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Analysis Of Physical And Chemical Impact On The Krueng Montala River, Aceh Besar Regency: Sand And Stone Mining Activity Effect

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Abstract – Rivers are important for human survival providing raw water for the community's clean water needs. Rivers also provide sand, gravel, and rocks commonly used for construction. However, improper exploitation of the river without considering environmental sustainability may cause future damage to it. The damage is usually caused by mining activities violating environmental regulations. The main point of this study is to evaluate the changes in the riverbank and riverbed of Krueng Montala River, Aceh, Indonesia, due to the mining activity around that place. The method used to analyze the changes was measuring the river's topographical contours at the end of mining activities and comparing the results with the initial licensing data based on the Mining License Number 540/DPMPTSP/414/IUP-OP/2020. Some of the equipment used in evaluating the condition of the river includes a Nikon Total Station, standard measuring tanks, Garmin 62Csx, and GPS. The measured data was also compared to the Technical Recommendation Number SA.02.03/BWS1/1542 from the River Basin Office of Sumatera 1. Based on the technical recommendation, the sufficient excavation volume is 10,201.44 m^3. The field data for lost and excavated materials at the research location was 40,861.4 m^3, and the total riverbank material loss at the study location was 7,566.33 m^3. The impact of mining activities on chemical parameters in the Krueng Montala River is still within the standard limits permitted by the government, such as TDS, TSS, COD, and BOD parameters. The influence of mining activities on chemical parameters in the Krueng Montala River did not show results that exceeded the standard limits permitted by the government, such as TDS, TSS, COD, and BOD parameters.

Keywords: River cross-section, Riverbank damage, River flow change, Sand and stone mining

Introduction

A river is a crucial natural resource that plays a significant role in supporting the lives of many living beings. Water availability in the river is essential for various organisms to survive and thrive (Zahra et al., 2018; Joseph, 2023). Additionally, rivers have a crucial role in sustaining agricultural businesses and directly impact the availability of daily human needs (Arsal et al., 2018; Du et al., 2023). In the Aceh province, there are fifteen watersheds, one of which is the Krueng Aceh watershed, consisting of seven sub-watersheds: Krueng Seulimuem, Krueng Keumireu, Krueng Jreue, Krueng Inong, Krueng Khea, Krueng Aneuk, and Krueng Aceh Hilir (Darwin et al., 2021). The Krueng Aceh watershed spans an area of 174,770.41 hectares and is characterized by a diverse landscape, including lowlands, basins, plains, undulating hills, mountains, and hills. The area's

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August 2023
doi: 10.13170/aijst.12.2.31526

topography varies from flat to steep, 0–1,710 meters above sea level (Maulidah & Brata, 2019). Notably, the central area downstream is dominated by 0-8% slopes, while hills and mountains flank the upstream area. Meanwhile, the undulating hills account for 17% of the downstream zone (Kartiwa & Sutrisno, 2006).

Moreover, the Krueng Aceh river is a vital water source for the Kuta Cot Glie community and the surrounding Keuliling reservoir, including villages such as Siron Krueng, Siron Blang, and Cucum. Figure 1 displays the map of the Krueng Jreu river, one of the sub-watersheds of the Krueng Aceh watershed, and comprises two rivers: Krueng Jreu and Krueng Montala. On the other hand, The Krueng Jreu and the Krueng Montala rivers are not only the primary water source for residents of Banda Aceh and Aceh Besar in Aceh Province but also have significant economic value due to their rich reserves of sand and stone, which are widely used as construction materials in both cities. Mining activities have been instrumental in extracting these materials and boosting the local economy.

