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Prediction of erosion and sedimentation rates using SWAT (soil and water assessment tool) method in Malino Sub Watershed Jeneberang Watershed

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Prediction of erosion and sedimentation rates using SWAT (soil and water assessment tool) method in Malino Sub Watershed Jeneberang Watershed

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Abstract. The increase in population will encourage the community to transfer the function of agricultural land in the Malino sub-watershed. Land use dramatically affects the level of erosion and sedimentation. The use of SWAT models can identify, assess, and evaluate the extent of a watershed's problems. This study aims to determine the spatial distribution of HRU and analyze the rate of erosion and sedimentation in the Malino sub-watershed. The results showed that the most HRU is found in secondary dryland forests, as much as 624 HRU (32.21%). The level of erosion rate of the category is very light with an erosion value of 5.21 tons/ha/year, light 31.19 tons/ha/year, moderate 104.91 tons/ha/year, weight 267.10 tons/ha/year, and hefty 616.74 tons/ha/year. The most significant sedimentation rate was found in sub-watershed 18 of 71.97 tons/ha/year and subwatershed 10 of 13.31 tons/ha/year.

1. Introduction

Erosion is a movement of soil from one place to another caused by natural media. The process of erosion in the watershed, especially upstream, will cause sedimentation downstream. Sedimentation is the deposition of material transported by water, wind, ice, or glaciers in a basin. The process of sedimentation in waters can cause shallowness and a decrease in water quality. The high sediment concentration in water bodies will cause turbidity, detrimental to biota and causes the water to be unproductive [1]. The amount of erosion that will occur and its distribution in a watershed can be estimated through prediction methods. Erosion prediction is a method for evaluating or estimating the rate of erosion on land used for certain businesses.

One of the most developed models is SWAT (Soil Water Assessment Tool) modelling. This physical-based modelin⁵ has been widely used in various types and conditions of the watershed. SWAT modelling can predict the influence of land management on water runoff, sediment, and agricultural land in a complex relationship to a watershed, including soil type, land use, and periodic control of land conditions. SWAT uses the MUSLE formula for erosion and sedimentation analysis. The SWAT model can identify, assess, evaluate the problem level and as a tool for selecting man¹⁶agement actions in controlling problems. So it is hoped that with the SWAT model, several scenarios can be developed to³ termine the best watershed management planning conditions [2]. This model initially divided the watershed into several sub-watersheds. Each sub-watershed will be divided into several hydrologic response units (Hydrologic Response Unit) based on land use, soil type, and slope class. SWAT output is summarized in files consisting of HRU, SUB, and RCH files. The output information in Sub-files and HRU files are area (AREA km²), amount of precipitation (PRECIP mm), actual evapotranspiration (ET



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mm H₂O), groundwater content (SW), surface flow (Q_{surf}), lateral flow (LATQ), basic flow (GWQ mm), sediment results (SED ton/ha) [3].

Malino subwatershed is one of the sub-watersheds of the Jeneberang watershed. It is located in the District Tinggimoncong Gowa regency, 8,759 ha 10.96% of the Jeneberang watershed a. The increase in population will encourage the community to transfer land initially forested into agricultural land in the Malino Subwatershed [4]. In addition to being converted into agricultural land, some areas of the Malino subwatershed are also widely carried out to construct tourist attractions. Transfer of land functions in various sectors can cause land damage and reduce land functions. Land use greatly affects the level of erosion and sedimentation. Poor land closure index has the potential for erosion. Large-scale erosion will potentially pose a landslide hazard. At the same time, sedimentation on a large scale will result in the shallowing of rivers and reservoirs, rising river surface/reservoirs to potentially cause flooding [5].

Based on the description above, it is hoped that the SWAT model's erosion and sedimentation predictions can be used as a reference in managing the Malino das Jeneberang sub-watershed.

2. Material and methods

2.1. Studi area

Subwatershed Malino is one of the sub-watersheds of the Jeneberang watershed, which is administratively located in two sub-districts (Figure 1). Most are located in Tinggimoncong Sub District, and a small part is located in Parangloe District, Gowa Regency, South Sulawesi Province. The Malino sub watershed has approximately 8,759.43 ha or about 10% of the total area of the Jeneberang watershed, consisting of 11 villages.

