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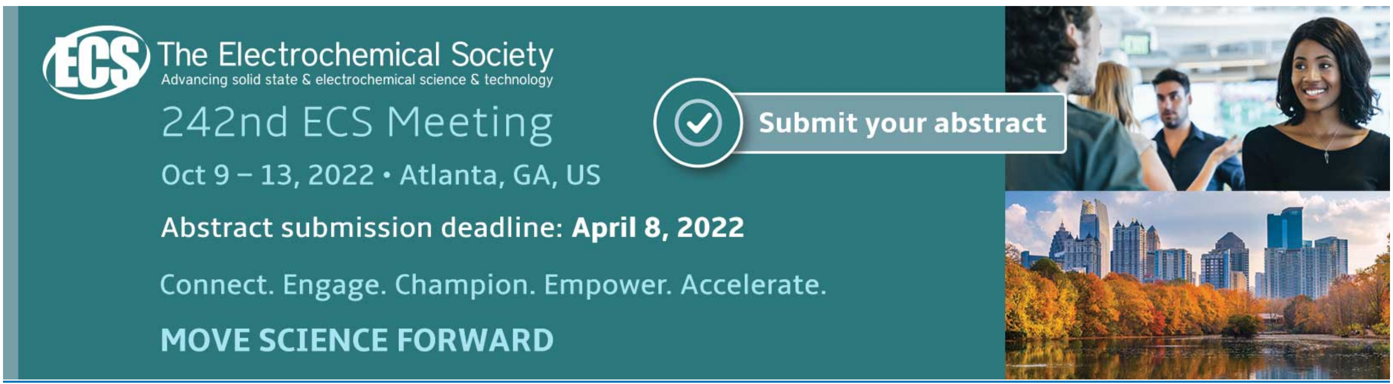

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Analysis of soil erosion and its relationships with land use/cover in Tabunio watershed

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Abstract. Erosion is detrimental to the health of the watershed exclusively in the upstream area of the watershed because it causes a lack of soil fertility because of being carried away by water, while in the downstream, it will reduce the river's capacity due to sediment deposits. This research aims to determine the annual rate of soil erosion and its relation to land cover using the Revised Universal Soil Loss Equation (RUSLE). Factors needed by RUSLE in estimating erosion include rain erosivity (R), Soil erodibility (K) length and slope (LS), land cover processing factor (CP), and the value of 0,61 as correction factors. We classify the result shows that the erosion rate in Tabunio watershed into five erosion classes, ranging from very light to very heavy classes. The erosion rate in the Tabunio watershed ranged from 0,000158 tons ha-1 year-1 to 9.453,6 tons ha-1 year-1. Very mild erosion occurred in 59.06% of the total area, mild erosion covered 18,80%, while moderate erosion occurred in an area 7,78%, the level of heavy erosion covers an area of 8,15%, while very heavy erosion occurred in an area of 6,21% of the total area of the Tabunio watershed. Forest dominates the erosion rate in the very mild class, the light class until the hefty class is dominated by plantation followed by settlement and mine. From this research, it is known that land cover and land use do not significantly affect the rate of erosion.

Keywords: natural disaster, watershed management, human activity.

1. Introduction

The rate of natural erosion and cropping in Indonesia lies at a fairly large level of 23 tons ha-1 year-1 for natural conditions, 40 – 400 ton ha-1 year-1 the cropping zone and has the second-highest rate of erosion on bare soil zone is at *120-460* ton ha-1 year-1 [1,2]. This erosion directly harms the health of the watershed in the upstream area of the watershed because it causes minimal soil fertility due to being carried away by water. On the other hand, downstream of the lack of river capacity due to sediment deposits, therefore it can cause runoff flooding [3].

A process in which the forces of water, wind and gravity destroy soil and then moved to another place is the definition of erosion. Sediment results from an erosion process, either as surface erosion, as surface, trench, or other types of erosions [4] and settles at the bottom of the foothills, in flood inundation areas, in waterways, rivers and reservoirs [5]. By combining factors such as planting

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systems, management levels, soil specifications, rainfall components and topography, we can calculate the erosion rate, and the result of which is the annual average erosion rate with units of ton ha-1 year-1 [6].

RUSLE, an erosion model intended used to predict the magnitude of annual erosion (A) by runoff from a field slope with certain crops and management systems. The factors needed by RUSLE in estimating erosion include rain erosivity (R), spill treatment factor and soil conservation (CP), soil erodibility (K) and slope length and slope (LS) and a value of 0.61 as a correction factor [7]. The cover management component (C-factor) represents the protective impact of soil cover against the erosive action of rainfall. This graph represents the link between soil loss in an area with particular plant cover and management and soil loss in an area with tilled soil that is permanently barren during the cropping season.

