remote sensing, GIS techniques, and field observation. This research is divided into several phases, i.e. soil data collection, getting satellite maps, obtaining rainfall data from 2011 to 2019, making the topographic maps of land slopes, land use, and soil types, whose overlay will be made, and data analysis. The results show that the areas with the highest risk of erosion were located on the hills and in the areas characterized by steep slopes of 1,395.48 (t/ha/year) with a slope level of >45% (very steep), which had the highest LS factor value and were characterized as areas with strong relief, i.e. hills (with a slope level of >20%). In conclusion, the erosion rate of the Khilau Sub-Sub Watershed is dominated by the erosion falling into the heavy category with an average erosion value of 405.17 (t/ha/year) by soil parameter, slope inclination, vegetation cover, and climate. The most influential factors in this study were the climate and slopes, where the lands used as mixed gardens and annuals had a high risk of erosion. So, it is of utmost importance to take soil protection and conservation measures for potential erosion protection in the area.

Keywords: Erosion, Slope Inclination, RUSLE, Khilau Sub-Sub Watershed, GIS.

1.0 INTRODUCTION

Land is basically a limited natural resource which is produced naturally and subjected to being harmed by mankind. Soil erosion is soil degradation having been one of the most important socio-economic and environmental problems since it results in a decrease in the productivity and quality of soil resources [1,2,3].

Indonesia has a tropical climate with hilly terrain and often has high rainfall rates. This combination poses a high risk of erosion. The steep slope of land contributes to the increasing rate of soil erosion [4]. Indonesia's increasing population (from 211 million people to 267 million people in the last two decades) is increasing pressure on the food sector, so that people use protected forest areas with steep slopes as their agricultural lands. Hillside farming, which is supposed to be done carefully in order to avoid soil erosion, is often done improperly. Sumatra Island itself is among the areas with the highest risk of erosion [5].

On the south of Sumatra Island, Lampung Province, there is a watershed called *Khilau Sub-Sub-Watershed* (Khilau SSW), the Way Bulok Sub-Watershed, as part of the Way Sekampung Watershed in Pesawaran. The upper reaches of the Khilau SSW were originally a protected forest area with land slopes steep in the majority [6]. Over time, this area changed into a cultivation plantation of societies producing cocoa, vegetables, rice, bananas, and coffee, with cocoa as its leading commodity. The technical implementation of agriculture in this area does not prioritize the importance of the geographical slopes of the land, which are its character. Therefore, the potential of erosion and flooding to occur increases [7].

Land erosion has a negative effect on local and downstream communities of watersheds (DAS), so it is necessary to predict it [8]. Numerical models play an important role in the investigation of soil erosion. Various models of soil erosion have been developed to assess soil loss. These models are distinguished by complexity, data, and usage [9]. The Universal Soil Loss Equation (USLE) was published in 1965 and revised in 1978 by Wischmeier and Smith, is an empirical model widely used to estimate soil erosion [10]. However, after in-depth analyses of the USLE method and theories of hydrology and erosion, the method was developed into the Revised Universal Soil Loss Equation (RUSLE) method, which is the modified version of USLE, to determine the estimation of soil loss in various parts of the world [10]. Now, RUSLE is a soil erosion model widely used to predict soil loss on different spatial scales. The calculation of the annual prediction of land erosion (such as that with the RUSLE model) is limited in thrift, representation, and reliability of data results [11]. However, researchers around the world widely use the RUSLE model extensively in spite of the disadvantage of taking a sample from a complementary and large environment, which is the inability to provide a spatial distribution of soil erosion loss [11]. The RUSLE method can be used to predict annual land erosion since it requires less field data than others, which are more complex models. Parameters of the RUSLE model are easily derived from other data sets, such as a slope inclination calculated based on a digital elevation model (DEM) with GIS or a land use map that derives from satellite imagery [12.13].

The application of the RUSLE model on the Khilau SSW was supported by the data from the research results of the Capacity Development for Implementing Rio Conventions through Enhancing Incentive Mechanisms for Sustainable Watershed/Land Management (CCCD) and some of the measurement results themselves. Data from 3 nearby rain stations and one year of direct retrieval of the field was used as multi-annual climatological data. This study resulted in the soil erosion estimation using the RUSLE method accompanied by GIS with the landscape specifications mostly hilly and having steep slope inclinations in order to provide a good basis for protective measures against erosion and the implementation of the targeted policies. The purpose of the study was to predict soil erosion through the application of the RUSLE model on the Khilau SSW, accompanied by the remote sensing, GIS technique, and field observation.

2.0 METHODOLOGY

2.1. Study Area

The research was conducted in the Khilau Sub-Sub-Watershed (SSW), which is the headwaters of the Way Bulok Watershed, the Way Sekampung Watershed of Pesawaran Regency. The main river in the Khilau SSW is the Right Cong River with a river length of 5 kilometers from the upper reaches of the watershed. The height difference between the highest point and the lowest point of the land is 700 meters, so that the gradient of the Khilau SSW is 15%. Administratively, it is an area of 6,280 ha, more or less [7], while by GIS measurement, it is only about 671.68 ha. The map of the study area was made and is represented by Figure 1.

