Prediction of erosion and sedimentation rates using SWAT (Soil and Water Assessment Tool) method in the Jenelata Sub Watershed

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Abstract. Erosion and sedimentation are problems that often occur in watershed ecosystems. The SWAT model (Soil and Water Assessment Tool) can be used to determine the output of a watershed's performance. Jenelata sub-watershed area is one of the largest sub-watersheds of the Jeneberang watershed with 22,800 ha. This study aims to determine the spatial distribution of the hydrologic response unit (HRU) and analyze the rate of erosion and sedimentation in the Jenelata sub-watershed. The results showed that most HRUs are in secondary dryland forests with 447 HRU (19.09%). The level of erosion in the very light category, namely 5.74 ton/ha/year (37.53%) and light 34.71 ton/ha/year (27.76%), was in the villages of Moncongloe, Tana Karaeng, Sicini, Paladindang, Towata, Parang Lampoa, Manuju, and Buakkang. Meanwhile, moderate erosion was 104.07 ton/ha/year (23.92%), high 289.65 ton/ha/year (9.59%), and very high 553.74 ton/ha/year (1.20%) located in the villages of Pattallikang, Mangempang, Bontomanai, Bissoloro, Rannaloe, Jenebatu, and Sapaya. The largest sedimentation is 133.18 ton/ha/year in sub-watershed 17, located in Bissoloro and Rannaloe villages.

1. Introduction
Erosion and sedimentation are problem that often occur in watershed ecosystems. Erosion is the loss or erosion of soil or land from one place transported by water or wind to another location. Eroded soil transported by surface runoff will be deposited in areas where water flow slows down, such as rivers, irrigation canals, reservoirs, and lakes, called sedimentation events. This impacts the shallowing of the river, causing in more frequent floods in the rainy season and drought in the dry season [1].

Research on erosion and sedimentation has been carried out by previous researchers using various methods such as USLE (Universal Soil Loss Equation), MUSLE (Modified Universal Soil Loss Equation), and RUSLE (Revised Universal Soil Loss Equation). In this study, to predict the rate of erosion and sedimentation by using MUSLE method in the SWAT model (Soil and Water Assessment Tool) because this model uses manual comparison with modeling [2,3].

The Jenelata sub-watershed is part of the Jeneberang watershed, which is located at Gowa Regency. The land-use area of the Jenelata sub-watershed in 2013 is 2339.08 ha of secondary dryland forest, 1013.2 ha of plantation forest, 122.93 ha of settlements, 11,022.60 ha of mixed dryland agriculture, and rice fields 3168.25 ha, Scrub 4,976.24 ha, and Water Bodies 241.20 ha [4]. Heavy rainfall in early 2019 in South Sulawesi resulted in floods and landslides. Manuju Sub-district, Gowa Regency, which is part of the Jenelata Sub-watershed, was the worst area buried by landslides, resulting in dozens of missing people [5]. According to the Directorate General of Natural Resources (2019), apart from the high...
rainfall factor, the causes of floods and landslides, especially in the Makassar city and Gowa districts, are damage to the upstream watershed of the Bili-Bili Dam and the high discharge of the Jenelata river. One form of flood anticipation is planning the construction of a new dam, namely the Jenelata Dam, which functions as flood control over the Jenelata river, 1,800.46 m$^3$/sec. 729.20 m$^3$/s.

Based on this, to overcome and minimize the problems of flooding and landslides, it is necessary to research the prediction of erosion and sedimentation rates as a reference in efforts to use land and soil conservation in the management of the Jenelata sub-watershed, Jeneberang watershed.

2. Research methodology

2.1. Time and Place

This research was conducted from October 2019 to October 2020. It was located in the Jenelata Sub-watershed, Gowa Regency of South Sulawesi (Figure 1). Analysis of the physical and chemical properties of the soil was carried out at the Silviculture and Tree Physiology Laboratory. Meanwhile, data analysis was conducted at the Watershed Management Laboratory.

