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ARAŞTIRMA MAKALESİ **RESEARCH ARTICLE**

Estimation of Erosion and Sediment using Gavrilović Method in Krueng Jreu Sub-basin, Aceh Province, Indonesia

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Abstract

Erosion and sediment in a basin can be estimated by calculating and forecasting using various methods. This study aims to assess erosion and sedimentation in the Krueng Jreu sub-basin in the province of Aceh, Indonesia, using the Gavrilović method. This research was carried out by analyzing secondary data for the last ten years, from 2012 to 2021. Data include geology, slope, land use, and river channel networks. The observed parameters include the coefficient of intensity of erosion, temperature coefficient, and sedimentation coefficient, which are used to analyze the erosion volume, spatial sediment rate, and total sediment rate in the Krueng Jreu sub-basin area. The results of calculations using the Gavrilović method show that four main parameters of the biophysical characteristics of the sub-basin, including (1) sensitivity of soil and local geological conditions to erosion, (2) land use, (3) erosion type, and (4) slope of land, have been shown to affect the occurrence of erosion and annual sediment rates. Geological conditions and land use provide a high level of sensitivity to the results of the coefficient of intensity of erosion. Temperature and rainfall are directly proportional to the annual erosion volume and the spatial sediment rate. The lowest yearly erosion volume and spatial sediment rate in 2019 were 64965.41 $m^3km^{-2}year^{-1}$ and 58206.18 $m^3km^{-2}year^{-1}$. Meanwhile, the highest annual erosion volume and spatial sediment rate will occur in 2021, 101500.71 $m^3km^{-2}year^{-1}$ and 90940.21 $m^3km^{-2}year^{-1}$. Fluctuations in the annual volume of erosion are caused by rainfall, affecting the spatial sediment rate and the total sediment rate.

Keywords: Aceh, Appropriate technology, Soil conservation, Erosion, Agricultural sustainability.

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1. Introduction

A basin is an ecosystem unit that interacts with living things and their environment. This is inseparable from the biophysical uniformity it has. The characteristics of the basin consist of morphology and morphometry. The morphological characteristics of the basin consist of geology, geomorphology, topography, and basin area. At the same time, basin morphometry consists of area and circumference, shape, length and width, river order, slope (river gradient), and river density, which influence each other (Kironoto et al., 2021).

Biophysical characteristics will influence the response to rainfall that falls in the basin. This response affects the magnitude or small value of characteristic hydrological parameters, such as evapotranspiration, infiltration, surface runoff, and soil water content. These parameters must be considered when estimating surface runoff, erosion, and sedimentation rates to provide a balance to the basin system (Lihawa, 2017; Sattari et al., 2020).

According to environmental services program data in 2006, several problems occurred in the Krueng Aceh sub-basin, one of which was in the Krueng Jreu sub-basin area, namely illegal logging, forest burning, land conversion, and over-exploitation at several points on the upstream side of the river. This will affect the characteristics of the sub-basin so that it will impact the soil's ability to absorb rainwater. If the intensity of the rain is high with the use of non-forest land and the steep slope, it will cause the surface runoff rate to be significant so that the soil will be eroded and transported along with the water, which is called erosion (McDonald et al., 2002; Meliho et al., 2019; Terranova et al., 2009). Erosion can cause nutrients to be lost in the soil. Deposits that occur continuously can cause silting at the bottom of the reservoir. Furthermore, there is a sedimentation process and there will be sedimentation or deposition in lower areas, such as rivers or reservoirs. Following these conditions, it is necessary to conduct research to estimate the annual erosion and sediment that occur.

Erosion in a basin can be estimated using calculations and estimates of erosion. This can be done directly using various methods; generally, several methods have been used, namely the USLE (Universal Soil Loss Equation), MUSLE (Modified Universal Soil Loss Equation), geographic information systems and sediment routing methods, and RUSLE (Revised Universal Soil Loss Equation) methods (Devianti et al., 2021; Ikhsan et al., 2021; Muntazar et al., 2021; Sari, 2022). These methods have differences in estimating the erosion that occurs. The USLE method estimates the erosion that appears at the kinetic energy of the intensity of the rain for 30 minutes (EI30), and it is said that the erosion has occurred after 30 minutes (Kinnell, 2017; Marques et al., 2007). The MUSLE method estimates erosion using surface runoff parameters that occur with runoff or peak discharge. At the same time, RUSLE estimates erosion by predicting the annual average soil loss over a long period caused by surface runoff (Hanafi and Pamungkas, 2021).