Getting information on these factors requires spatial-based processing with the help of GIS and remote sensing imagery for the data source of land parameters [8–10]. Remote sensing can give valuable information for enhancing the spatial modelling of soil erosion by identifying parameter erosion. These instruments are becoming increasingly essential for gathering surface data that will aid in the planning of soil cover. Remote sensing provides a variety of advantages over conventional data collecting methods, including the ability to gather data at a lower cost, perform data analysis quickly and precisely, and need fewer apparatus than on-site surveys. When combined with a geographic information system, remote sensing data may be used to examine changes in land use [11,12], monitor soil deterioration, and expect soil erosion [1,13].

The Tabunio Watershed Tanah Laut Regency, South Kalimantan Province, is one of the 108 watersheds in Indonesia designated as a watershed with priority management (Ministry of Forestry Decree No. SK. 328/Menhut-II/2009). The results of research on the characteristics of the Tabunio watershed in 2016 stated that the land condition in the Tabunio watershed comprised very high recovery critical land with a critical land area of 19.109,89 ha. Therefore, this study tried to determine the value of the erosion rate that causes critical land and found the relationship between erosion with land use and land cover in the Tabunio watershed. The availability of data and analysis of erosion rates are essential so that in the future, it can be planned with more reference to optimization, which can be used as recommendations for better watershed management.

2. Materials and Method

2.1. Data Source

Rainfall data from the *Center of Hidrometeorology and Remote Sensing* (*CHRS*) data portal website in https://chrs.web.uci.edu/, Map of Soil Type Review Scale of South Kalimantan Province by the Center for Research and Development of Land Resources in 2011, National DEM data from the website https://tanahair.indonesia.go.id/demnas, Sentinel-2 image obtained from the website https://sentinel.esa.int/web/sentinel/sentinel-data-access. Data on soil structure, soil texture, organic matter content and soil permeability value of each land unit were taken from field data and laboratory analysis results.

2.2. Study Area

The research location is in the Tabunio Watershed (DAS), which is located in Tanah Laut Regency with an area of 62.558,56 ha which is geographically located at 3°37'2.72"-3°51'51.43" LS and 114° 36'12.02 "-114°57'47.62" East Longitude. The Tabunio watershed from upstream to downstream is a rural, urban, and coastal area with a distinctive heterogeneous land cover, covering ten land cover classes, namely: settlements, plantations, rice fields, bare land, mining, forest, swamps, shrubs, ponds, and water bodies. The Tabunio watershed consists of 44 villages administratively, 4 sub-districts, and 10 sub-watersheds (ecologically). The map of the Tabunio watershed research location is shown in Figure 1.

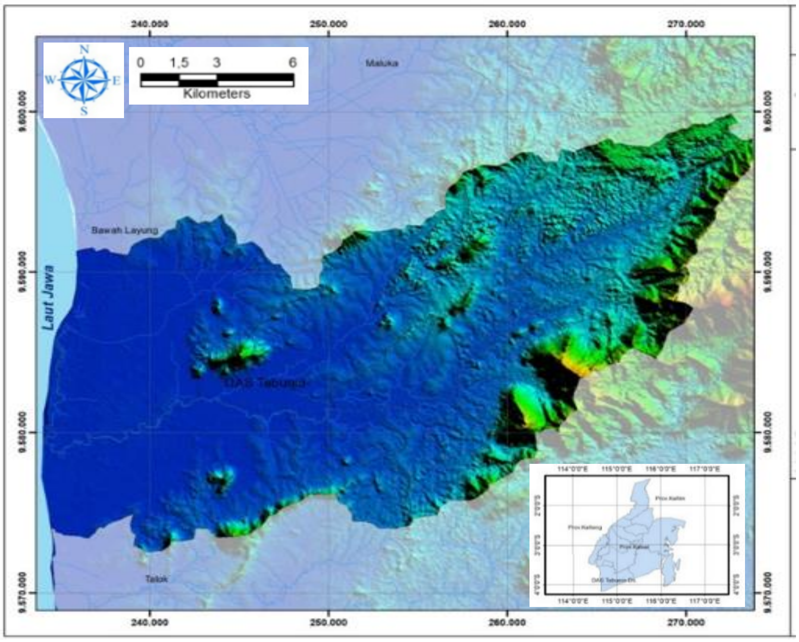

Figure 1. Location of the study area in Tabunio watershed.