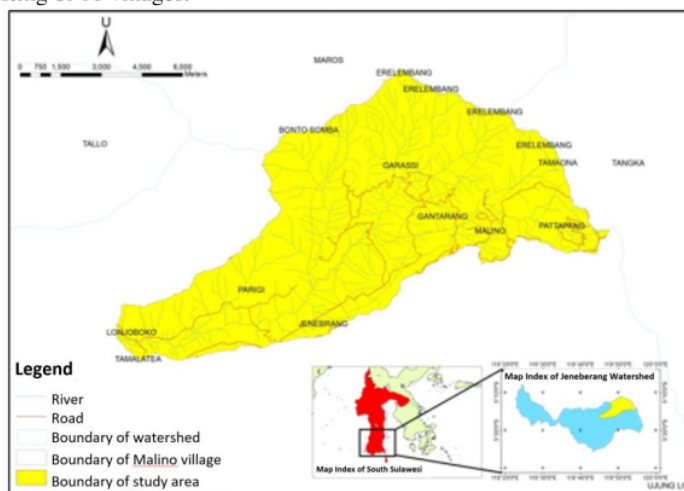


Figure 1. Map of the study area.

2.2. Materials

The tools used in this study were a laptop (with GIS software, ArcGIS 10.3 software, Arc SWAT, and Microsoft Office), GPS receiver, stationery, camera, sample ring, hoe, plastic bag, label, oven, measuring cup, dropper, roll film bottles, burettes, pipes. The material used is spatial data and non-spatial data, as well as soil samples. The spatial data used are DEM data, Sentinel imagery recorded at 2019, Topographic map at scale 1:50,000 in 1999, watershed boundary map and river network, **land cover map, slope map, and land type map**. The non-spatial data used are climate data and soil

characteristics data from laboratory tests. The climate data used consist of daily rainfall, temperature, relative humidity, wind speed, and solar radiation for ten years.

2.3. Procedure

2.3.1. Stage of preparation and data collection A subsection. The initial stage is to conduct literature studies related to the research, including Soil Science, Hydrology, SWAT, and Research Methods. The literature can be sourced from books, research journals, and other information obtained from the website. The data collected at this stage are primary data and secondary data. Primary data in the form of data on the Malino sub-watershed was land cover data, data on physical and chemical properties of the soil. Moreover, secondary data in slope, soil type data, and climate data include daily rainfall, temperature, relative humidity, wind speed, and solar radiation.

2.3.2. Observation stage. At this stage, a survey is conducted for soil sampling to determine the characteristics of soil properties produced from laboratory tests. The method used to determine the number and location of soil samples is Purposive Sampling, while soil sampling itself using soil sample methods are not disturbed by using sample rings and disturbed soil.

2.3.3. SWAT procedures. The procedures carried out in the use of SWAT applications are:

1. Formation of HRU (Hydrology Response Unit Analysis) with input data the land use map, topographic map, soil type map, and soil physical properties data. HRU is a unit of land with sub-watershed characteristic elements that affect erosion. Each HRU will have sub-watershed information, HRU number, land closure type, land type, and HRU area. HRU is obtained from the land map overlay and land closure map.
2. Climate database creates data generator climate (weather generator data) calculation of rainfall data, temperature, solar radiation, humidity, and wind speed.
3. Combining HRU with climate data, this process is carried out after the analysis is formed. At this stage, the simulation period is determined in advance for the entry of climate data.
4. SWAT simulation, performed by selecting the time to be simulated in SWAT Run mode. Storage of simulation output data is done by selecting Read SWAT Output.

2.3.4. Processing stage. To predict erosion by rain and surface flow, the SWAT model uses the Modified Universal Soil Loss Equation (MUSLE), which is a further development of the Universal Soil Loss Equation (USLE) developed by Wischmeier and Smith (1978). Erosion results are calculated using the equation:

$$SY = R \times K \times LS \times CP \quad (1)$$

Where :

$$R = a (V_Q \times Q_P)^b \quad (2)$$

Description :

SY: Amount of erosion soil (ton/year)

R: runoff

K: Soil erodibility factor

LS: Slope factor

CP: Land use factor

V_Q: Surface flow volume (m³)

Q_P: Peak flow (m³/s)

a: 11.8

b: 0.56

Sediment results in SWAT models are calculated using equations :

$$\text{Sed} = 11.8 (Q_{\text{surf}}, Q_{\text{peak}}, \text{Areahru})^{0.56} \cdot \text{Kusle} \cdot \text{Cusle} \cdot \text{Pusle} \cdot \text{LSusle} \cdot \text{CFRG} \quad (3)$$