2.2. Tools and Materials

The tools used in this study were a laptop with geographic information system software ArcMap 10.3 application, GPS receiver, hoe, sample ring, label, sample plastic, writing instrument, camera, dropper, film roll bottle, pH meter, measuring cup, digital scales, burettes, and pipes. The materials used in this research are spatial data and non-spatial data, as well as soil samples. Spatial data used include DEMNAS data (National Digital Elevation Model) resolution of 8 meters, watershed boundary map, RBI map, land cover map, and soil type map Jenelata sub-watershed area. The non-spatial data used are climate data, including daily rainfall data, temperature, relative humidity, wind speed, solar radiation for the last ten years (2010 – 2019), and data on soil's physical and chemical properties taken from the research site and materials used. It will be used in water, equates, penitar, sulfuric acid, and indicator solutions used in the laboratory.

2.3. Procedures

2.3.1. Data collection and preparation stage. The initial stage is carried out by conducting a literature study 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. Preliminary data in the form of Jenelata Sub-watershed, closure data, soil data in soil physical and chemical properties, while secondary data were slope data, soil type data, climate data include daily rainfall, air temperature data, air relative humidity, wind speed, and solar radiation.

2.3.2. **Observation stage.** At this stage, a survey is carried out to take soil samples to determine the characteristics of the soil properties, which will be produced from laboratory tests. The method used to determine the number and location of soil samples is purposive sampling, while the soil sampling itself using the undisturbed soil sample method using a ring sample and disturbed soil.

2.3.3. **SWAT application.** The procedures carried out in the use of the SWAT applications were:

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.

2. Database of a climate is created by processing climate data (weather generator data) to calculate rainfall data, temperature, solar radiation, humidity, and wind speed.

3. HRU Merging with climate data. This process is carried out after the analysis is formed. At this stage, the simulation period is determined first, and then climate data entry is carried out.

4. SWAT simulation is done by selecting the time to be simulated in the SWAT model Runs. The results of the simulation of output data storage are 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:

\[
SY = R \times K \times LS \times CP
\]

Where:

\[
R = a \times (V_Q \times Q^b)
\]

Description:

SY : Amount of erosion soil (ton/year)
R : Runoff
K : Soil erodibility factor
LS : Slope factor
CP : Land use factors
V_Q : Surface flow volume (m³)
Q : Peak flow (m³/s)
\(a\) : 11.8
\(b\) : 0.56

Sediment yield in the SWAT models was calculated using the equation:

\[
Sed = 11.8 \times (Q_{surf} \times Q_{peak} \times Area/hru)^{0.56} \times K_{usle} \times C_{usle} \times P_{usle} \times LS_{usle} \times CFRG
\]

Description:

Sed : Amount of segmented soil
\(Q_{surf}\) : Surface volume runoff
Qpeak : Peak runoff rate
AreaHRU : HRU area
Kusle : Soil erodibility factor
Cusle : Plant factors
Pusle : Soil conservation factors
Lusle : Slope factor
CFRG : Rough fragment factor

3. Results and discussion
3.1. HRU (Hydrologic Response Unit)
The Jenelata Sub-watershed area has different HRU variations that consist of 2342 HRU are formed. It causes differences in the hydrological response in each of these sub-watersheds. Based on Table 1 and Figure 2, the highest variation of HRU was in secondary dryland forest cover with a total of 447 HRU (19.09%). The large variation in HRU is because the Jenelata sub-watershed has a secondary dryland forest cover of 45.82% with an area of 10446.9 ha, spread over almost the entire watershed area and evenly distributed soil types and classes of flat to very steep slopes.