2.3. Revised Universal Soil Loss Equation (RUSLE) parameter estimation

The application of Revised Universal Soil estimates means annual soil erosion Loss Equation (RUSLE)[14]. This equation predicts how several factors such as rainfall (R), soil (K), relief-slope factor (L, S) and land use and land cover pattern (cover management factor, support practice factor-P) control soil erosion entire in the entire basin. RUSLE uses five parameters to predict soil erosion rate and denotes soil erosion risk zone. This model deals with several developments and conservation strategies to protect soil erosion at land use and land cover level. We estimate soil erosion from each square cell in a grid of every land use and land cover throughout the watershed.

RUSLE is computed by modifying different parameters from USLE according to [7] to determine the rate of erosion calculated using the following equation:

A = R x K x L x S x C x P x 0,61 (1)

Where A denotes the mean value of potential annual soil loss in ton ha-1 year- 1; R means rain erosivity factor (MJ.mm-1); K means soil erodibility factor, LS means length and slope factor, and CP is a land cover factor management.

2.4. Rainfall erosivity factor (R)

Rainfall data is used to calculate the value of the rain erosivity factor (R). Furthermore, interpolation of the data is carried out to create a rain erosivity index (R) map. Interpolation using the IDW (*Inverse Distance Weighting method*) and Erosivity Index value was calculated using the equation developed by Bols (1978).

R = 6,119(Rain)1,21(Day S)-0,47(Max P)0,53 (2)

Where R mean average monthly precipitation erosivity (mj.mm.ha-1); (Rain) means monthly average rainfall (cm); (Days) means the number of monthly average rainy days (days); (MaxP) means Maximum average daily rainfall (cm).

2.5. Estimation of soil erodibility factor
This factor has been calculated from the textural classification of soil (% silt plus very fine sand, % sand), % organic matter, soil structure, and permeability. Then all values are plotted in nomograph using Wischmeier and Smith method [6]. K factor is determined by the following equation:

$$100K = 2,\ 1M^{1,14}(10^{-4})\ (12 - a) + 3{,}25(b - 2) + 2{,}5(c - 3) \quad (3)$$

Where K means factor reveals erosion susceptibility; M means particle size (% dust + % fine sand) x (100 - % clay); a means organic matter content (% C x 1.724); b means soil structure class and c is permeability class.

*2.6. Estimation of soil erodibility factor*We have calculated this factor from the textural classification of soil (% silt plus very fine sand, percentage of sand), and organic matter, soil structure, and permeability. Then all values are plotted in nomograph using Wischmeier and Smith method [6]. *K* factor is determined by the following equation:

100K = 2, 1M1,14(10-4) (12 – a) + 3,25(b – 2) + 2,5(c – 3) (3)

Where K means factor reveals erosion susceptibility, M means particle size (% dust + % fine sand) x (100 - % clay); a means organic matter content (% C x 1.724); b means soil structure class, and c is permeability class.

2.7. Estimation of slope length and slope steepness (LS) factor
DEM data is used to calculate the LS factor value. DEM data is revealed to be a slope, the flow direction *(flowdirection),* and the accumulated flow *(flow*accumulation).

2.8. Estimation of land cover management factor (C) and support practise factor (P)
The computation of C factor better understands information about LULC. The C factor, derived from diverse land use and land cover classes, detects the role of farming and management practices on soil erosion rate. We integrate them into a thematic layer using RS and GIS technique.

Following different favorable affects of such support practices, the ratio of soil loss corresponding to up and downslope cultivation, showed by support practice factor (P), is merged with straight-row farming along the slope. P variables that follow the same C factors influence several practice kinds [15,16].

2.9. Land use/cover classification
Determining land cover factors is carried out using the software ENVI with *Support Vector Machine* (SVM) classification. We took ten land cover categories, namely: water body, forest, bare land, residential, plantations, agriculture, swamps, shrubs, pond, mining. Approximately 86.345 sample points were used for training and then tested for accuracy assessment. We often use training samples for accuracy assessments [17–19]. We observed the accuracy classifications based on field survey data and high-resolution satellite imagery from Google Earth randomly for each land cover class.