Description :

Sed: Amount of segmented soil

Q_{surf} : Surface volume runoff

Q_{peak} : Peak runoff rate

Areahru: HRU area

Kusle: Soil erodibility factor

Cusle: Plant factors

Pusle: Soil conservation factors

LSusle: Slope factor

CFRG: Rough fragment factor

3. Results and discussion

3.1. HRU (Hydrologic Response Unit)

Malino sub-watersheds has different HRU variations (Table 1 and Figure 2). It will cause differences in hydrological response in each subwatershed. HRU is the largest in the closure of secondary dryland forest land, with the number of HRU as much as 624 (32.21%). The number of HRU is because the Malino sub-watershed area is dominated by secondary dryland forest with 5,791.97 (67.81%) scattered on flat class very steep slopes. Hydrologic Response Unit (HRU) can be observed based on land cover because HRU overlaps land cover, slopes, and soil characteristics [6].

Table 1. Number of HRU in Each Land Cover.

No.	Land Cover	Area		HRU	
		(ha)	(%)	Unit	(%)
1	Mixed Dryland Forest	743.08	8.7	249	12.85
2	Settlement	176.25	2.06	232	11.98
3	Secondary Dryland Forest	5,791.97	67.81	624	32.21
4	Farmland	42.78	0.5	43	2.22
5	Rice Field	1,488.95	17.43	492	25.4
6	Shrubland	209.16	2.45	202	10.43
7	Water bodies	89.27	1.05	95	4.9
	Total	8,541.45	100	1,937	100

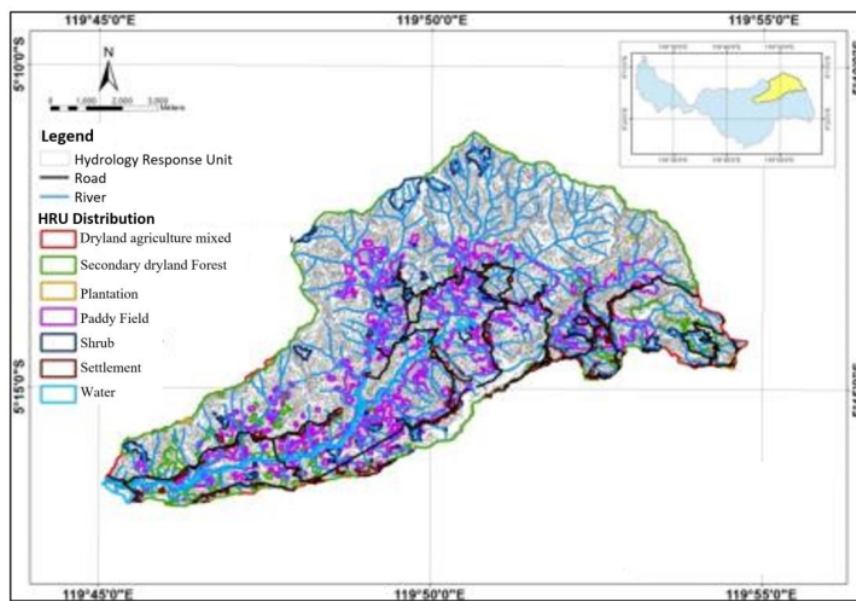


Figure 2. Map of HRU Distribution.

The pattern of secondary dryland forest HRU distribution can almost be seen throughout the Malino sub-watershed area. Sub-watersheds 8, 20, and 14 were the large HRU with an area of 247.48 ha, 137.03 ha, and 106.37 ha, respectively, with kambisol soil type with a slope of $>40\%$. The distribution pattern of HRU dryland agriculture mixed with shrubs is dominantly seen in the upstream and downstream sub-watersheds of Malino. The widest HRU is in sub-watershed 21 Kambisol soil type at 25-40% slopes with an area of 39.60 ha and at $>40\%$ slopes with 35.53 ha.

The dominant rice field HRU distribution pattern is seen in the middle to downstream of the Malino sub-watershed. Sub-watershed 8 with an area of 36.73 ha and subwatershed 11 covering 35.93 ha at $>40\%$ and 15-25% slopes with Kambisol soil type. The pattern of the dominant bush HRU distribution is found in sub-watershed 6. The widest HRU is found in sub-watershed 6 with an area of 27.59 ha in $>40\%$ slopes with Kambisol soil type.