| Land Cover                        | Area (ha) | (%)   | HRU   | Units (%) |
|-----------------------------------|-----------|-------|-------|-----------|
| Mixed Shrub Dry Land Agriculture  | 2,790.78  | 12.24 | 366   | 15.63     |
| Secondary Dry Land Forest         | 10,446.9  | 45.82 | 447   | 19.09     |
| Plantation                        | 2,352.12  | 10.32 | 253   | 10.80     |
| Rice field                        | 4,292.69  | 18.83 | 418   | 17.85     |
| Shrubs                            | 2,070.92  | 9.08  | 280   | 11.96     |
| Cloud                             | 21.8747   | 0.10  | 13    | 0.56      |
| Settlement                        | 451.73    | 1.98  | 363   | 15.50     |
| Water                             | 373.381   | 1.64  | 202   | 8.63      |
| Amount                            | 22,800.4  | 100   | 2,342 | 100       |

Figure 2. Map of HRU Distribution in land cover of Jenelata Subwatershed.
The distribution pattern of the secondary dryland forest HRU is almost visible throughout the Jenelata sub-watershed area. The widest HRU is in Sub-watersheds 23, 7, and 19 with an area of 508.28 ha, 367.36 ha, and 355.64 ha, respectively, on soil types Dystropepts, Humitropepts, Tropohumults with slopes >40%. The distribution pattern of HRU for shrubs is dominant in Sub-watersheds 10 and 16. The widest HRU is in Sub-Watershed 16 with an area of 275.74 ha on soil types Dystropepts, Humitropepts, Tropohumults with slopes >40%.

The distribution pattern of the dominant plantation HRU is in the downstream area of the Jenelata Sub-watershed in Sub-watersheds 1, 3, 4, and 10. The widest HRU was found in Sub-watersheds 1, 3, and 4 with an area of 167.91 ha, 153.95 ha, and 136.56 ha on dystropepts haplorthox, tropudults soil types with a slope of 0 - 8%. The distribution pattern of HRU for dry land mixed with shrubs is dominant in Sub-watershed 6, 13, 18, and 21. The widest HRU is in Sub-Watershed 6 and 13 with an area of 133.63 ha and 105.57 ha, respectively, on Dystropepts soil type. Haplorthox, Tropudults with slopes >40%.

The distribution pattern of the dominant rice field HRU is in the upstream and middle parts of the Jenelata sub-watershed. The widest HRU is in Sub Sub-DAS 16 with an area of 141.73 ha on soil types Dystropepts, Humitropepts, Tropohumults with a slope of 25-40%. The pattern of distribution of residential HRUs spreads in almost every area Sub-sub-watershed. The widest HRU is in Sub Watersheds 3 and 4 with an area of 17.5 ha and 1369 ha, respectively, on soil types Dystropepts, Haplorthox, Tropudults with a slope of 0-8%. The distribution pattern of the HRU of water bodies follows the pattern of the Jenelata sub-watershed river network. The widest HRU is in Sub Watershed 3 with an area of 15.79 ha on Dystropepts, Haplorthox, Tropudults soil types with a 0-8% slope.

3.2. Erosion and Sedimentation Rate

3.2.1. Erosion. The classification of erosion levels in the Jenelata sub-watershed can be seen in Table 2 based on the Minister of Environment and Forestry Regulation No.P.3/V-SET/2013 concerning Guidelines for Identification of Watershed Characteristics.

| Erosion Class | Erosion Rate Value (ton/ha/year) | Erosion Value (ton/ha/year) | Eroded Land (cm/year) | Area (ha) | Area (%) |
|---------------|---------------------------------|-----------------------------|-----------------------|----------|---------|
| Very Light    | <15                             | 5.74                        | 0.06                  | 8,547.64 | 37.53   |
| Light         | 15-60                           | 34.71                       | 0.35                  | 6,322.24 | 27.76   |
| Moderate      | 60-180                          | 104.07                      | 1.04                  | 5,447.44 | 23.92   |
| Heavy         | 180-480                         | 289.65                      | 2.90                  | 2,184.57 | 9.59    |
| Very Heavy    | > 480                           | 553.74                      | 5.54                  | 272.83   | 1.20    |
| Amount        |                                 |                             |   | 22,774.72 | 100     |