3. Results and Discussion

3.1. Land use/cover Map
Land use/cover factors are obtained from image data classified using the ROI (*Region of Interest*) as a classification reference. Classification carried out there are two samples of ROI for each year of research, namely *training samples* and *testing samples*. *We used the training sample* as a sample for land cover classification, and we used the testing sample as a land cover sample regarding *google earth* which will later test the accuracy of land cover classification.

The number of ROI samples for each land cover varies by more than 100 pixels. Types of land cover classified include water bodies, swamps, ponds, mines, shrubs, agriculture, forests, plantations, settlements and open land. *Support Vector Machine Classification* was chosen because it has the most representative results. Overall accuracy (OA), user accuracy (UA), and producers accuracy (PA) are calculated and tested using the confusion matrix and Kappa coefficients. All classification results show a high overall accuracy (OA) ranging from 86% to 95% [20]. We classify the spatial distribution of land use/ land cover map based on the SVM approach shown in Figure 2, while the land cover area of the Tabunio watershed is given in Table 1.

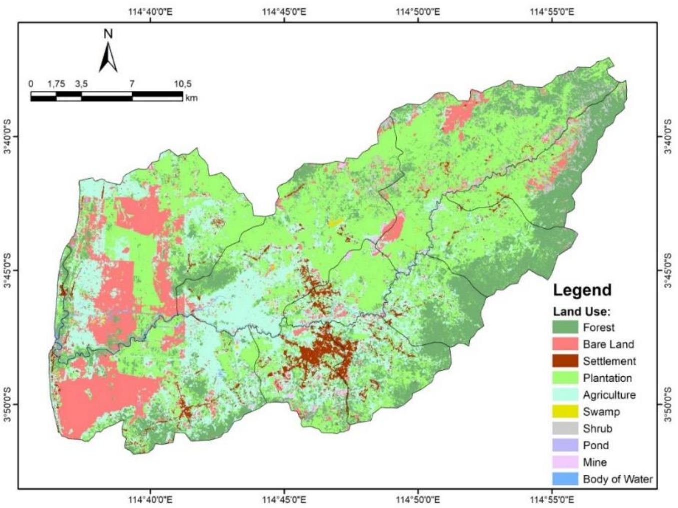

Figure 2. Land cover map classified based on SVM approach in Tabunio watershed.

Table 1. Table of land cover and CP value.

Land cover	Area (ha)	Percent (%)	CP value
Water Bodies	406,48	0,65	0.001
Forest	13.166,88	21,07	0.001
Bare land	7.906,35	12,65	0.02
Settlements	2.001,24	3,20	1
Plantation	24.313,31	38,90	0.3
Agriculture	12.917,27	20,67	0.02
Swamp	181,88	0,29	0.01
Shrub	1.216,33	1,95	0.05
Pond	36,14	0,06	0.001
Mine	350,50	0,56	1

Source: [21]

The land cover of the research area is 406,48 ha, water bodies, 13.166,88 ha of forest, 7.906,35 ha of bare land, 2.001,24 ha of settlements 24.313,31 ha of plantations. Agriculture is about 12.917,27 ha, swamp a181,88 ha, shrubs 1.216,33 ha, ponds 36,14 ha, and mines 350,50 ha. The dominant land cover in the research area is plantations, which is 38.9 percent of the total area of the Tabunio watershed, followed by agricultural land and forests.

3.2. RUSLE parameters
3.2.1. R Factor
In the Tabunio watershed area, the rainfall values vary. We took rainfall data based on the input point that has been determined by taking into account the distribution of rainfall in the Tabunio watershed. The rainfall data show that the highest value occurs downstream, and rainfall with the lowest value occurs upstream. Therefore, *R* value shows that the lowland surface is located under a high rainfall intensity zone than plateau fringe and undulating topography [15,22]. Rainfall in the Tabunio watershed area in the last ten years has a distinct pattern. There is much local rain at several points and has very different intensities. The rainfall erosivity factor from the value of the amount of rainfall at each point ranges from 1.161,7 to 1.409,53. Annual rainfall erosivity is obtained from monthly erosivity from January to December. After calculating the value of rain erosivity every year at each point. The calculated values are then interpolated into a rain erosivity map. The resulting rain erosivity map can be seen in Figure 3.