The pattern of distribution of HRU bodies of water follows the river network of sub-watershed Malino. Sub-watersheds 21 and 20 at 0-8% slopes with an area of 21.7 ha and 7.73 ha, respectively, with Gleisol soil types. The pattern of plantation HRU distribution is found in sub-watersheds 9 and 10. The widest HRU is in sub-watershed 10 with an area of 10.81 ha at 15-25% slopes with Andosol soil type. The pattern of settlement HRU distribution is almost present in every sub-watershed. Sub-watershed 12 Kambisol soil types at 15-25% slope with 7.95 ha and 8-15% slopes with an area of 7.70 ha.

3.2. Erosion and Sedimentation Rate

3.2.1. *Erosion.* Classification of erosion rates based on ¹Minister of Forestry Regulation Number P.3/V-SET/2013 about Guidelines for Identification of Watershed Characteristics in Malino subwatershed can be seen in Table 2.

Table 2. Classification of Erosion Rate in Malino Sub Watershed.

No	Erosion Class		Erosion Value (Ton/ha/year)		Area	
	Category	Erosion Rate Value (Ton/ha/year)		(ha)	(%)	
1	Very light	<15	5.21	5434.73	63.63	
2	Light	15-60	31.19	2518.16	29.48	
3	Moderate	60-180	104.91	423.83	4.96	
4	Heavy	180-480	26.1	141.19	1.65	
5	Very Heavy	>480	616.74	23.55	0.28	
Total				8,541.45	100	

Based on Table 2, the area of the Malino sub-watershed, which belongs to the category of very light erosion class, is 5,434.73 ha (63.63%) with an erosion value of 5.21 tons/ha/year. In comparison, the area that belongs to the category of hefty erosion class with an erosion value of 616.74 tons/ha/year has an area of 23.55 ha (0.28%). It is because the closure of forest land in the Malino Subwatershed is still quite good. After all, it has reached the minimum standard as stipulated in Law No. 41 of 1999 on Forestry that the minimum area of forest in watersheds is 30%. The level of erosion is very light to moderate in each sub-watershed.

In contrast, the level of heavy and very heavy erosion is found in sub-watersheds 3,4,7,8,9,10,12,15,21 located in Garassi, Parigi, and Gantarang villages Malino, Pattapang, and Lonjoboko. The erosion class map can be seen in Figure 3. Based on the erosion class-map, erosion in the Malino sub-watershed with heavy to hefty erosion rates is upstream with the closure of the dominant land of dry land mixed with shrubs and rice fields on sloping slopes to very steep.

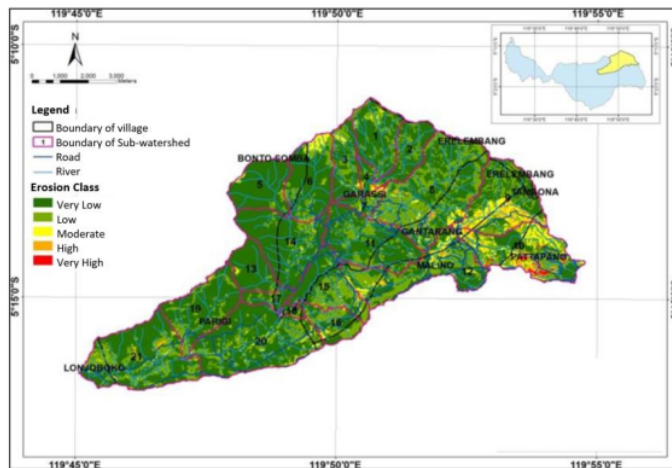


Figure 3. Malino Sub Watershed Erosion Class Map in 2010-2019.

SWAT simulation results for predicted erosion rate in 2010-2019 on land closure HRU distribution can be seen in figure 3.