Several approaches for assessing sediment production and erosion intensity have been developed in recent decades. The approach sensitivity and uncertainty evaluations are now being used more frequently to reduce mistakes resulting from the model idea and its key assumptions to improve model performance. An empirical is the Gavrilovi model (erosion potential model) designed to measure gross erosion, assess erosion coefficients, and estimate yearly sediment yield. This semi-quantitative approach was developed through an experimental study on a Serbian station, while it has also been used in Switzerland and Italy (Auddino et al., 2015). It is known that this model can perform better than others. Unfortunately, this has not been proven for tropical areas such as Indonesia, especially in the province of Aceh.

Other methods can be used to estimate erosion and sediment using the erosion potential method or the Gavrilović method. This method calculates the level of erosion and annual sediment yields that occur in a basin area by considering the characteristics of the basin, such as geology, geomorphology, topography, climate, and land use, without evaluating the soil erodibility factor (Ali et al., 2016; Dalaris et al., 2013; Dragičević et al., 2018; El Badaoui et al., 2021). This erosion estimation method is often used in basin areas with a sub-tropical climate. However, it has also been carried out under tropical climate conditions followed by the influence of rainfall to provide information to determine erosion and sediment control measures in the Krueng Jreu sub-basin area. Therefore, this paper aims to estimate the erosion and sediment in the Krueng Jreu sub-basin using the erosion potential method or Gavrilović method.

2. Materials and Methods

2.1. Research location and data collection

This research was carried out in the Krueng Jreu sub-basin, Indrapuri sub-district, Aceh Besar district, Aceh province, Indonesia. The data collected related to this research was obtained from the Indrapuri Meteorological, Climatology and Geophysics Agency and the maps were obtained from the Krueng Aceh Basin Management Center. The data collected are for the last 10 years from 2012 to 2021.The administrative location of the Krueng Jreu sub-basin can be seen in *Figure 1*.