2.2 Stages of Research

The research was conducted in several phases, which were:

1. Collection of Information and literature (desk study)
2. Collection of the necessary secondary data from the Capacity Development for Implementing Rio Conventions through Enhancing Incentive Mechanisms for Sustainable Watershed/Land Management (CCCD) Team, which was the soil data of the Khilau SSW to obtain a soil type map.
3. Obtaining data in the form of satellite maps from the Geospatial Information Agency, which were then processed into the map of the Indonesian landscape in Pesawaran.
4. Acquiring the data of rainfalls from 2011 to 2019 from 3 nearby rain stations; Way Gatel, Gading Rejo, and Gedong Tataan rain stations, along with the primary data in the form of the data of rainfalls in 2020 according to their own measurements.
5. Creation of the topographic maps of land slopes, land use, and soil types.
6. Analysis of the data of rainfalls, soil structure, slope inclinations, land use, and conservation management in the Way Khilau Sub-Sub-Watershed with GIS.
7. Creation of an overlay from the topographic maps of land slopes, land use, and soil types.
8. Determination of the land area according to the overlay.
9. Analysis of the calculation results of land erosion.

2.3. Data Analysis

The parameters of RUSLE modified according to the factors are as follows: the erodibility of the soil, the topography of the slope inclinations, the cover management, and the conservation. The factors requiring analysis encompassed the rain data and erosivity. In order to get the value of the rainfalls in the area, the Thiessen Polygon method from the 3 nearest rain stations; Way Gatel, Gading Rejo, and Gedong Tataan stations, was applied. The results were then put in tables and the calculation of rain erosivity (R) was performed with the Lenvain equation [14.15];

$$R = (2.21Rt)^{1.36} \quad (1)$$

Where R is the value of rain corrosiveness, Rt is the annual average rainfall (cm).

Soil erodibility (K) is the illustration of the resistance of soil particles when eroded and transported due to the kinetic energy of rainwater [16] as well as the illustration of the susceptibility of soil or surface material to erosion, sediment transportability, and the rate of the runoff magnitude with certain rainfall inputs measured under standard circumstances. K represents the soil characteristics related to erosion in terms of the rate of soil loss per rain-runoff [12]. The K value was calculated through the following equation [17]:

$$100\ K = 1.292\ [2.1\ M1{,}14\ (10\text{-}4)\ (12\text{-}a) + 3.25\ (b\text{-}2) + 2.5\ (c\text{-}3)] \qquad (2)$$

Where K is the soil erodibility value, M is the value of particle-sized soil texture (% dust + % fine sand) (100% clay), a is the percentage of organic matter (laboratory), b is the soil structure class, and c is the soil permeability class (laboratory).

The next step was to calculate the slope values of the land, with the slope lengths (L) regarded as the lengths of the slopes affected by erosion. The slope steepness (S) is the influence of the inclinations of the slopes on erosion. LS represents the ratio of the soil loss at the slope length and steepness and the soil loss on the slope. If the slope of the land surface was steeper, the probability of erosion in the area was greater [18]. The following is the equation applied to the calculation of the LS values:

$$LS = L0.5\ (0.0138+0.00965\ s+0.0138\ s^2) \qquad (3)$$

Where L is the length of the slope (m) and S is the inclination of the slope (%). The slope inclination and the value of each class is shown in Table 1 [18].

As for the analysis of the land cover factor (CP), the C value (crop management factor) was carried out based on the land use map or the use of the land with the help of GIS and the table of land use and cover values, while the P (soil conservation) value was obtained from direct observation of the research site.

Table 1 Slope Classes

Class	Slope Inclination (%)
Flat	0-8
Ramps	8-15
A Bit Steep	15-25
Steep	25-45
Very Steep	>45

(Source: Arsyad, 2010)

The next analysis covered the determination of the land obtained from the combination of the three maps (overlay). The map was initially processed through the processing of the satellite imagery from the Geospatial Information Agency (BIG) into the map of the Indonesian landscape in Pesawaran with the aid of GIS to obtain the topographic maps of soil types, slope inclinations, and land use. With GIS, the three maps were then overlaid to obtain the land units by type.

The next one was calculating the predictions of land erosion with the RUSLE model, taking into account rain erosivity, soil erodibility, and topographic factors as natural factors determining the erosion processes or as factors of erosion susceptibility or potential. The erosion rates were calculated using the following equation:

