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Erosion Rate in Post-Coal Mining Reclamation Area in Kutai Kartanegara District, Indonesia

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

Erosion is the transport of parts of the soil from one place to another by natural agent, namely water, and wind. Mining in Indonesia generally uses open-pit mining methods. Generally, open pit mining has a very high erosion rate due to damage to soil aggregation and high interaction with rainwater. This study aims to determine the erosion rate and hazard class in the post-coal mining reclamation area. The research location was in the Jembayan Muarabara Group, Kutai Kartanegara Regency, East Kalimantan Province, from February 2021 to May 2021. The erosion rate measurement in this study used the stick method by measuring the erosion rate based on the change in soil surface loss in centimetres (cm) units. Erosion rate data collection is carried out periodically every month. The results showed that the highest erosion was in the Disposal area,

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namely 558.55 - 1341.94 tons/ha/year, including class V (very high), in the Stock Soil area with an erosion rate of 471.79 - 693.51 tons/ha/year including class IV (high) to class V (very high) and the lowest erosion rate in the reclamation area in 2019, namely 189.51 - 673.88 tons/ha/year including class IV (high) to class V (very high). Factors that affect the magnitude of the erosion rate are land cover vegetation, soil slope, and the soil's physical properties.

Keywords: Erosion; reclamation; post mine; Indonesia.

1. INTRODUCTION

Open-pit coal mining techniques are widely used in Indonesia causing changes in the landscape and loss of ground cover vegetation, thereby increasing the rate of erosion and sedimentation in the waters. In theory, open pit mining has a very high erosion rate due to the breakdown of soil aggregation and the high interaction with rainwater resulting from the loss of land cover vegetation and removal of overburden [1,2]. Consequently, efforts are made to restore environmental damage through reclamation and rehabilitation [3].

Erosion is the event of being transported or moving parts of the soil from one place to another by natural media. In erosion events, parts of the soil in one place are eroded and transported, then deposited elsewhere. This is caused by natural media, namely water (caused by the force of the wind) and angina (caused by the force of the water). Erosion caused by water often occurs in wet climates, while erosion caused by wind is an event that occurs in dry climates. Indonesia is a tropical area with a wet or slightly wet climate [4]. The factors that affect erosion are climate, topography, vegetation, soil, and humans [5].

As stated by Decree of the Minister of Energy and Human Resources No. 1827 of 2018, reclamation is an activity carried out throughout the mining business to organize, improve and restore the quality of the environment and ecosystem so that it can function again according to its designation. one of the assessments of the success of reclamation is the erosion and sedimentation control measure which weights 10% [6].

Reclamation must occur on disturbed land in ex-mining and outside ex-mining areas. Land outside the ex-mining includes stockpiles of raw materials, heaps of overburden, roads for transportation, processing/refining, factories/ installations, offices, housing, and ports/docks. The principles of reclamation activities are: 1. Reclamation must be considered an integral part of mining activities. 2. Reclamation activities must be carried out as early as possible and do not have to wait for the entire mining process to be completed [7].

Revegetation attempts to repair and restore vegetation cover through planting and maintenance activities. The purpose of revegetation is to increase the productivity of ex-mining land. The stages of revegetating post-mining land include making nurseries, procuring seeds, planting, and maintaining plants [8].

Erosion can be known by predicting its capacity so that it can be avoided as early as possible. One way is to use the small plot method [9]. Apart from using the small plot method, in Regulation of the Minister of State for the Environment No. 07 of 2006, another method for predicting erosion is using a yardstick (measuring stick) [10]. This method is simple and practical for predicting erosion because the tools are easy to obtain and read. This method uses a tool to measure changes in soil depth due to erosion or sedimentation in the form of a measuring stick with weather-resistant material during use, lightweight and readily available. The measuring stick is immersed in the soil until the zero mark is right on the surface of the soil, and monitoring the rate of soil erosion in a field requires more than one observation point. Therefore it is necessary to place a measuring stick that can represent the appearance of the land [9].

Jembayan Muarabara Group is a company engaged in coal mining. The research locations generally consist of two types of area closure, namely active areas covering Disposal areas (overburden rock piles) and Stock Soil areas (topsoil), as well as post-mining areas covering Reclamation areas in 2019, which have been revegetated.