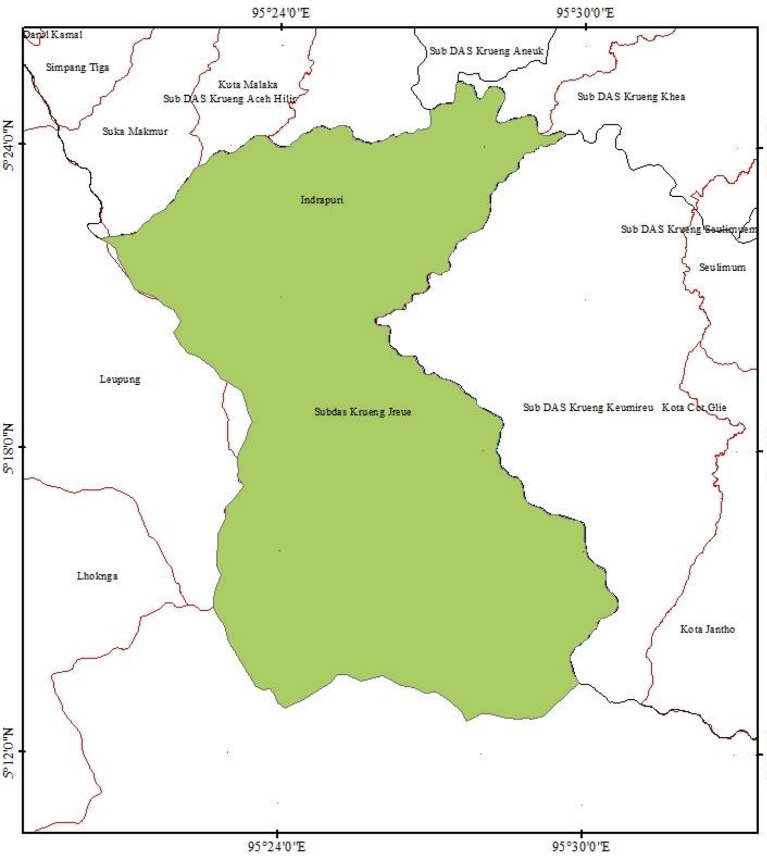

Figure 1. Research site map

2.2. Data analysis

The coefficient of erosion intensity (Z) is obtained by calculating parameters such as the coefficient of sensitivity of geological conditions and soil to erosion (Y), the coefficient of land use (Xa), the coefficient of erosion in facies or sampling units (Φ), and the average slope of the basin (I). Therefore, it can be calculated using Equation 1. The average slope of the basin can be calculated using Equation 2. E_2, E_1, and L are the highest, lowest elevation and river length (km). The coefficient of sensitivity of geological conditions and soil to erosion (Y), the coefficient of land use (Xa), and the coefficient of erosion in facies or sampling units (Φ), respectively, were obtained from the research results Ali et al. (2016); Amiri (2010); Sakuno et al. (2020). After obtaining the erosion intensity value, the next step is to classify the erosion intensity according to *Table 1* (Dunkerley, 2019; Toure et al., 2011).

$$Z = Y \cdot Xa \cdot \left(\phi + \sqrt{I}\right) \quad \text{(Eq.1).}$$

$$I = \frac{E_2 - E_1}{L} \quad \text{(Eq.2).}$$

Table 1. Erosion intensity coefficient

Z-Value	Erosion Intensity
<0.20	Very low
0.20 – 0.40	Low
0.40 – 0.70	Currently
0.70 – 1.00	High
>1.00	Very high

The annual volume of erosion that occurs in the basin area is determined by the annual rainfall (H), the coefficient of erosion intensity (Z), and the temperature coefficient (T). The annual erosion volume (WSP) can be calculated using Equation 3. The temperature coefficient (T) can be calculated using Equation 4, considering the yearly temperature in °C (t).

$$WSP = \pi \cdot T \cdot H \cdot Z^{1.5} \qquad \text{(Eq.3).}$$

$$T = \sqrt{\frac{t}{10} + 0.1} \qquad \text{(Eq.4).}$$

The spatial sediment rate (GSP) is obtained by multiplying the annual erosion volume (WSP) by the sedimentation coefficient. The spatial sediment rate (GSP) can be calculated using Equation 5 considering the sedimentation coefficient (Ru) obtained using Equation 6. The sedimentation coefficient (Ru) is calculated based on the circumference of the basin in km (P), the length of the main river in km (L), and the elevation difference. The highest and lowest elevations of thebasin (D). Furthermore, the total sediment rate (GS) can be calculated by multiplying the results of the spatial sediment rate (GSP) by the area of the basin in km^2 (F) using Equation 7.

$$GSP = WSP \cdot Ru \qquad \text{(Eq.5).}$$

$$Ru = \frac{4 \cdot \sqrt{P \cdot D}}{L + 10} \qquad \text{(Eq.6).}$$

$$GS = GSP \cdot F \qquad \text{(Eq.7).}$$

3. Results and Discussion

3.1. Description of the Krueng Jreu Sub-basinArea

Administratively, the Krueng Jreu sub-basin is part of the Krueng Aceh basin area, which is located in Indrapuri District, Aceh Besar District. Geographically, the Krueng Jreu sub-basin is located at coordinates between 5°12'39.8” to 5°25'18.6” North Latitude and 95°20'27.1” to 95°30'42.46” East Longitude. The Krueng Jreu sub-basin has an area of 232.66 km^2, with the main river being 24.80 km long.

3.2Distribution of Rainfall and Temperature Coefficient at the Study Site

The distribution of the rainfall and the temperature coefficient at the study site in the last ten years is presented in *Figure 2*. Rainfall data and temperature coefficient (T) are used to analyze the annual erosion volume in the Krueng Jreu sub-basin. *Figure 2* shows that the annual rainfall in the Krueng Jreu sub-basin is categorized as being in very low to high conditions and, for ten years, has very diverse values, with the highest annual rainfall occurring in 2021, which is 2274.4 mm/year. Meanwhile, the lowest rainfall occurred in 2019 at around 1450.5 mm/year. The level of rainfall will affect the amount of annual erosion and the rate of sediment that occurs.