$$EA = R.\ K.\ L.\ C.\ P \qquad (4)$$

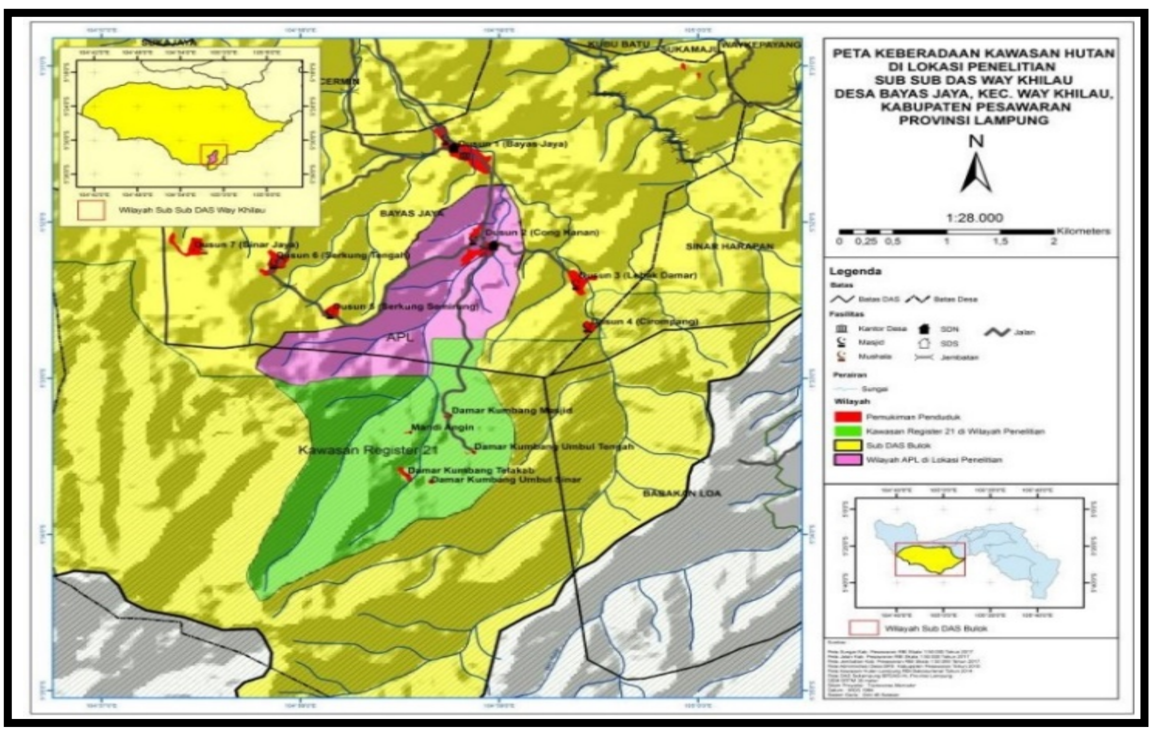


Figure 1 Research Location Map
(Source: BBWS, 2020)

Where *EA* is the amount of the average soil loss per year (t/ha/th) or (t/acre/th), *R* is the soil erosive factor/erosion power index, *K* is the soil erodibility factor, *L* is the slope length and steepness factor, *C* is the land cover factor, and *P* is the management and conservation effort factor. After the erosion rate analysis was conducted, it was viable to do the identification and mapping of soil erosion-prone areas based on the land area data obtained from the overlay of slope, land use, and soil type maps.

3.0 RESULTS AND DISCUSSION

3.1. Analysis of Rain and Erosive Data (R)

The analysis of the rain data in this study involved the data of the daily rain from 2011 to 2019 obtained from the 3 nearby rain stations; Way Gatel, Gading Rejo, and Gedong Tataan rain stations, and the primary data in the form of the data of the rain in 2020 with their own measurements. After processing all the rain data, the data needed for erosivity (R) analysis was obtained and is shown in Table 2.

As informed by Table 2, the highest rainfall occurred in 2013 with an average rainfall of 155.57 cm. Then, the calculation of erosivity was carried out with the data of the monthly average rainfalls for the last 10 years using the Lenvain formula;

$$R = (2.21Rt)^{1.36}$$
$$= 2.21(155.57)^{1.36}$$
$$= 2.115.5193 \text{ tons/ha/cm of rain}$$

Based on the calculation results, the corrosiveness of the rain in the Khilau SSW was 2.115.5193 tons/ha/cm of rain.

Table 2. Monthly Average Rainfalls in the Khilau SSW

Year	Month (mm)													
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total	Rainfall (cm)
2011	278.40	136.00	137.33	147.33	110.17	36.00	38.50	102.93	73.93	126.00	123.17	159.50	1469.27	146.93
2012	220.33	200.50	97.50	132.00	52.17	29.83	12.67	0.50	20.17	81.67	91.67	281.17	1220.17	122.02
2013	289.33	330.17	100.67	157.33	112.83	35.33	191.67	89.17	79.17	136.00	197.33	371.33	2090.33	209.03
2014	317.00	170.67	115.00	72.00	115.33	75.67	25.00	86.67	1.00	43.33	66.00	288.67	1376.33	137.63
2015	401.00	233.67	176.33	171.33	64.33	42.33	16.00	0.33	12.33	0.00	105.33	195.67	1418.67	141.87
2016	223.00	296.00	252.33	237.67	203.00	79.00	113.33	26.00	124.33	91.67	270.00	128.00	2044.33	204.43
2017	148.00	281.33	157.00	175.67	135.33	53.67	99.33	72.33	105.33	192.67	153.50	252.67	1826.83	182.68
2018	165.00	207.33	319.67	217.67	105.33	94.00	8.67	8.33	50.00	18.00	97.00	128.67	1419.67	141.97
2019	200.93	295.33	246.83	185.33	45.00	58.00	68.67	12.00	6.00	9.67	19.67	208.83	1356.27	135.63
2020	324.31	138.00	146.78	87.00	43.10	150.00	107.06	6.71	6.72	80.94	45.84	198.82	1335.28	133.53
Average	256.73	228.90	174.94	158.33	98.66	65.38	68.09	40.50	47.90	77.99	116.95	221.33		155.57

(Source: Processed primary data, 2022)

3.2. Soil Erodibility Factor (K)

Soil sample taken from the Khilau SSD was tested for organic matter content in the soil laboratory. The results showed the majority of the sample was the dystropept type with a figure range of 1.78%-5.12%. The results of the soil laboratory test were analyzed using permeability tables and the following values were obtained: the land cover values (K) of the primary huts, mixed gardens, shrubs, annuals, and rice fields were 0.13, 0.31, 0.23, 0.16, and 0.21 respectively. The values fell into the *low* to *medium* categories. Then, the map of the soil types of the Khilau SSW was made and is represented by Figure 2.