The research aims to determine the magnitude of the rate of erosion and the class of erosion hazard that occurs in the reclamation area so that a precaution can be taken to preserve the soil.

2. MATERIALS AND METHODS

2.1 Time and Place

This research was carried out from February 2021 to May 2021. The location of research was carried out in Jembayan Muarabara Group, Kutai Kartanegara Regency, East Kalimantan Province, which consisted of PT Arzara Baraindo Energitama (ABE), PT Jembayan Muarabara (JMB) and PT Kemilau Rindang Abadi (KRA). Research activities were carried out in three areas at each company: the Disposal area, Stock Soil, and the 2019 Reclamation area.

2.2 Materials and Tools

The materials used in this study are the height of soil loss, unit weight, soil texture, permeability, C-Organic, and rainfall of the Jembayan Muarabara Group in 2021.

The tools used in this study were GPS (Global Position System), erosion sticks (120 cm), calipers, tape measure (50 m), hammers, clinometers, sample rings, soil and plastic drills, and writing tools, namely pens and datasheets.

2.3 Research Procedure

This study used the stick method and was carried out in three locations: Disposal (overburden), Stock Soil, and Reclamation in 2019. There were three erosion rate plots at each study location, so the total erosion rate plot points were 9 points (Fig. 1). The erosion stick is 120 and 50 cm long and is buried in the soil. Then measure the distance from the ground to the red line on the erosion stick as the initial limit (Fig. 2).

The erosion rate is measured based on the change in soil surface loss in centimeters (cm). Measure using a caliper and a ruler by measuring from the ground surface to the red mark on the erosion stick. Erosion rate data collection is carried out periodically every month. Soil sampling uses a sample ring to obtain soil unit weight data.

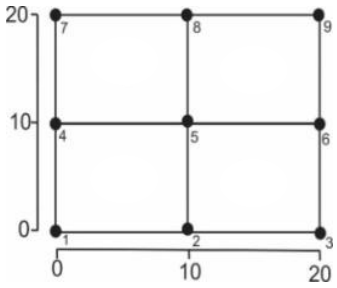

Fig. 1. Erosion plot measuring 20 M × 20 M

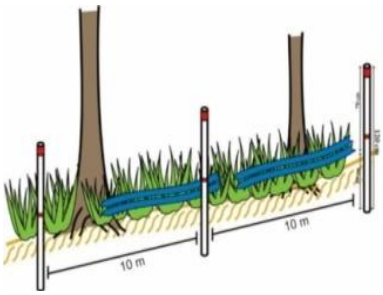

Fig. 2. Installation of erosion sticks spaced 10 m x 10 m

Data collection is carried out every month to determine the amount of erosion that occurs in that month. The data obtained is initial data, which is then measured the following month again, seen the difference, is added up, and then averaged in each erosion measuring plot. The calculation to get the rate of soil erosion (tons/ha/year) is as follows:

Weight of eroded soil (g) = [average thickness of erosion (cm)] × [area of erosion plot (cm^2)] × [unit weight g/cm^3]

Erosion Rate (tons/ha) =

$$\frac{[\text{the weight of the eroded soil (g)}/1.000.000\ g]}{[\text{erosion area (m2)} / 10.000\ m^2]}$$

Erosion rate (tons/ha/year) = [Σ 3 months erosion rate] × [1 year rainfall : 3 month rainfall]

The Erosion Hazard Class is obtained from calculating the one-year erosion rate and is grouped into the erosion hazard class. The following is a Table 1 of erosion hazard classes [11].

Table 1. Erosion hazard class

No.	Erosion rate (tons/ha/year)	Erosion hazard class	Description
1	<15	I	SR
2	15-60	II	R
3	60-180	III	S
4	180-480	IV	T
5	>480	V	ST

Source: Suripin, 2002

Information: SR = Very Low, S= Moderate, T = High, R = Low, S = Very High

3. RESULTS AND DISCUSSION

3.1 Characteristics of Reclamation Land

Rainfall is the height of rainwater that collects in a flat place and does not seep, flow or evaporate. Rainfall uses units of millimeter (mm) [12]. The highest rainfall in one year in Jembayan Muarabara Group (Table 2) was at PT Arzara Baraindo Energitama at 2682.87 mm, and the lowest was at PT Kemilau Rindang Abadi at 1658.07 mm.