3.3 Erosion Parameters

The geological conditions in the Krueng Jreu sub-basin have several types: tangla formation, young alluvium, idi formation, lhoong formation, raba limestone formation, reef members, Indrapuri complex, meucampli formation, and seulimeum formation. The percentage of geology in the Krueng Jreu sub-basin in succession from large to small, namely the formation of raba limestone with the name clay-limestone, silica, is 26.40%. The reef members with the name limestone, as in reefs, are 23.11%. Meucampli formation with the name micaan sandstone, conglomerate of various materials, conglomerate sandstone, siltstone, limestone by 21.28%. Indrapuri complex, serpentinite tectonic melange, ultramafic serpentinite, igneous, and undifferentiated sediment of 8.77%. Lhoongformation with the name of a volcano, a small sandstone, and siltstone, mafic volcanic, is 7.67%. The appearance of theseulimeumwith calcareous andtuffaceous sandstone, conglomerate, and mudstone is 5.22% lower. The idi formation with the name Sand and gravel is 3.87%. The young alluvium with the name gravel, sand, and mud is 3.48%. Tangla formation of volcanic origin, sandstone, gravel conglomerate, and 0.20% quartz arenite.

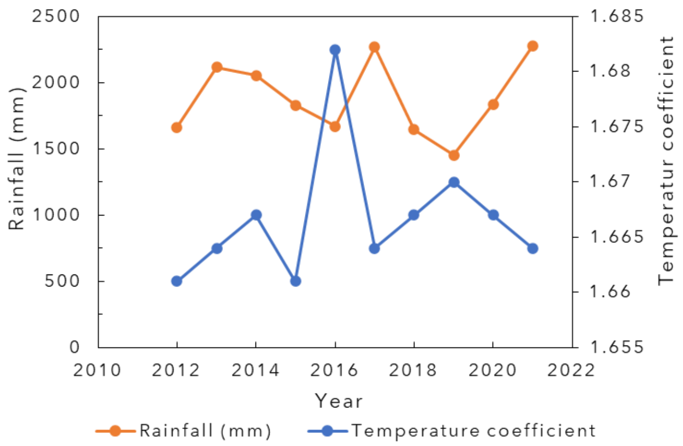

Figure 2. Distribution of rainfall and temperature coefficient on-site

The value of the Y coefficient for geological factors shows that geology sensitive to erosion is worth 1, namely tangla formation, young alluvium, idi formation, seulimeum formation and lhoong formation by 20.44%. Meanwhile, the less sensitive value is 0.1, namely, the Indrapuri formation of 8.77%. Each type of geology has a different value of the Y coefficient to show the level of sensitivity of geological conditions and soil to erosion. The higher the Y value, the more sensitive it will be to erosion. According to Lihawa (2017),the potential for erosion movement depends on the condition of the soil and geological conditionscomponents, including geology as the leading cause of movement. The weathering process in geological conditions is influenced by high or low rainfall and causes geological conditions strength to weaken and soil to thicken. Geological factors such as tectonic and volcanic activity trigger soil movements such as erosion.

Based on the 2019 Krueng land use map, the Krueng Jreu sub-basin area is classified into protected and cultivated areas. Protected areas include primary dryland forests, secondary dryland forest, and water bodies. Meanwhile, the cultivation area includes settlements, dry land agriculture, mixed dry land agriculture, savanna, rice fields, shrubs, and open land. The Krueng Jreu sub-basin area is dominated by regions protected with 64.33%, including primary dryland forest, secondary dryland forest, and water bodies. Protected areas have the most significant percentage value of 57.87%, including primary dryland forests, and the smallest at 0.17%, namely water bodies. Meanwhile, the cultivation area has a percentage of 35.67%, including settlements, dry land agriculture, mixed dry land agriculture, savanna, rice fields, shrubs, and open land. The cultivation area has the most significant percentage of savanna at 18.79%, and the smallest is a settlement at 0.58%. Based on the classification of the land use coefficient (Xa), the Xa value for open land is 1, settlements and rice fields is 0.9, dry land agriculture and mixed dry land agriculture is 0.8, the savanna is 0.7, rice fields are 0.6, primary land agriculture and secondary land agriculture is 0.4.