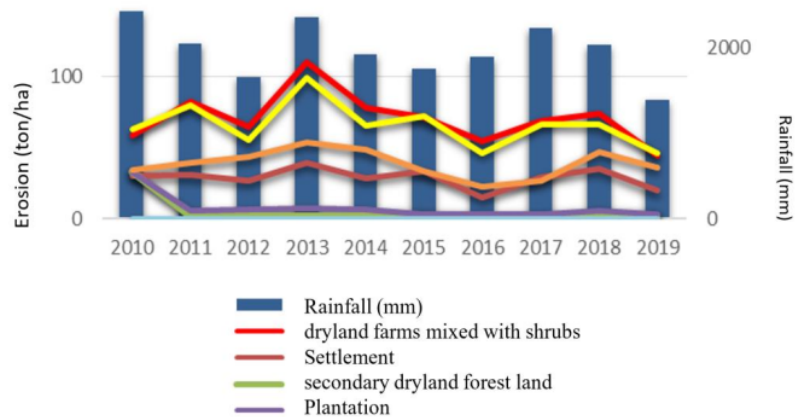


Figure 4. Annual Erosion Rate of Malino Subwatershed in Annual Erosion Rate of Malino Subwatershed in 2010-2019 on Land Cover.

Based on Figure 4, it can be seen that the spread of HRU in various land closures affects the erosion that occurs in the Malino sub-watershed. The land closures that have the most impact on erosion are dryland farms mixed with shrubs and rice fields. The influence is related to vegetation and soil processing so that it is easily eroded. The agricultural conditions of dry land mixed with shrubs at the research site mainly consisted of mixed plants on sloping slopes up to very steep. The closure of land with low erosion is in secondary dryland forests. There is vegetation with varying header strata and lower plants in secondary dryland forests to reduce surface flow to prevent erosion.

Based on research conducted by Bhan and Behera (2014) [7], vegetation has a significant influence on erosion because vegetation blocks rainwater from falling directly on the soil's surface so that the power to destroy the soil can be reduced. According to Saputri (2008) in Dedy (2016) [8], the influence of land cover on the erosion rate can protect the soil surface from raindrops and decrease the speed of running water to minimize erosion. Besides, the slope factor also affects erosion. The slope of the slope exerts a significant influence on the erosion that occurs, as it dramatically affects the speed of surface runoff. The greater the slope value, the chance of water entering the soil (infiltration) will be hampered. The volume of surface runoff is more significant, resulting in erosion hazards [9].

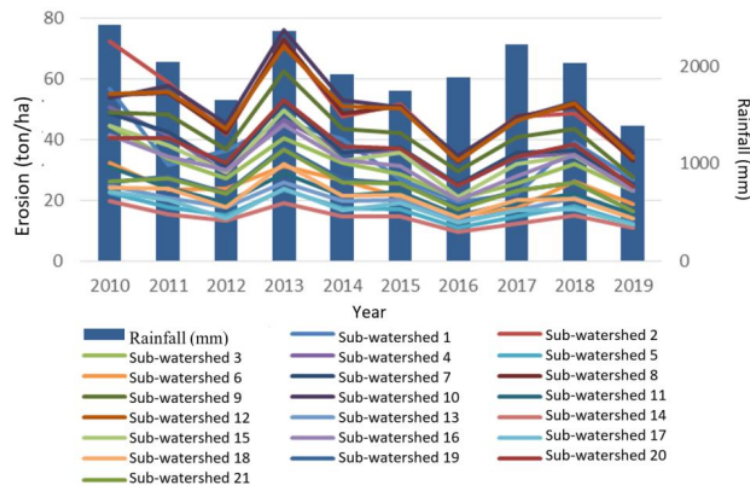


Figure 5. Erosion Rate of Malino Sub Watershed in 2010-2019 in Each Sub-sub Watershed.

The results of the SWAT simulation for predicted erosion rate in sub-watershed can be seen in Figure 5. The image shows an increase in erosion following the high annual rainfall in the Malino Subwatershed. The most extensive erosion occurred in 2013, which was influenced by high rainfall in that year, while in 2016 and 2017. There was a difference between rainfall and erosion. Large amounts of rain do not always cause heavy erosion if the intensity is low.

On the contrary, heavy rain in a short period may also cause only a slight erosion because the amount of rain is small. The influence of rainfall on erosion is strengthened by Warih (2002) [10] states that the amount of rain intensity is proportional to the erosion value of rain, meaning that the greater the intensity of precipitation, the higher the erosion of rain, with high erosion of rain, can cause more significant erosion. Nur'saban (2006) [11] stated that the amount of rainfall intensity and distribution of rain determines the strength of rain dispersion to the soil, the amount and speed of surface flow, and erosion damage. Long-lasting, heavy rains with large grains will cause erosion more significant than thunderstorms. It is related to the amount of energy from the rain grains that hit the ground level and the amount of rainwater that immerses the fragments of the soil.