Table 2 shows that the erosion class with a large area is a very light erosion class of 37.53% with an erosion value of 5.74 tons/ha/year. In comparison, the erosion class with the smallest percentage is a hefty 1.20%, with an erosion value of 553.74 tons/ha/year. The forest land cover in the Jenelata sub-watershed is still relatively good because it has reached the minimum standard as stipulated in Regulation Number 41 of 1999 concerning Forestry that the minimum forest area in the Watershed is 30%.
Based on the erosion map in Figure 3, very light and light erosion levels are in Moncongloe, Tana Karaeng, Sicini, Paladindang, Towata, ParangLampo, Manuju, and Buakkang. Meanwhile, the moderate to hefty erosion class was in Pattallikang, Mangempang, Bontomanai, Bissoloro, Rannaloe, Jenebatu, and Sapaya. In addition to this, it can also be seen that most of the erosion in the Jenelata sub-watershed with moderate to very heavy levels is in the upstream and middle part of the Jenelata sub-watershed with a cover of paddy fields, dryland agriculture mixed with shrubs and shrubs from low-slope to very steep slopes.
Based on Figure 4, it can be seen that the distribution of HRU in various land covers dramatically affects the amount of erosion. The distribution of HRU with paddy field cover and Mixed Shrub Dry Land Agriculture is the distribution that has the most influence on erosion in the Jenelata sub-watershed area. The research results by Amaliah et al. (2020) stated that land cover dramatically affects the output hydrology of a watershed [6]. This proves that paddy fields and mixed dryland agriculture affect erosion because it is related to soil processing. The soil aggregate becomes unstable and easily eroded. In addition, the slope factor also affects the velocity of surface runoff in transporting soil particles, considering that the HRU distribution pattern is dominant in the slightly steep to very steep slope class [7].

The results prediction of the 2010-2019 erosion rate in the Sub-watershed can be seen in Figures 4 and 5. The figures show an increase in erosion following the high average annual rainfall in the Jenelata Sub-watershed. The biggest erosion occurred in 2013; this was due to the high rainfall that year. Meanwhile, in 2010, 2016 and 2017 there was a significant difference between rainfall and erosion. This is caused by the erosivity of rain which also greatly affects the potential for erosion, this is in accordance with what was stated by Sutedjo and Kartasapoetra (2002) that rainwater becomes surface runoff is the main element causing erosion. Rain with high rainfall and intensity, for example 50 mm in a short time (1 hour) has more potential to cause erosion than rain with the same rainfall but in a longer time (> 1 hour) [8].

Based on this, rainfall dramatically affects the amount of erosion. Following previous research, erosion increases in line with the intensity of rainfall [7]. Based on Figure 5, it can be seen that the highest erosion rate is in sub-watersheds 21 and 19. The erosion value in sub-watershed 21 was 78.90 ton/ha/year, comes from the percentage of land cover of 35.93% Mixed Shrub Dry Land Agriculture and 11.95% rice fields. It is greater than sub-watershed 19 which is 73.22 ton/ha/year with a percentage of land cover of 17.18% Mixed Shrub Dry Land Agriculture and 9.88% rice fields, considering that the most extensive erosion rate distribution in the Jenelata sub-watershed.

3.2.2. Sedimentation. The results prediction of sedimentation rates from 2010-2019 in the sub-watersheds can be seen in Figure 6.
Figure 6. Sedimentation Rate of The Jenelata Sub-watershed in 2010-2019 in Each Sub-watershed.

The graph shows that the sedimentation rate in the Jenelata sub-watershed increases in line with the increase in the amount of river flow discharge. Thus, the greater the flow rate of the river, the sedimentation result will also increase. It is following previous studies that sedimentation rises in line with river discharge. The amount of flow discharge is influenced by the amount of surface runoff, where surface runoff is also affected by rainfall and the type of land cover, slope, and soil characteristics [7].

Figure 7. Sedimentation Map of Jenelata Sub-watershed in Each Sub-watershed.
Figures 6 and 7 showed that the most significant sedimentation rate is in sub-watersheds 17 and 21 or Bissoloro, Rannaloe, and Sapaya villages. Comparison of erosion and sedimentation values can be seen in Figures 4 and 5. The difference in these values is that not all eroded soil will be deposited as sediment, but some will be deposited in soil surface basins, the foot of the slopes, and other forms of shelter. Therefore, the sediment value varies according to the watershed’s physical characteristics [9].