The slope class in the Krueng Jreu sub-basin is divided into five categories, ranging from flat to very steep. The slope of the Krueng Jreu sub-basin varies from the slope to the slope, with the widest percentage of 35.67% being on a slope of 16% - 25% with a rather steep condition category. The narrowest rate, which is 3.14%, is in steep conditions with a slope of 26% - 40%. Slopes less than 8% are usually used for the development of agricultural, urban, and cultivation in a short time. According to Devianti (2016), a slope of land of 8% to 15% should be used to cultivate annual crops and plantations. Areas with a slope of 16% to 25% are part of primary dryland forests with forest plantations. Additionally, the slope of 26% to 40% with a steep category is usually used for crops with agroforestry systems. Finally, land slopes greater than 40% with very steep conditions should be planted with perennials to protect plants.

The evaluation of the slope of the land using the Gavrilović method considers the average slope of the basin, which is 0.028%. This is influenced by the morphological parameters of the sub-basin, such as the highest elevation, the lowest elevation, and the length of the river. So different slope levels on land or basin have no effect because the slope used is the average slope in the basin.

The Krueng Jreu sub-basin area with erosion in the form of landscapes and land with little erosion is 90.71%. Furthermore, a50% cover area of the quarter covered by surface erosion is 8.72%. Additionally, the span with the cover having surface erosion without severe erosion is 0.06%. The last is the form of erosion, with an area covered by 80% by groove erosion, 0.51%. The values of the erosion coefficient also vary from 1 to 0.9.

3.4 Erosion of the Krueng Jreu sub-basin

The coefficient of erosion intensity is essential to calculate the annual erosion volume. The calculation of the coefficient of erosion is carried out using several parameters such as the coefficient of sensitivity of geological conditions and soil to erosion, the coefficient of land use, the coefficient of erosion form, and the average slope of the sub-basin (Kouli et al., 2009; Solaimani et al., 2009; Sun et al., 2014). Additionally, the geometry of the krueng jreu sub-basin includes the highest elevation, the lowest elevation, the elevation difference, the length of the main river, the circumference of the sub-basin and the area of the sub-basin are 0.706 km, 0.021 km, 0.685 km, 24.80 km, 88.70 km and 232.66 km, respectively. The average slope of the Krueng-Jreu sub-basin is 0.028%. *Table 2* shows the intensity coefficient of erosion for various land uses. The highest coefficient of erosion is the use of open land of 4.38 or 2.98% of the total, and the lowest is the use of residential land, which is 0.91 or 0.58% of the total.

Table 2. Classification of erosion intensity values

Land Use	Z-value	Area(km^2)	Percentage (%)
Primary dryland forest	1.66	134.64	57.87
Secondary dryland forest	1.08	14.64	6.29
Settlement	0.91	1.35	0.58
Dryland farming	0.60	5.77	2.48
Mixed dry land farming	0.77	5.72	2.46
savanna	3.37	43.72	18.79
Ricefield	0.72	3.79	1.63
Shrubs	2.73	15.72	6.76
Open Ground	4.38	6.94	2.98
Total		**232.66**	**100**

The annual erosion volume calculates the amount of erosion in the Krueng Jreu sub-basin annually. The yearly volume oferosion is calculated using the temperature coefficient, the annual rainfall, and the erosion intensity coefficient. The volume of erosion in various land uses presented in *Figure 3*. During the 10 years, the land use that experienced the most significant changes occurred on open land by up to 36.69%, savanna by 21.02% and shrubs by 15.93%. Meanwhile, land use such as primary dry land forest, secondary dry land forest, settlements, dry land agriculture, mixed dry land agriculture, and rice fields provide a relatively stable erosion volume of 26.37%.