Based on Figure 5, it can be seen that the most significant erosion rate occurs in sub-watersheds 2 and 10. The sequence of the largest to lowest erosion rate in the Malino Subwatershed is in sub-watershed 2, 10, 12, 8, 9, 7, 20, 4, 1, 15, 16, 3, 19, 21, 6, 11, 18, 13, 17, 5, 14 with a total erosion value of 665.55 tons/ha/year. Figure 5 shows sub-watersheds 2 and 10 found on the upstream that is in the slope is a bit steep to very steep.

3.2.2. *Sedimentation.* The results of the SWAT simulation for the predicted sedimentation rate in 2010-2019 can be seen in Figure 6.

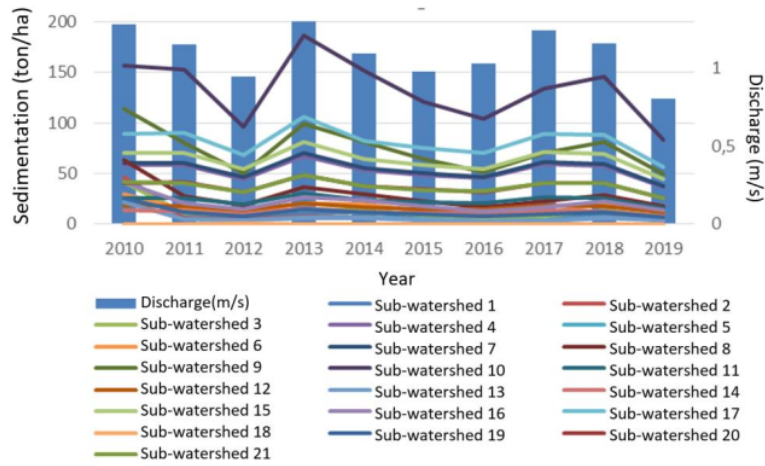


Figure 6. Sedimentation Rate of Malino Sub Watershed in 2010-2019 in Each Sub-sub Watershed.

Based on Figure 6, the annual sedimentation rate in the Malino sub-watershed increases in line with the increase in river flow discharge. It means that the greater the discharge of the river flow, the sediment produced will also increase. It follows Aryanto's (2010) [12] statement, which states that the greater the volume of discharge, the amount of sediment suspended in the river discharge flow becomes greater. The amount and variation of river discharge depend on the thickness of the rain, the intensity of the precipitation, the length of rain, and the distribution of rainfall [13]. Rainfall that directly becomes running water can be caused by several factors including slope, and cover vegetation (land cover).

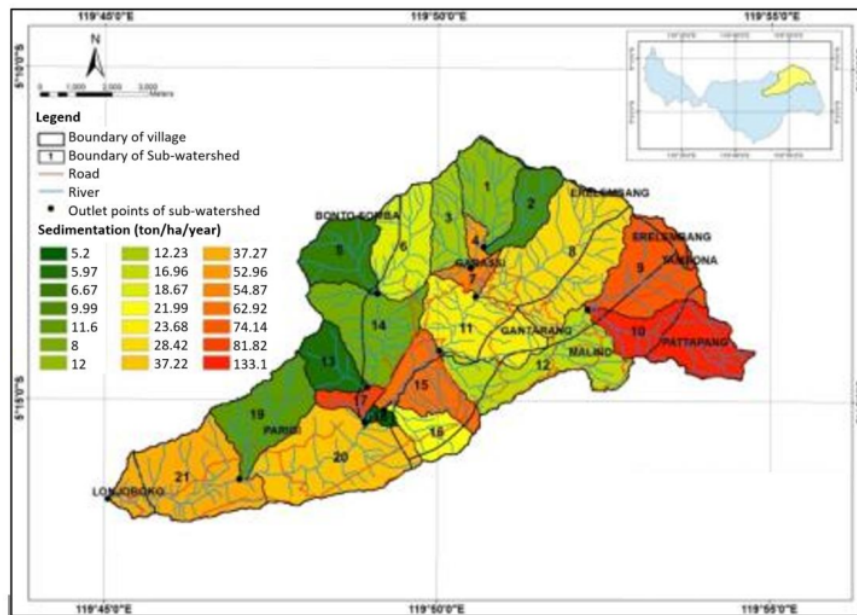


Figure 7. Malino Sub Watershed Sedimentation Map in 2010-2019.