Based on the data presented in Table 3, the slopes of the land in the study area tend to be steep. The highest land slope is at PT ABE, namely in the 2019 Reclamation area of 35% (steep), and the lowest land slope is generally at PT KRA with the lowest slope, namely in the Stock Soil area of 10% (slightly sloping).

Table 2. Rainfall in research locations

Month	Location					
	PT ABE		PT JMB		PT KRA	
	(mm)	(%)	(mm)	(%)	(mm)	(%)
January	150.10	5.59	140.30	5.43	25.90	1.56
February	264.00	9.84	171.20	6.63	164.50	9.92
March	338.10	12.60	196.80	7.62	264.80	15.97
April	172.50	6.43	154.40	5.98	57.90	3.49
May	208.00	7.75	168.10	6.51	173.00	10.43
June	178.60	6.66	166.50	6.45	49.70	3.00
July	118.40	4.41	96.90	3.75	49.70	3.00
August	249.97	9.32	275.40	10.66	203.87	12.30
September	243.90	9.09	310.70	12.03	183.60	11.07
October	182.80	6.81	264.50	10.24	81.40	4.91
November	198.50	7.40	234.20	9.07	115.20	6.95
December	378.00	14.09	404.00	15.64	288.50	17.40
Total	2682.87	100	2583.00	100	1658.07	100

Source: Jembayan muarabara group

Table 3. Land slope

Location/Area of reclamation		Slope (%)	Information
PT ABE	Over burden	29	Steep
	Stock soil	24	Sloping
	Reklamasi 2019	35	Steep
PT JMB	Over burden	28	Steep
	Stock soil	30	Steep
	Reklamasi 2019	25	Steep
PT KRA	Over burden	15	Sloping
	Stock soil	10	Slightly Sloping
	Reklamasi 2019	23	Sloping

Source: Field observation results

The vegetation condition in all 2019 Stock Soil and Reclamation research locations contained fast-growing species, fruit trees, local plants and natural trees. There were no plants in all research locations in the Disposal. In all areas of Stock Soil, vegetation density is not dense. The primary plants in the 2019 Reclamation area in each company, namely in the 2019 Reclamation at PT ABE and PT KRA were Johar with dense vegetation density and in the 2019 Reclamation at PT JMB Sengon Laut with vegetation density that was not dense.

In this study, several parameters of soil physical properties were used: soil texture, unit weight, permeability, and c-organic. The results of the analysis of the soil's physical properties are presented in Table 4.

3.2 Erosion Rate

The erosion rate at the study site is influenced by climatic, topographical, vegetation and soil physical factors. Erosion can take many forms due to movement, including water, wind, stars and vehicles. The pull of the earth's gravity slowly makes the ground move or quickly as a landslide [13]. The thickness of the eroded soil in each plot is presented in Table 5.

In general, in all research areas, the highest erosion is in the Disposal area, and the lowest is in the 2019 Reclamation area (Table 5). The erosion rate (tons/ha) at PT ABE, the highest erosion rate, was in the Disposal area, namely in the 3rd month (74.44 tons/ha) and the lowest in the 2nd month (37.55 tons/ha). This can be affected by the steep slope of the soil (29%), high unit weight (1.56 g/cm^3) and lack of vegetation. The Stock Soil area had the highest erosion rate after the Disposal area, with the highest erosion rate in the 2nd month (81.83 tons/ha) and the lowest in the 1st month (26.06 tons/ha). The Stock Soil location has a sloping slope (24%), dominant sand soil (71.40%) and plants that grow not densely. The 2019 Reclamation area has the lowest monthly erosion rate in the 1st month (14.18 tons/ha). This could be due to the lush growth of reclamation plants and dense vegetation, even though the 2019 Reclamation area has a steep slope of 35%.