Different uses of land influence the amount of erosion volume each year. The highest average volume of erosion in 10 years appeared in the use of open land of 30832.99 $m^3km^{-2}year^{-1}$, or 36.69% of the total. Furthermore, the use of land as a savanna will contribute to an average volume of erosion of 17661.02 $m^3km^{-2}year^{-1}$, or 21.02% of the total. The use of shrubs will contribute to an average erosion volume of 13384.07 $m^3km^{-2}year^{-1}$ or 15.93% of the total. The lowest average volume of erosion occurred in dryland agricultural land use of 2914.52 $m^3km^{-2}year^{-1}$, or 3.47% of the total. This is influenced by land cover or vegetation on land use. The open land with the highest erosion volume indicates that this land use is not covered by plants that can withstand the erosion rate.

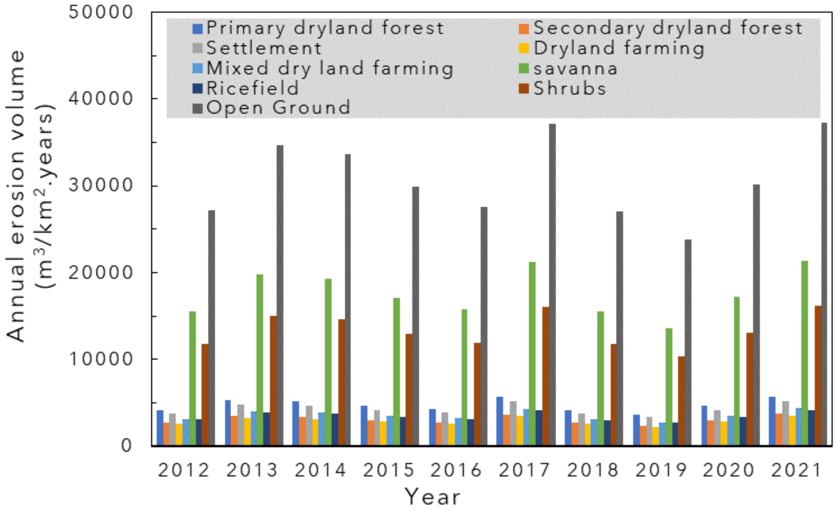

Figure 3. Erosion volume on land use

The total annual erosion volume is presented in *Figure 4*. The lowest total annual erosion volume occurred in 2019, which was 64956.41 $m^3km^{-2}year^{-1}$. The highest total erosion volume appeared in 2021, 101500.71 $m^3km^{-2}year^{-1}$. The average volume of erosion that occurred for ten years from 2012 to 2021 in the Krueng Jreu sub-basin is 84038.14 $m^3km^{-2}year^{-1}$. Rainfall parameters significantly affect the appearance of annual erosion volume. The volume of erosion will decrease or increase after low or high rainfall.

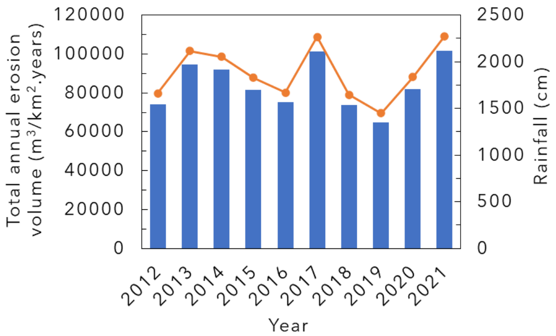

Figure 4. Annual erosion volume of Krueng Jreu sub-basin

This shows that temperature and rainfall influence the volume of erosion, but the level of sensitivity of rainfall is higher than that of temperature. Therefore, temperature and rainfall are directly proportional to the volume of annual erosion. The value of the coefficient of erosion will change when there is rain, resulting in an annual erosion volume. The annual volume of erosion will influence the rate of sediment that occurs.