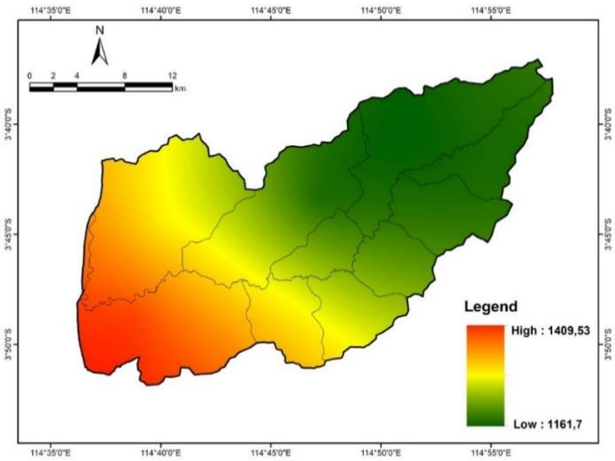

Figure 3. Rainfall Erosivity map in Tabunio watershed.

3.2.2. Soil erodibility factors
Tabunio watershed has twenty types of soil, soil erodibility values found in Hapludox, Kanhapludults and Hapludox, Kandiudox (skel), Hapludox (skel), Kanhapludults (skel) are quite high criteria. The higher the erodibility of the soil, the greater the ability of the soil to erode.

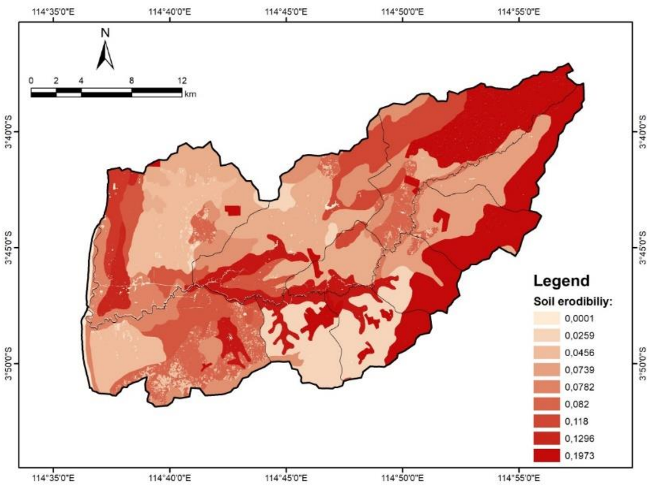

Figure 4. Soil erodibility map in Tabunio watershed.

Table 2. Table of soil type and soil erodibility value of Tabunio watershed.

No.	Soil Map Unit (SPT)	Soil Type	Area (ha)	Percent (%)	Soil Erodibility
1	1	Endoaquepts (Sulfic) (D), Dystrudepts	4.043,45	6,46	0,1937
2	7	Endoaquepts (Sulfic), Sulfaquents	3.749,95	5,99	0,1008
3	10	Eutrudepts, Udifluvents, Endoaquepts	643,87	1,03	0,0817
4	16	Endoaquepts (Sulfic) (D), Endoaquents, Sulfaquepts	5.792,29	9,26	0,0456
5	20	Quartzipsamments (D), Endoaquents, Psammaquents	483,53	0,77	0,3064
6	23	Sulfaquents (D), Hydraquents, Endoaquents	901,09	1,44	0,1226
7	25	Endoaquents, Sulfaquents, Fluvaquents (Sulfic)	1.085,08	1,73	0,0782
8	26	Fluvaquents (Sulfic), Endoaquents, Endoaquepts	1530.08	2,45	0,0782
9	28	Endoaquepts, Sulfaquents, Sulfaquents	916,21	1,46	0,1296
10	34	Hapludox, Kanhapludults	10.371,45	16,58	0,082
11	35	Hapludox (D), Kandiudults	369,86	0,59	0,0259
12	37	Acrudok, Hapludok, Kanhapludults	3.252,14	5,20	0,118
13	39	Eutrudepts (D), Eutrudox, Acrudox	4.480,11	7,16	0,0749
14	49	Plinthudults, Kanhapludults (skel), Distrudepts (skel), Kandiudox (skel)	2.511,88	4,02	0,0631
15	50	Kandiudox (skel), Hapludox (skel), Kanhapludults (skel)	6.788,51	10,85	0,0631
16	51	Ha pludox (D), Kandiudox, Hapludults	509.89	0,82	0,0631
17	59	Kandiudox (D), Hapludox, Kanhpludults	4.697,23	7,51	0,0739
18	66	Kandiudox (D), Hapludox	4.959,61	7,93	0,1973
19	68	Hapludox, Haplults, Kandiudox	200,52	0,32	0,1973
20	69	Inceptisols, Ultisols, Oxisols	5.271,80	8,43	0,1973
	Total		62,558.55	100.00	