The sedimentation map on the Malino Subwatershed can be seen in Figure 7. Based on Figure 7, the largest sedimentation rate is in sub-watershed 10 of 133.11 tons/ha/year in Pattapang, Malino, and Gantarang villages. The largest to smallest sedimentation rate sequences in malino sub-watersheds are 10, 17, 9, 15, 7, 4, 21, 20, 8, 11, 16, 12, 6, 3, 1, 14, 19, 2, 5, 13, 18 with a total sedimentation value of 717.48 tons/ha/year. Nine sub-watersheds have a greater sediment value than the erosion of sub-watersheds 4, 7, 9, 10, 11, 15, 17, 20, and 21. Wischmeier and Smith (1978) in Arsyad (2000) [13] stated that predictable erosion is an erosion of sheets or grooves but cannot predict deposition and does not consider sediment results from the erosion of trenches, rivers cliffs, and riverbeds. Based on the statement, sediment value is derived from other sedimentary material transported other than sheet erosion, namely river cliff erosion.

Subwatershed 4 has an area of 63.89 ha dominated by a steep slope class of 24.52 ha (38.37%), secondary dryland forest land closure of 54.31 ha (85.01%), and rice fields 9.58 ha (14.99%). Subwatershed 7 covering an area of 90.16 ha dominated by a steep slope class of 27.91 ha (30.95%), secondary dryland forest land closure of 50.95 ha (56.52%), and rice fields 35.22 ha (39.06%). Subwatershed 9 covering an area of 558.39 ha dominated by steep slope class of 223.16 ha (38.98%), closure of secondary dryland forest land 32.33 ha (57.75%), rice fields 121.75 ha (21.81%), dryland agriculture mixed with shrubs 101.30 ha (18.15%). Subwatershed 10 covering an area of 558.66 ha dominated by steep slope class of 197.34 ha (35.34%), closure of dry land mixed bushland 248.67 ha (44.53%), secondary dryland forest 149.67 ha (26.80%), rice fields 91.89 ha (16.46%). Subwatershed 11 covering an area of 546.02 ha dominated by a steep slope class of 209.81 ha (38.43%), secondary dryland forest land closure of 386.77 ha (70.83%), rice fields 129.30 ha (23.68%). Subwatershed 15 covering an area of 371.23 ha dominated by a steep slope class of 106.09 ha (28.58%), closure of secondary dryland forest land 209.13 ha (56.34%), rice fields 143.19 ha (38.58%). Subwatershed 17 covering an area of 96.33 ha dominated by steep slope class (33.87%), secondary dryland forest land closure of 79.59 ha (82.63%), rice fields 14.80 ha (15.36%). Subwatershed 20 covering an area of 830.91 ha dominated by a steep slope class of 286.95 ha (34.55%), secondary dryland forest land closure of 549.42 ha (66.16%), rice fields 153.94 ha (18.54%). Subwatershed 21 covering an area of 762.88 ha dominated by steep slope class of 238.67 ha (31.31%), closure of secondary dryland forest land 367.73 ha (48.24%), dryland agriculture mixed with shrubs 229.63 ha (30.12%). Based on these characteristics, sediment value is also influenced by topography, where the subwatershed is found in the dominance of the steep slope class. According to Asdak's (2007) [14] statement, sediment values may vary according to the watershed's physical characteristics.

4. Conclusion

Based on the research that has been done can be concluded that:

1. Hydrologic Response Unit (HRU) distribution in Malino Subwatershed is most at closing secondary dryland forest land with HRU as much as 624 (32.21%).
2. Erosion rate in Malino Subwatershed area with very light erosion rate category of 5.21 ton/ha/year (63.63%), light 31.19 tons/ha/year (29.48%), moderate 104.91 tons/ha/year spread in each subwatershed. In contrast, heavy erosion is 267.10 tons/ha/year (1.65%) and very heavy 616.74 tons/ha/year (0.28%) Garassi, Parigi, Gantarang, Malino, Pattapang, and Lonjoboko villages. The most significant sedimentation rate is in sub-watershed 10 of 133.11 tons /ha/year in Pattapang, Malino, and Gantarang villages.

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