3.5 Sediment rate of Krueng Jreu sub-basin

The spatial results of the sediment rate come from sediment derived from the annual erosion volume processes. The relationship of spatial sediment rate with various land uses is presented in *Figure 5*. *Figure 5* shows that different types of land use have different spatial sediment rates. The highest spatial sediment rate for ten years occurred in three types of land use: open land at 36.69%, savanna at 21.02% and shrubs at 15.93%. Meanwhile, the lowest spatial sediment rate occurred in dry land agriculture at 3.47%.

The spatial sediment rate for ten years has increased and decreased, directly proportional to the annual erosion volume. The highest spatial sediment rate occurred in 2021, 90940.21 $m^3km^{-2}year^{-1}$, and the lowest occurred in 2019, 58206.18 $m^3km^{-2}year^{-1}$. The average spatial sediment rate for ten years is 75294.51 $m^3km^{-2}year^{-1}$. The high or low annual volumes of erosion influence the sediment rate fluctuations that occur.

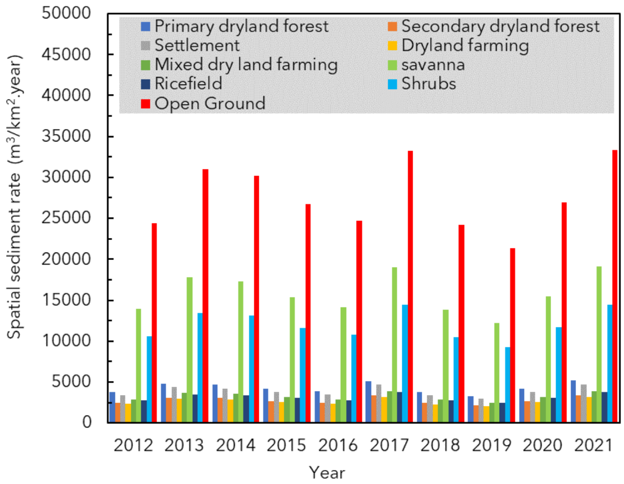

Figure 5. Spatial sediment rate on land use

The relationship between annual erosion volume and spatial sediment rate can be seen in *Figure 6*. In *Figure 6*, it can be seen that rainfall, annual erosion volume, and spatial sediment rate are closely related. This can be seen from the coefficient of determination for the relationship between rainfall and erosion volume which is 99.96%. Furthermore, the coefficient of determination for the relationship between rainfall and spatial sediment rate is 99.96%. This indicates that rainfall will significantly affect the annual erosion volume and spatial sediment rate occurrence. If the amount of rainfall that occurs is high, the volume of erosion and the rate of sediment will also increase (vise versa). The resulting spatial sediment rate is directly proportional to the volume of annual erosion. According to Sudrajat (2018), regression is an equation that states the relationship between one variable and another or more variables. The regression equation is obtained from the relationship between the independent variable (X) and the dependent variable (Y). According to Ghozali (2016), the value of the coefficient of determination has a value range of 0-1. The closer the value is to 1, the independent variable will significantly affect the dependent variable; on the contrary, if it is not close to the value of 1, then the relationship between the two variables will be further away or other variables will affect it.

The total sediment rate is the result of sediment production in the entire basin. It is calculated using the parameters of the spatial sediment rate and the sub-basin area. The results of the analysis of the total sediment rate for various land uses are presented in *Figure 7*. *Figure 7* shows that the spatial sediment rate affects the total sediment rate. It can be seen that the increase and decrease in the total sediment rate follow the spatial sediment rate. The highest total sediment rate occurred in the use of open land, savannas, and shrubs. At the same time, the lowest occurred in dry and agricultural land use.

The total sediment rate has increased and decreased for ten years. There was an increase in the total sediment rate from 12773680.87 m^3 in 2019 to 19957353.88 m^3 in 2021. Based on the results of research by Ali et al. (2016) and Amiri (2010), the total sediment rate produced is influenced by the total area of the basin. Therefore, the total sediment rate produced is more than the annual erosion volume. Total sediment is the amount of soil deposited in a place as a result of erosion (Asselman et al., 2003). Annual erosion volume is the amount of soil that is eroded and moved from one place to another in volume units per year (Jakubínský et al., 2019). The amount of annual erosion volume is more significant than the total sediment thought to occur because the complete sedimentation depends on the area of sediment, which may still be able to move back due to other potentials, such as the amount of rainfall that is too high. The same phenomenon was also found by Ghimire et al. (2013) in estimating soil erosion and sedimentation in Nepal. The unit used in the Gavrilović method to show the erosion potential is $m^3km^{-2}year^{-1}$ and can be converted into $tonsha^{-1}year^{-1}$. The total annual erosion volume and spatial sediment rate occurring in the krueng Jreu sub-basin are presented in pada *Table 3*.