In Tabunio watershed, K values vary from 0.04 (Endoaquepts (Sulfic) (D), Endoaquents, Sulfaquepts) to 0,3064 (Quartzipsamments (D), Endoaquents, Psammaquents) out of twenty soil taxonomic name, prepared by Map of Soil Type Review Scale of South Kalimantan Province by the Center for Research and Development of Land Resources in 2011 (Table 2 and Figure 4). Least K value denotes that most soils have low permeability and high organic content, while a higher value indicates high permeability and low organic content [20,23,24]. Soil erodibility map minutely scrutinised that most inconsistent K values are found in plantation and agriculture because of high silt content, low organic matter, and high permeability following different studies. K value is more consistent than those in forest and settlement with high organic content, mulch cover and low permeability in Figure 4. Different studies validate these results carried out in Tabunio watershed [23–26].

3.2.3. Slope length and slope factors

In this study, slope maps were obtained from DEM data processing. The greater the slope value, the greater the erosion rate.

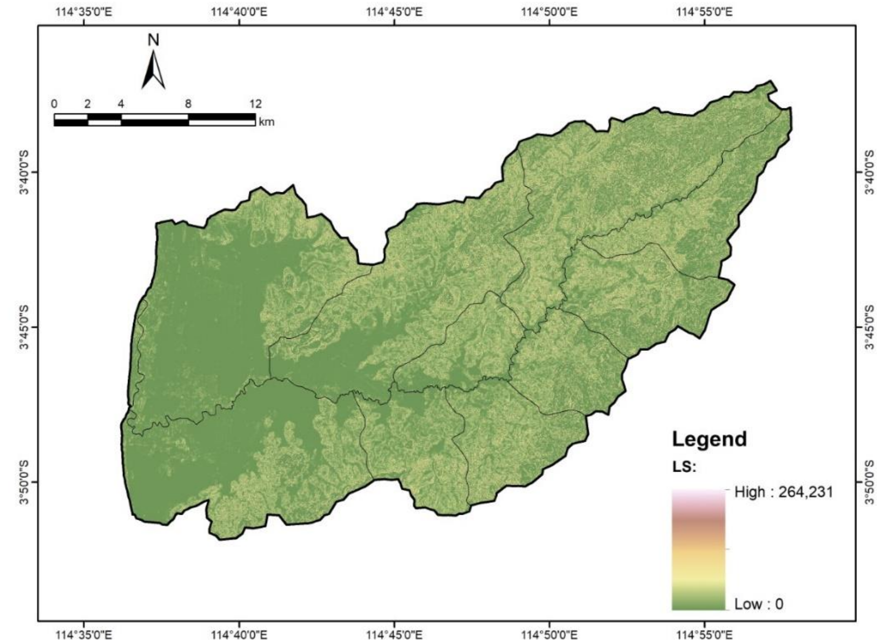

Figure 5. Map of LS factor in Tabunio watershed.

Table 3. Table of slope values for the Tabunio watershed.

No.	Slope	Area (ha)	Percent (%)
1	0 - 2%	29,134.66	46.57
2	2 - 7%	20,819.02	33.28
3	7 - 14%	4,610.35	7,37
4	14 - 21%	2,636.65	4.21
5	> 21%	5,357.88	8.56
	Total	62,558.55	100.00

The researchers discovered that, throughout the whole Tabunio watershed, the Least Significant Difference (LS) ranged from 0 to 264,23. Because of the accumulation of flow and the direction of flow throughout the basin, as well as the m factor and ß factor, the highest LS factor is found in isolated hillocks or dissected highland in plateau peripheral locations, while the lowest value is found in lowland or plain surface areas (Figure 5). In contrast, we find most of the higher mean values of the LS factor in forest and plantation because of their presence in plateau fringe and undulating topography, whereas lower mean values correspond to agriculture because of their location in low land (Table 3). It is at this moment that flow buildup occurs [22,27,28].

3.3. Estimation of soil erosion using RUSLE

RUSLE model estimated the spatial distribution of potential mean soil erosion through overlaying the five dominant factors at 30 m pixel size under raster surface. The rate of erosion was calculated using the raster calculator tool. The calculation process is carried out after all the RUSLE factors (R, K, LS, CP, 0,61) are in raster format. Based on the distribution of the erosion rate, we have categorized the rate into five classes. The erosion class consists of very mild with an erosion rate of fewer than 15 tons ha-1 year-1, mild class 15– 60 tons ha-1 year-1, moderate class 60 – 180 tons ha-1 year-1, heavy 180 – 480 tons ha-1 year-1, and hefty more than 480 tons ha-1 year-1. Increased soil loss or susceptibility zone corresponds to the high potential class in the plateau fringe site, whereas decreased soil loss or susceptibility zone belongs to the low potential class or low land encompassing the plateau fringe site. The undulating terrain is related to a middle potential class or mild susceptibility zone and corresponding to a moderate potential class [29].