The erosion rate (tons/ha) at PT JMB, the highest erosion rate every month is in the Disposal area, with the highest erosion rate in the 2nd month (104.84 tons/ha) and the lowest in the 3rd month (75.29 tons /Ha). The 2019 Reclamation area is the highest location after the Disposal area, with the highest erosion rate in the 3rd month (52.19 tons/ha) and the lowest in the 1st month (38.84 tons/ha). The soil erosion rate was lowest in the Soil Stock area, with the lowest erosion rate in the 1st month (20.84 tons/ha) and the highest in the 3rd month (40.94 tons/ha). The high erosion rate in the 2019 Reclamation area can be caused by uneven rainfall, having a considerable unit weight (1.52 g/cm3) and the highest fraction, sand (59.78%), and dense as well as vegetation on the soil surface that is not dense. Erosion of disturbed land caused by human hands can carry large amounts of sand, stone and silt carried by water [13].

Regarding the erosion rate (tons/ha) at PT KRA, the highest erosion was in the Disposal area, and the lowest was in the 2019 Reclamation area. The highest erosion rate in the Disposal area was in the 1st month (109.19 tons/ha) and the lowest in the 3rd month 2 (86.80 tons/ha). The next highest erosion rate was in the Stock Soil area, with the highest erosion rate in the 1st month (80.41 tons/ha) and the lowest in the 3rd month (61.17 tons/ha). The research location in the 2019 Reclamation area has the lowest erosion rate every month and the lowest in the 2nd month (20.63 tons/ha). The low eroded soil in the 2019 Reclamation area can be caused by dense vegetation growth, despite its sloping slope (23%). The existence of this vegetation growth will reduce the destructive power of the soil caused by rainwater and can also reduce the speed of surface runoff so that less soil is eroded and carried away by water and making the transported soil settle more quickly [14].

Each subsidiary's erosion rate in one year at the Jembayan Muarabara Group is different (Fig. 3). In all research areas, the highest erosion rate was in the Disposal area ranging from 558.55 tons/ha/year to 1341.94 tons/ha/year. The highest erosion rate was at PT JMB at 1341.94 tons/ha/year, PT KRA at 1003.38 tons/ha/year, and PT ABE at 558.55 tons/ha/year.

After the Disposal area, the research areas with the most outstanding value are generally in Stock Soil areas ranging from 558.55 tons/ha/year to 471.70 tons/ha/year. The most considerable erosion rate in the Stock Soil area was at PT KRA at 693.51 tons/ha/year, PT ABE at 552.39 tons/ha/year, and PT JMB at 471.79 tons/ha/year. The lowest erosion rate in one year is generally in the 2019 Reclamation area,

with the lowest erosion rate value being at PT ABE, which is 189.51 tons/ha/year, PT KRA, which is 369.87 tons/ha/year, while the 2019 Reclamation research location at PT JMB, namely 673.88 tons/ha/year. PT JMB in the Stock Soil area has a lower erosion rate value than the 2019 Reclamation area, this can be due to the 2019 Reclamation area being caused by uneven rainfall, having a considerable volume weight (1.52 g/cm3) and the highest fraction is sand (59.78%), as well as vegetation on the soil surface that is not dense.

Table 4. Soil physical properties

Location	Parameter	Unit	Reclamation area		
			Reclamation 2019	Stock soil	Disposal
PT ABE	Sand	%	35.57	71.40	7.95
	Silt	%	33.85	14.15	46.60
	Clay	%	30.58	14.45	45.45
	Bulk density	g/cm^3	1.45	1.43	1.56
	Permeability	cm/jam	1.53	5.40	2.34
	C-Organic	%	0.66	0.46	*
PT JMB	Sand	%	59.78	73.47	49.69
	Silt	%	25.12	16.44	30.02
	Clay	%	15.10	10.09	20.29
	Bulk Density	g/cm^3	1.52	1.34	1.40
	Permeabilitas	cm/jam	3.06	2.45	3.46
	C-Organic	%	0.22	0.32	*
PT KRA	Sand	%	29.12	65.95	50.28
	Silt	%	37.75	17.82	29.80
	Clay	%	33.13	16.23	19.92
	Bulk Density	g/cm^3	1.56	1.48	1.55
	Permeability	cm/jam	2.85	6.93	1.73
	C-Organic	%	0.92	0.46	*