3.3. Length (L) and Slope (S) Factors

The analysis of the slopes in the Khilau SSW was carried out based on the slope inclination map (Figure 3) and the area of the class of each slope inclination is found in Table 3.

Table 3. Area of the Class of Each Slope

Class	Slope (%)	LS value	Space (ha)	Percentage (%)
I	0-8 (Flat)	0.32	18.1245	2.90
II	8-15 (Hilly)	0.96	57.25	9.17
III	15-25 (A Bit Steep)	2.3	142.501	22.82
IV	25-45 (Steep)	6.29	276.906	44.35
V	>45 (Very Steep)	9.56	129.626	20.76
Total			624.41	100

3.4. Land Cover Factor (CP)

The most dominant plant factor (C) has a different influence from the conservation factor (P), so in the RUSLE method, the two variables are separated [19]. For the Khilau SSW, the P factor was set at 1 because in the entire watershed, no significant anti-erosive engineering activities existed. Figure 4 shows the distribution of the C values derived from the land use patterns based on the interpretation of the satellite imagery in the form of a land use map.

3.5. Determination of Land Areas by Land Use, Soil Type, and Slope Inclination

The determination of the land areas was on the basis of the overlay of the three maps; soil type, slope inclination, and land use maps, in the Khilau SSW. The result was 25 land units with their respective areas, as shown by Table 4. Figure 5 portrays the land area map.

3.6 Land Erosion Prediction (EA)

Based on the values of the factors in the RUSLE equation, the prediction of land erosion was calculated. The analysis of the erosion prediction is in Table 4.

Referring to Table 4, the erosion calculation with the RUSLE method signified that the annual average soil loss of the Way

Khilau SSW was approximately r 265,918.64 (t/year) or at a specific rate of 405.17 (t/ha/year).

In the table, it is clear that the large distribution is seen in the distribution of erosion per land use type in the watershed, with varied erosion values, from 0.19 (t/year) to 79,113.72 (t/year). From the observation, it appears that the areas with the highest risk of erosion were the hills and those marked with steep slopes of 1,395.48 (t/ha/year) and with a slope level of >45% (very steep), which led to the highest LS factor value and were characterized as strongly embossed areas, i.e. hills (slopes >20%), while the lowest erosion value belonged to a flat topography area (forest) with a slope level of 0-8%. This area had an erosion potential value of 0.09 (t/ha/th).

The review of the model parameters led to the assessment that the highest R value resulted in the high potential for the erosion from rainfall, the high K value indicated how easily the land eroded [20], a minimum C value signified a land with dense vegetation so that it was protected from erosion, while for a maximum P (close to 1), it indicated an area without conservation.

Table 4. Area of Each Slope Class

Land Unit	Land Use	R	Slope	K	LS	CP	EA ton/ha/yr	Space (ha)	Total Erosion ton/year
1	Forest	2115.52	0-8%	0.13	0.32	0.001	0.09	2.17	0.19
2	Mixed Garden	2115.52	0-8%	0.31	0.32	0.1	20.99	9.45	198.40
3	Paddy	2115.52	0-8%	0.21	0.32	0.01	1.42	1.64	2.33
4	Shrubs	2115.52	0-8%	0.23	0.32	0.3	46.71	1.53	71.42
5	Annuals	2115.52	0-8%	0.16	0.32	0.4	43.33	2.34	101.52
6	Forest	2115.52	8-15%	0.13	0.96	0.001	0.26	6.60	1.74
7	Mixed Garden	2115.52	8-15%	0.31	0.96	0.1	62.96	34.43	2,167.64
8	Paddy	2115.52	8-15%	0.21	0.96	0.01	4.26	3.42	14.57
9	Shrubs	2115.52	8-15%	0.23	0.96	0.3	140.13	4.54	636.59
10	Annuals	2115.52	8-15%	0.16	0.96	0.4	129.98	6.64	863.56
11	Forest	2115.52	15-25%	0.13	2.3	0.001	0.63	23.18	14.66
12	Mixed Garden	2115.52	15-25%	0.31	2.3	0.1	150.84	92.11	13,893.95
13	Paddy	2115.52	15-25%	0.21	2.3	0.01	10.22	3.03	30.95
14	Shrubs	2115.52	15-25%	0.23	2.3	0.3	335.73	9.13	3,064.14
15	Annuals	2115.52	15-25%	0.16	2.3	0.4	311.40	13.01	4,050.83
16	Forest	2115.52	25-45%	0.13	6.29	0.001	1.73	36.22	62.65
17	Mixed Garden	2115.52	25-45%	0.31	6.29	0.1	412.51	191.79	79,113.72
18	Paddy	2115.52	25-45%	0.21	6.29	0.01	27.94	2.19	61.27
19	Shrubs	2115.52	25-45%	0.23	6.29	0.3	918.16	18.71	17,177.47
20	Annuals	2115.52	25-45%	0.16	6.29	0.4	851.62	27.45	23,378.28
21	Forest	2115.52	>45%	0.13	9.56	0.001	2.63	12.37	32.52
22	Mixed Garden	2115.52	>45%	0.31	9.56	0.1	626.96	119.64	75,010.96
23	Paddy	2115.52	>45%	0.21	9.56	0.01	42.47	0.36	15.12
24	Shrubs	2115.52	>45%	0.23	9.56	0.3	1,395.48	14.57	20,334.02
25	Annuals	2115.52	>45%	0.16	9.56	0.4	1,294.36	19.79	25,620.12
Total area of land units in Khilau Sub-Sub-Watershed								**656.31**	
Amount of erosion in Khilau Sub-Sub-Watershed (ton/year)									**265,918.64**
Average erosion in Khilau Sub-Sub-Watershed (ton/ha/year)									**405.17**