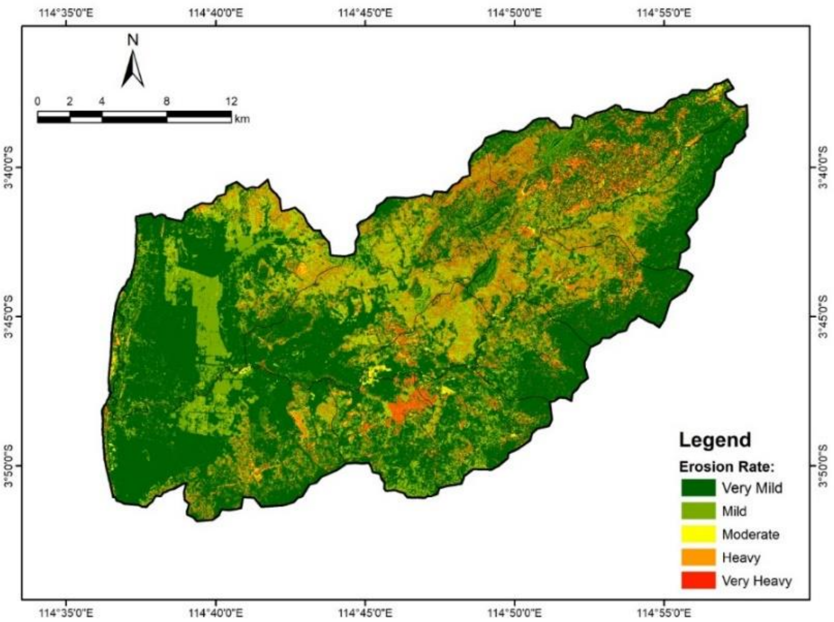

Figure 6. Rate of erosion map in Tabunio watershed.

Table 4. Table of erosion class.

No	Erosion Class	Rate (ton ha^{-1} year^{-1})	Area (ha)	Percent (%)
1	Very Mild	< 15	36.948,3	59,06
2	Mild	15 – 60	11.762,4	18,80
3	Moderate	60 – 180	4.864,8	7,78
4	Heavy	180 – 480	5.099,9	8,15
5	Very Heavy	> 480	3.883,2	6,21

Table 4 show that very mild erosion with an erosion rate of less than 15 tons ha-1 year-1 occurred in an area of 36.948,3 ha or equivalent to 59,06% of the total area of the Tabunio watershed. Mild erosion with an erosion rate of 15-60 tons ha-1 year-1 covers an area of 11.762,4 ha or equal to 18,80% of the total area of the Tabunio watershed, while moderate erosion (erosion rate 60-180 tons ha-1 year-1) occurs in an area with a total area of 4.864,8 ha which is equivalent to 7,78% of the total area of the Tabunio watershed. The erosion rate of 180 – 480 tons ha-1 year-1 is categorized as heavy erosion and covers an area of 5.099,9 ha, which is equivalent to 8,15% of the total area of the Tabunio watershed. Very heavy erosion with an erosion rate greater than 480 tons ha-1 year-1 occurred in an area of 3.883,2 ha, which is equivalent to 6,21% of the total area of the Tabunio watershed. We present the erosion class map of the Tabunio watershed in Figure 6. The relationship between the erosion rate and land use land cover show that the maximum annual soil loss recorded in the mine was 9.453,6 tons ha-1 year-1, while the minimum annual soil loss found in the water body was 0,000158 tons ha-1 year-1. Forest, whereas the mild class until hefty class is dominated by plantation (Table 5 and Figure 7) dominates the erosion rate in the very mild class.