Source: Laboratory of soil science and forest nutrition, faculty of forestry, university of Mulawarman and center for agricultural technology studies in East Kalimantan
*Note: * = data not available*

Table 5. Average thickness of eroded soil and erosion rate (tons/ha)

Location/ Reklamation Area		Month Ke-1		Month Ke-2		Month Ke-3	
		Erosion thickness (cm)	Erosion rate (tons/ha)	Erosion thickness (cm)	Erosion rate (tons/ha)	Erosion thickness (cm)	Erosion rate (tons/ha)
PT ABE	Disposal	0.24	37.59	0.24	37.55	0.47	74.44
	Stock Soil	0.18	26.06	0.57	81.83	0.28	40.04
	Reklamation 2019	0.10	14.18	0.12	17.24	0.13	19.33
PT JMB	Disposal	0.64	89.60	0.75	104.84	0.54	75.29
	Stock Soil	0.16	20.84	0.25	33.05	0.31	40.94
	Reklamation 2019	0.26	38.84	0.29	44.42	0.34	52.19
PT KRA	Disposal	0.70	109.19	0.56	86.80	0.67	104.02
	Stock Soil	0.54	80.41	0.44	65.78	0.41	61.17
	Reklamation 2019	0.34	52.69	0.13	20.63	0.24	37.27

Source: Research data and monthly erosion rate calculation results

Table 6. Erosion rate (tons/ha/year) in the Jembayan Muarabara Group

Location/ Reklamation area		Percentage of rainfall 3 months (%)	Erosion Rate In 3 Months (tons/ha)	Erosion Rate (tons/ha/year)
PT ABE	Disposal	26.78	149.58	558.55
	Stock Soil		147.93	552.39
	Reklamation 2019		50.75	189.51
PT JMB	Disposal	20.10	269.73	1341.94
	Stock Soil		94.83	471.79
	Reklamation 2019		135.45	673.88
PT KRA	Disposal	29.90	300.01	1003.38
	Stock Soil		207.36	693.51
	Reklamation 2019		110.59	369.87

Source: Annual erosion rate calculation results

The amount of soil eroded in one year in the Disposal area is due to the absence of vegetation growth. It has too steep slopes, even though the soil permeability class in the Disposal area at PT ABE and PT JMB is moderate. Land slope and length are topographical elements that significantly affect runoff and erosion. The steeper the slope, the higher the erosion potential caused by the soil surface splashing to the bottom of the slope caused by the collision of more and more raindrops [14]. Land or vegetation cover benefits the soil because it can protect the soil from rainwater so that it does not hit the ground surface directly. High rain intensity will cause surface runoff and transport the soil particles to a lower place [14].

The magnitude of eroded soil is low due to land cover at the Stock Soil research location and the 2019 Reclamation research location. However, the Stock Soil research location has less vegetation than the 2019 Reclamation research location. Thick and dense vegetation is magnificent for reducing the influence of rainfall and topography on erosion, while less vegetation will be more easily eroded and transported by runoff [15].

3.3 Erosion Hazard Class

Based on the Erosion Hazard Class in the Jembayan Muarabara Group, Kutai Kartanegara Regency (Table 7), it is generally included in class V, which is very high. PT ABE in the Disposal area (558.55 tons/ha/year) and Stock Soil (552.39 tons/ha/year) fall into class V, while at the 2019 Reclamation research location (189.51 tons/ha/year) entered into class IV, namely high. At PT JMB, in the Disposal area (1341.94 tons/ha/year) and 2019 Reclamation (673.88 tons/ha/year), it is included in class V which is very high, while in the Stock Soil area (471.79 tons/ha/year) entered into class IV, namely high. PT KRA in the Disposal area (1003.38 tons/ha/year) and Stock Soil (693.51 tons/ha/year) is in class V which is very high, while in the 2019 Reclamation area (369.87 tons/ha/year) entered into class IV, namely high (Table 7). The class of soil erosion hazard from high to very high on the reclamation land is also shown in Fig. 3, where groove erosion has formed up to gully erosion.