In the USLE method, LS is effective if it is used for layer erosion, and short slopes (<300 m) are not suitable for concentrated flows or those with long slopes. This is because this model was originally intended to predict soil erosion on slopes that tend to be flat and homogenous (or without taking into account concave, convex, or the combination of the two, erosion of strong relief and complex basins) [21].

In the application of USLE, most of the time, only homogenous slopes are given inclinations, not those in poor local topography. Also, USLE is inapplicable to a slope length of less than 4 meters [22]. The reason is that on a slope of that length, the erosion is mostly groove erosion and slope erosion is often overlooked [23]. This is in line with the predicted erosion value obtained through the RUSLE method. It was higher than that obtained through the USLE method, which was 55,936.76 (t/year) or at a specific rate of 93,529 (t/ha/year) (Results of the previous studies in the same location). With all this in mind, considering the character of the Khilau SSW's, the majority of which have steep slopes, it is proven that erosion prediction values obtained through the RUSLE model are better for the planning of the risk management of erosion-triggered natural disasters in the region.

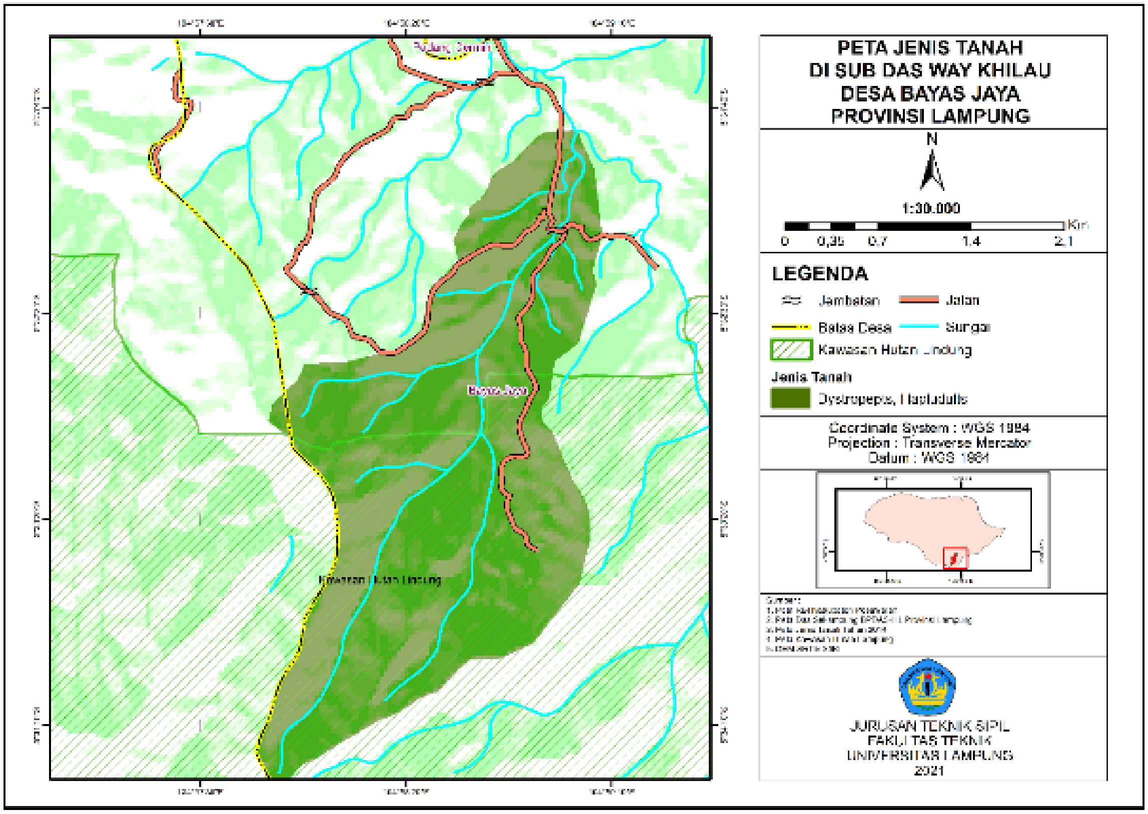


Figure 2. Soil Type Map

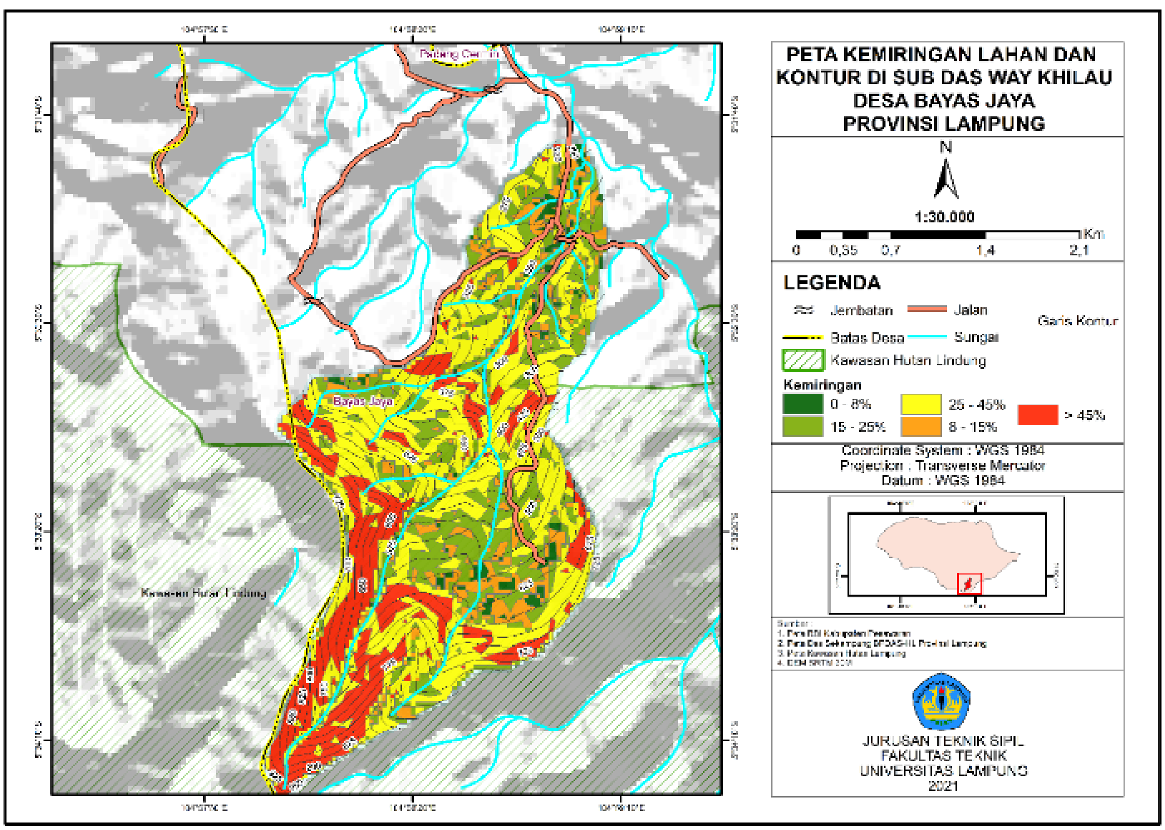


Figure 3. Slope Map

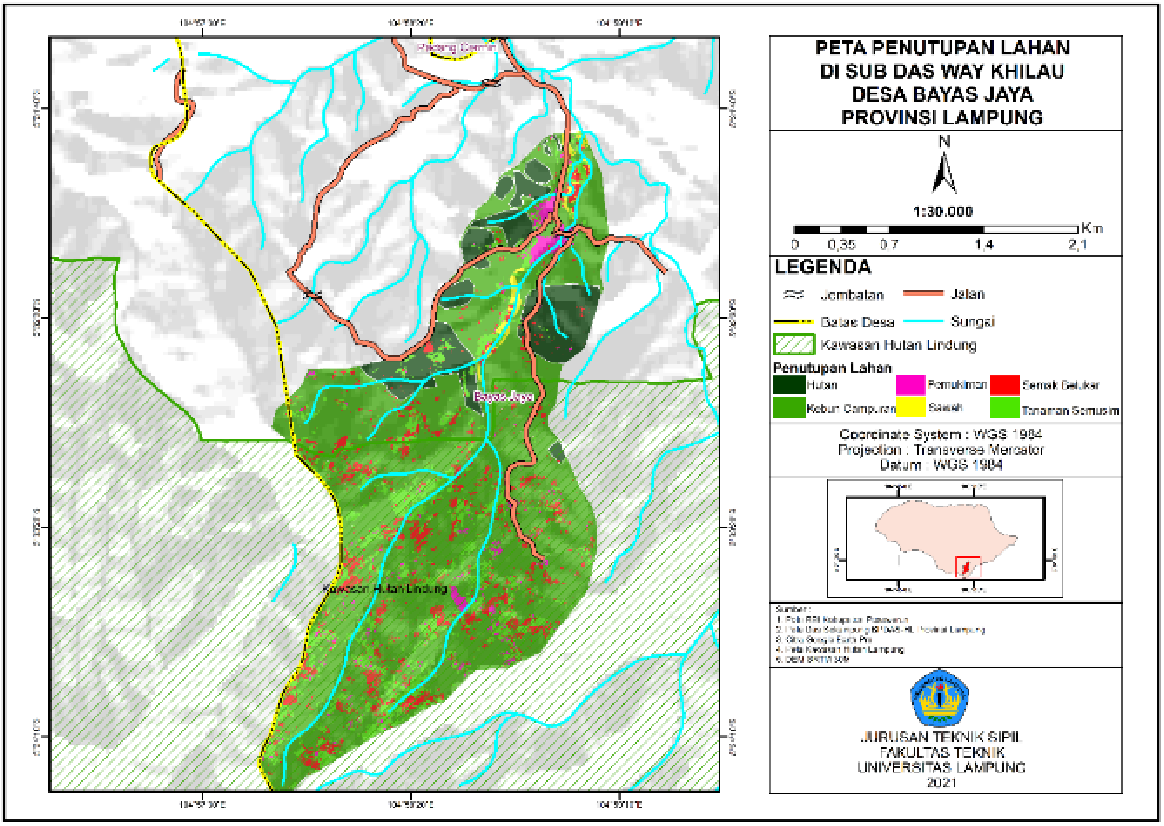


Figure 4. Land Cover Map

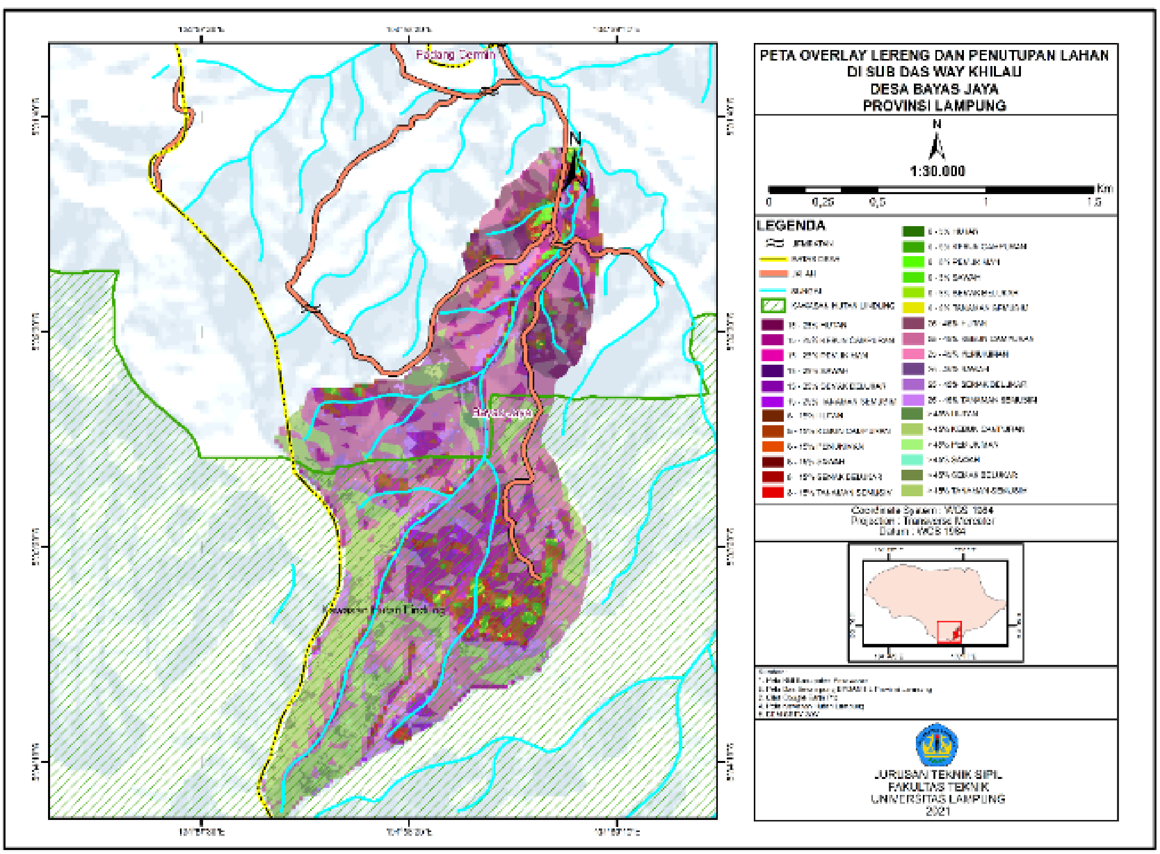


Figure 5. Land Area Map

4.0 CONCLUSION

In fine, from the results of the analysis of the erosion rate in the Khilau SSW, it is known that the forms of erosion are dominated by those categorized as heavy erosion with an average erosion value of 405.17 (t/ha/year) by soil parameter, slope inclination, vegetation cover, and climate. The most influential factors causing the erosion are the climate and slopes. The land use in the forms of mixed gardens and annuals has the highest risk of erosion. There is no need for soil protection and conservation measures for potential erosion prevention in the area.

Acknowledgement

We would like to thank Institute for Research and Community Service (LPPM), University of Lampung for their helpful feedback and support.

References

[1] Eswaran, H., Lal, R., Reich, P. F., 2001. Land degradation: An overview. In E. M. Bridges, I. D. Hannam, L. R. Oldeman, F. W. T. Penning de Vries, S. J. Scherr, & S. Sombatpanit (Eds.), Response to land degradation 20–35. New Hampshire, USA: Science Publishers, Inc: Enfield. https://www.nrcs.usda.gov/wps/portal/nrcs/detail/soils/use/?cid=nrcs142p2_054028.

[2] Lambin, E.F., Gibbs, H.K., Ferreira, L., Grau, R., Mayaux, P., Meyfroidt, P., Munger, J., 2013. Estimating the world's potentially available cropland using a bottom-up approach. Global Environmental Change 23 (5),892–901. https://doi.org/10.1016/j.gloenvcha.2013.05.005.