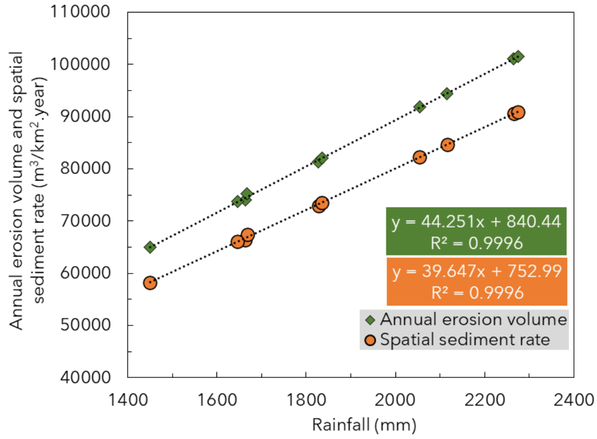

Figure 6. Relationship of rainfall, annual erosion volume, and spatial sediment rate

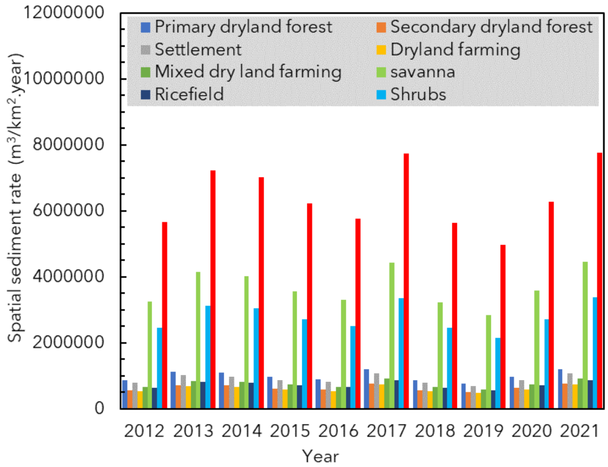

Figure 7. Total sediment rate on land use

Table 3. Erosion volume, spatial sediment rate and total sediment rate in the Krueng Jreusub-basin

Year	Annual erosion volume		Spatial sediment rate	
	$m^3\ km^{-2}\ year^{-1}$	$Tonha^{-1}year^{-1}$	$m^3\ km^{-2}\ year^{-1}$	$Tonha^{-1}year^{-1}$
2012	74090.31	1185.44	66381.68	1062.11
2013	94431.72	1510.91	84606.70	1353.71
2014	91848.01	1469.57	82291.81	1316.67
2015	81404.90	1302.48	72935.24	1166.96
2016	75235.98	1203.78	67408.16	1078.53
2017	101107.99	1617.73	90588.35	1449.41
2018	73717.04	1179.47	66047.26	1056.76
2019	64965.41	1039.45	58206.18	931.30
2020	82079.33	1313.27	73539.50	1176.63
2021	101500.71	1624.01	90940.21	1455.04

4. Conclusions

Biophysical characteristics such as geology and land use have a high sensitivity to the coefficient of erosion intensity produced, while different slopes do not. Annual erosion volume and spatial sediment rate results are directly proportional to temperature and rainfall, but the sensitivity of rainfall is more significant than temperature. The results of the erosion and sediment analysis using the Gavrilović method for ten years in the Krueng Jreu sub-basin show an average annual erosion volume of 84038.14 m^3km^{-2} and a spatial sediment rate of 75294.51 m^3km^{-2}. The volume of erosion and the rate of sediment are known to have a very close relationship with rainfall. This is shown from the results of the coefficient of determination of these two factors, which is 99.96%.

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