The sub-watersheds with sedimentation rates more significant than the erosion rate are sub-watersheds 17, 19, and 21, with erosion values of 65.44 ton/ha/year, 73.22 ton/ha/year and 78, respectively. 90 ton/ha/year. The sedimentation values for these sub-watersheds are 133.18 ton/ha/year, 81.98 ton/ha/year, and 128.24 ton/ha/year. According to Wahyuningrum, et al. (2014), sedimentation values that are greater than erosion indicate the presence of other sources of sedimentary material carried by surface flow and until sedimentation occurs, in addition to sheet erosion [10]. In accordance with the USLE formula which only predicts the amount of sheet erosion, so that the sediment material can come from river bank erosion or roadside erosion which is not taken into account in this study.

Asdak (2010) stated that the characteristics of the watershed that affect the ratio of the size of the erosion to sedimentation value are the area of the catchment area, including the catchment area’s topography [9]. Based on the watershed’s physical characteristics, sub-watershed 17 has an area of 1,007.95 ha, which is dominated by steep slope class 322.37 ha (32.01%) and very steep 465.34 ha (46.21%) in dryland forest cover, secondary 452.4 (44.92%), PLKCS 227.55 (22.59%) and rice fields 134.17 ha (13.32%). In Sub-watershed 19 with an area of 978.20 ha, which is dominated by steep slope class 272.78 ha (27.89%) and very steep 452.97 ha (46.32%). The land cover was dominated by secondary dryland forest 651.16 ha (66.58%), dryland mixed bush farming 174.12 ha (17.80%), and rice fields 96.68 ha (9.88%). While Sub-watershed 21 with an area of 817.88 ha which is dominated by steep slopes of 250.78 ha (30.67%) and very steep 233.87 ha (28.60%), land cover is dominated by secondary dryland forest cover 421.04 ha (51.50%), dryland agriculture mixed with shrubs 293.79 ha (35.93%) and rice fields 97.74 ha (11.95%).

Based on the characteristics of the three sub-watersheds, the sedimentation value in the three sub-watersheds is strongly influenced by topography, where the distribution of steep and very steep slope classes in sub-watershed 17 is greater than the distribution of slope classes in sub-watersheds 19 and 21, so that the sedimentation value in sub-watershed 17 is more significant than sub-watershed 19 and 21. According to Asdak (2010), the velocity of the river water flow downstream is relatively constant if the difference in river surface height is not too significant so that the value of sediment transport will decrease, resulting in the sedimentation rate will be lower [9]. It is reinforced by the research of Wahyuningrum et al. (2014), which states that topography significantly affects the sediment value because it is related to the travel time of soil particles to the river.

4. Conclusion
Based on the research that has been done can be concluded that:
1. The highest distribution of HRU was in secondary dryland forest cover with a total of 447 HRU (19.09%) because it land cover spreads over almost all watershed areas, soil types and also slope classes.
2. The level of erosion in the very light category was 5.74 ton/ha/year (37.53%) and light was 34.71 ton/ha/year (27.76%) located in the villages of Moncongloe, Tana Karaeng, Sicini, Paladindang, Towata, Parang Lampoa, Manuju, and Buakang. Meanwhile, moderate erosion was 104.07 ton/ha/year (23.92%), heavy was 289.65 ton/ha/year (9.59%), and very heavy was 553.74 /ha/year (1.20%) were located in the villages of Patallilangan, Mangempang, Bontomonai, Bissoloro, Rannaloe, Jenebatu, and Sapaya.
3. The average of sedimentation in the Jenelata sub-watershed from 2010-2019 was 754.27 ton/ha/year. The largest sedimentation was 133.18 ton/ha/year in sub-sub watershed 17, located in Bissoloro and Rannaloe villages.
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