Table 5. Table of erosion class areas by land cover

No	Land Cover	Erosion Class (ha)					Total
		Very Mild	Mild	Moderate	Heavy	Very Heavy	
1	Water Body	409,0	-	-	-	-	409,0
2	Forest	13.181,3	-	-	-	-	13.181,3
3	Bare Land	7.233,6	563,8	111,1	1,0	-	7.909,5
4	Settlement	34,5	313,5	441,4	574,4	638,3	2.002
5	Plantation	3.956,6	9.121,1	3.737,5	4.360	3.149,2	24.324,5
6	Agriculture	11.074,4	1.576,5	264,3	6,9	-	12,922,1
7	Swamp	182	-	-	-	-	182
8	Shrub	802,2	152,6	198,1	88,2	-	1.241,1
9	Pond	36,1	-	-	-	-	36,1
10	Mine	38,5	34,9	112,3	69,5	95,7	350,9

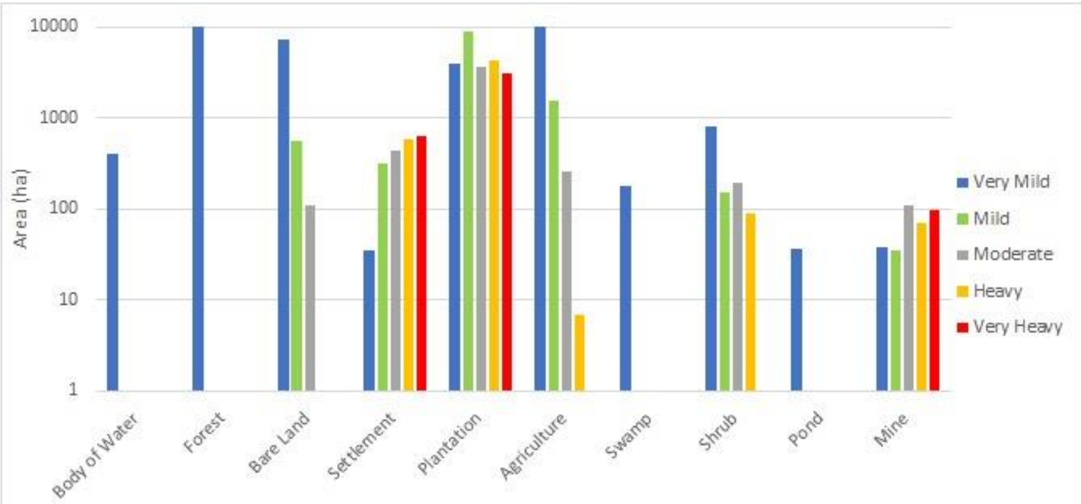

Figure 7. Graphic of erosion class areas by land cover in Tabunio watershed.

An alternative management plan for soil conservation in the watersheds was offered, which included changing land cover and cutting back the number of slope fields to 7% of the total and eliminating the area of abandoned fields. When the land cover conversion is complete, the percentages of flat and slope fields, forests, shrubs, abandoned fields, and other land covers should be 35 per cent, 7 percent, 5 percent, 45 percent, 0 percent, and 8 percent for flat and slope fields, forests, shrubs, abandoned fields, and other land covers, respectively. According to the study's findings, statistical models may be successfully utilized for processing inventory data to make judgments on soil conservation. According to [22] [30], the most influential parameter in calculating the erosion rate is the slope with an influence level of 72.9%, while the land cover processing parameter only contributes 5%, the smallest effect on the erodibility parameter is 0.15%. According to some research, erosion-prone land use and land cover encourage uneven erosion rates due to the rapid shift in erosion variables [31–33]. One of the most crucial truths to remember is that a body of water cannot be considered in the absence of erosion causes or soil cover as a guide for land use and land cover to prevent erosion [34,35].

4. Conclusion

We offered an alternative management plan for soil conservation in the watersheds, which included changing land cover and cutting back the number of slope fields to 7% of the total and eliminating the area of abandoned fields. When the land cover conversion is complete, the percentages of flat and slope fields, forests, shrubs, abandoned fields, and other land covers should be 35, 7, 5, 45, 0, and 8 per cent for flat and slope fields, forests, shrubs, abandoned fields, and other land covers, respectively. According to the study's findings, statistical models may be successfully utilized for processing inventory data to make judgments on soil conservation. According to [22] [30], the most influential parameter in the erosion's calculation rate is the slope with an influence level of 72.9%, while the land cover processing parameter only contributes 5%, the smallest effect on the erodibility parameter is 0.15%. According to some research, erosion-prone land use and land-cover encourage uneven erosion rates because of the rapid shift in erosion variables [31–33]. One of the most crucial truths to remember is that a body of water cannot be considered in the absence of erosion causes or soil cover, as a guide for land use and land cover to prevent erosion [34,35].

Acknowledgments

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