The conservation technique in the Jembayan Muarabara Group is making bench terraces (terracing). The bench terrace is very helpful for reducing the erosion rate because it aims to reduce the slope length, retain water to reduce the speed and amount of surface runoff and increase the opportunities for water absorption by the soil. In addition to making bench terraces, there is also the construction of drains in the 2019 Reclamation area, but there are no drains in the Disposal and Stock Soil areas. Taking into account several other factors that affect the magnitude of the erosion rate at the study site in Jembayan Muarabara Group besides rainfall, vegetation cover, slope, volume weight and soil texture, namely at the Disposal location, there is no management of ground cover, there is no drainage around the barrier, especially at Disposal and Stock Soil locations.

Erosion that occurs on land cannot be eliminated but can be reduced by carrying out soil

Table 7. Erosion hazard class

Location/ Reklamation Area		Erosion rate (tons/ha/year)	Erosion hazard class	Description
PT ABE	Disposal	558.55	V	ST
	Stock Soil	552.39	V	ST
	Reklamation 2019	189.51	IV	T
PT JMB	Disposal	1341.94	V	ST
	Stock Soil	471.79	IV	T
	Reklamation 2019	673.88	V	ST
PT KRA	Disposal	1003.38	V	ST
	Stock Soil	693.51	V	ST
	Reklamation 2019	369.87	IV	T

Information: ST = very high; T = high

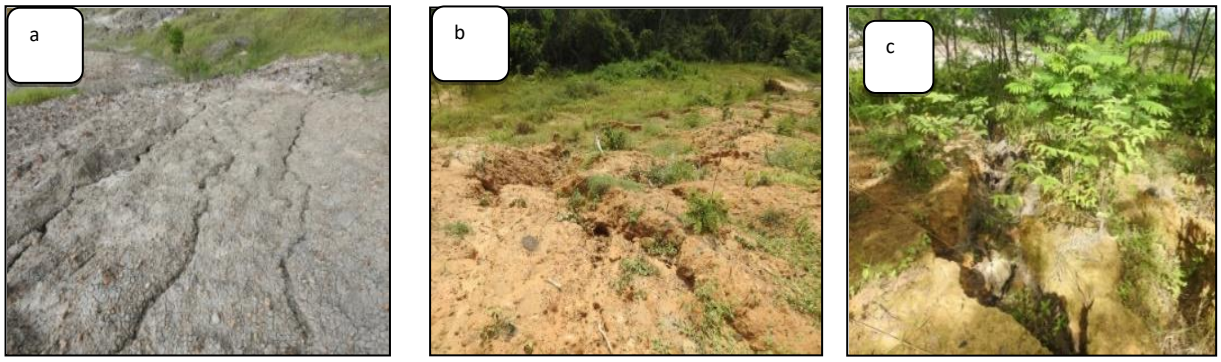

Fig. 3. Condition of reclamation land
a) Disposal Area, b) Stock Soils Area, c) Reclamation area in 2019

conservation efforts, while several proposed strategies that can be carried out are:

1. Stockpiling and arranging cover soil according to the type of soil because this type of soil is prone to erosion and landslides and is also a type of loose soil.
2. Increase the types of vegetation that cover the ground so that rainwater does not directly hit the ground surface.
3. Construction of bench terraces accompanied by drains on the landfill, shortening the length of the slope and the slope angle of the barrier, which increases water absorption, reduces the flow rate of the soil surface and can regulate water so that it can flow in certain places.

4. CONCLUSION

1. The erosion rate in the Disposal area ranges from 558.55 - 1341.94 tons/ha/year, the erosion rate in the Stock Soil area ranges from 471.79 - 693.51 tons/ha/year, and the erosion rate in the 2019 Reclamation area ranges from 189.51 - 673.88 tons/ha/year.
2. The erosion rate belonging to class V (very high) occurred at six locations, namely at PT Arzara Baraindo Energitama in the Disposal and Stock Soil area, at PT Jembayan Muarabara in the 2019 Disposal and Reclamation area, at PT Kemilau Rindang Abadi in the Disposal and Stock Soil area. The erosion rate belonging to class IV (high) occurred in three locations, namely PT Arzara Baraindo Energitama in the 2019 Reclamation area, PT Jembayan Muarabara in the Stock Soil area, and PT Kemilau Rindang Abadi in the 2019 Reclamation area.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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