[3] Yadav GS, Das A, Kandpal B K, Babu S., Lal Rattan, Datta M, Das B, Singh R, Singh VK, Mohapatra KP, Chakraborty M.2021. The food-energy-water-carbon nexus in a maize-maize-mustard cropping sequence of the Indian Himalayas: An impact of tillage-cum-live mulching. Renew. Sust. Energ. Rev. 10.1016/j.rser.2021.111602.

[4] Lulseged Tamene A, Zenebeadimassu B,N, Ermiasaynekulu C, Tesfayeyaekob, 2018. Estimating Landscape Susceptibility To Soil Erosion Using A GIS-Based Approach In Northern Ethiopia. Nternational Soil And Water Conservation Research Journal. Vol. 5. P. 221-230. DOI Http://Dx.Doi.Org/10.1016/J.Iswcr.2017.05.002

[5] Dede Sulaeman & Thomas Westhoff, 2020. T*he Causes and Effects of Soil Erosion, and How to Prevent It. Article.* World Resources Institute.

[6] Banuwa, I. S., 2018. *Capacity Development for Implementing Rio Conventions through Enhancing Incentive Mechanisms for Sustainable Watershed/Land Management (CCCD)*. Lampung University.

[7] Zainal Abidin, 2018. S*tudy and discussion, socio-economic and gender studies in Way Khilau sub-watershed, Bulok sub-watershed, Sekampung sub-watershed,* Lampung province.

[8] BP Ganasri. 2015. Assessment of soil erosion by RUSLE model using remote sensing and GIS - A case study of Nethravathi Basin Duxbury, A.B. dan A.C. Duxbury, 1993. *Fundamental of Oceanography*. Wm. C Brown Publisher. Washington. 291 hal.

[9] Merritt, W.S., Letcher, R.A., Jakeman, A.J., 2003. A review of erosion and sediment transport models. Environmen. *Modelling Software* 18(8–9): 761–799. https://doi.org/10.1016/S1364-8152(03)00078-1

[10] Renard, K.G., Foster, G.R., Weesies, G.A., McCool, D.K., Yoder, D.C. 1997. P*redicting Soil Erosion by Water: A Guide to Conservation Planning With the Revised Universal Soil Loss Equation (RUSLE).* USDA Agriculture Handbook

[11] Yaser Ostovari, Shoja Ghorbani-Dashtaki, Hossein-Ali Bahrami, Mehdi Naderi, Jose Alexandre Melo Dematte, 2017. Soil loss prediction by an integrated system using RUSLE, GIS and remote sensing in semi-arid regionversi. *Geoderma regional Journal*. 11: 28-36.

[12] Zhujun Chen, LeiWang, Ansheng Wei, Jingbo Gao, Yongli Lu, Jianbin Zhou, 2018. Land-Use Change From Arable Lands To Orchards Reduced Soil Erosion And Increased Nutrient Loss In A Small Catchment. *Science of the Total Environment Journa*l. 648: 1097–1104.

[13] Habtamu Sewnet Gelagay, Amare Sewnet Minale , 2015. Soil Loss Estimation Using GIS And Remote Sensing Techniques: A Case Of Koga Watershed, Northwestern Ethiopia. *International Soiland Water Conservation Research Journal*. 4: 126–136.

[14] Fitriani, Sitti Nur Faridah2, dan Daniel Useng, 2019. Prediction of Erosion Rate Using the RUSLE Method and Remote Sensing in Bangkala Sub-watershed. *Jurnal Agritechno,* 12(1): 36-43. https://doi.org/10.20956/at.v12i1.188

[15] Danny Pamungkas, 2020. Mapping the Erosion Hazard Level with the RUSLE Method in the Garang Hulu Sub-watershed. Thesis. Department of Geography, Faculty of Social Sciences, Semarang State University

[16] Asdak, C., 2010. *Hydrology and Watershed Management.* Gadjahmada University Press. Yogyakarta. Fifth revised edition.

[17] Wang, B., Zheng, F., Römkens, M.J.M & Darboux F. 2013. Soil erodibility for water erosion: A perspective and Chinese experiences

[18] Arsyad, 2010. *Slope Class, Slope Analysis.* Erosion. IPB Pres

[19] Aprillya Nugraheni, Sobriyah, Susilowati. 2013. Comparison of Erosion Rate Prediction Results with the Usle, Musle, RUSLE Method in the Keduang River Basin. *e-Journal Matrix Civil Engineering*. 1(3): 318 – 325

[20] Arif Ashari., 2013. Study of the Erodibility Level of Several Soil Types in the Baturagung Mountains, Putat and Nglanggeran Villages, Patuk District, Gunungkidul Regency. *Information Journal 39 (2) 15 – 31*.

[21] Nikolaos Efthimiou, Evdoxia Lykoudi & Emmanouil Psomiadis. 2020. Inherent relationship of the USLE, RUSLE topographic factor algorithms and its impact on soil erosion modelling. *Hydrological Sciences Journal* 65(11): 1879 – 1893. DOI: 10.1080/02626667.2020.1784423

[22] M.E, Obi, F.K. Salako, R.Lal. 1989. Relative Susceptibility Of Some Southeastern Nigeria Soils to Erosion. *Catena.* 16(3): 215-225.

[23] Presbitero, Alan Ludovice. 2003. Soil Erosion Studies on Steep Slopes of Humid-Tropic Philippines. Thesis. Griffith University, Queensland, Australia. DOI: https://doi.org/10.25904/1912/3182