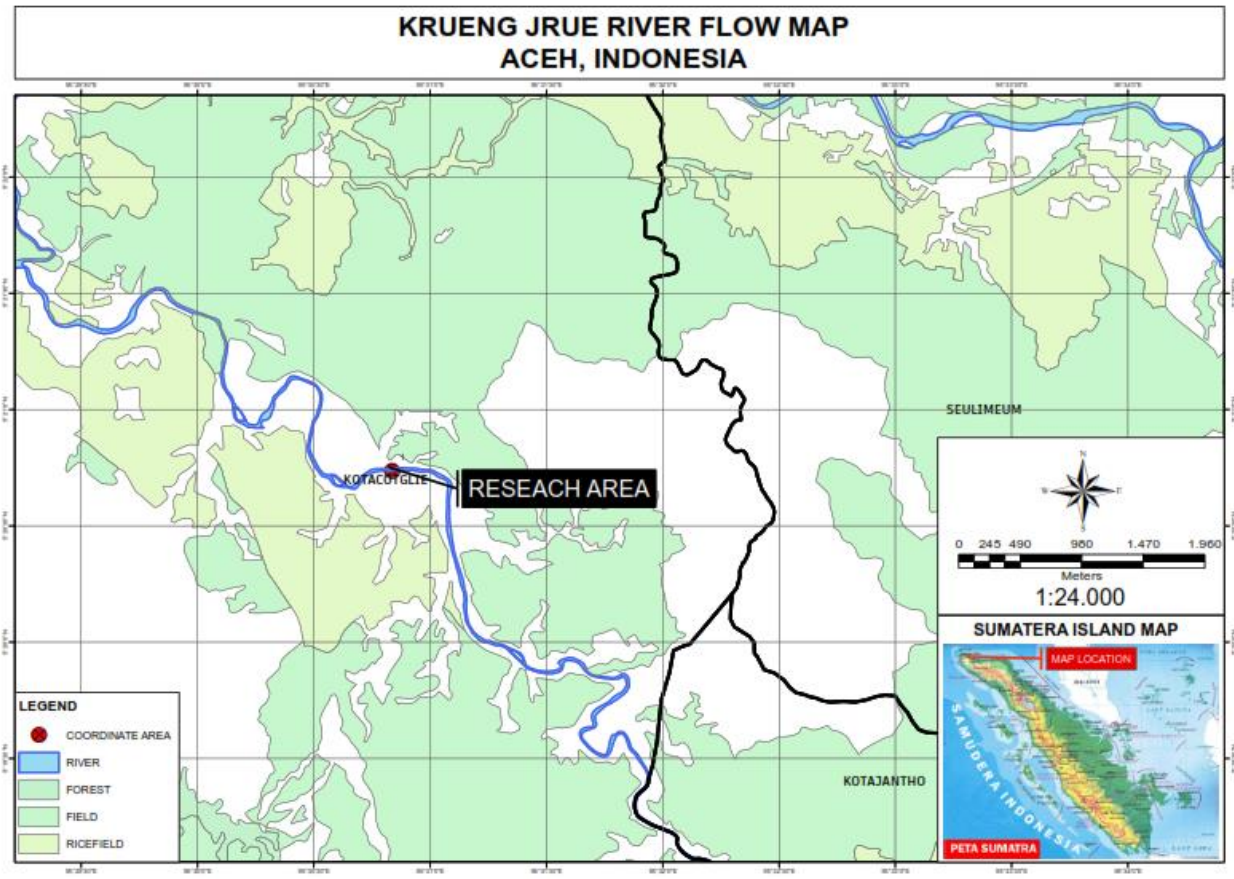

Figure 1. A map of the Krueng Jreu Sub-Watershed

While mining activities may positively affect infrastructure development and the economy, they also negatively impact the environment, such as degradation in river morphology and riverbanks (Pitchaiah, 2017; Bendixen et al., 2021; Rentier & Cammeraat, 2022; Nasare et al., 2023; Rangel-Buitrago et al., 2023). These negative impacts are often caused by improper implementation of mining procedures, which can result in significant changes in river depth, shallowing and widening of some river bodies, and inundation in others (Iriani & Bahtiar, 2013; Vandana et al., 2020; Sunarsih, 2021). In addition, after mining activities, stone piling can alter the river's flow pattern, causing the water to change its direction and hit the river walls, leading to the collapse of riverbanks and a reduction in the river area. Therefore, proper mining procedures and regulations should be in place to mitigate these negative impacts and ensure the sustainability of rivers as vital natural resources.

This study presents a comprehensive evaluation and analysis of the physical and chemical impacts of sand and stone mining at the Krueng Montala river in Aceh, Indonesia by analyzing various factors such as the width, Volume, and depth of the excavation, the safe distance of the excavation site from the riverbank, river

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characteristics, and geological conditions. The study highlights the importance of considering the riverbank's slope on the river's cross-section when assessing the damage caused by mining. Furthermore, the study provides valuable insights into the eligibility of the mining site for an extension of the mining permit. This study provides a better explanation of the level of physical damage and how it affects the chemical parameters of the Krueng Montala River so that future mining activities in the area are no longer allowed based on this study. The location already has a mining business license as a basis for being allowed to dig sand in the area. This study is needed to measure and guide parties who will issue or extend mining permits in this location.

Materials and Methods

Sampling Area

The sample collection site was at the Kreung Montala river, Siron blang village, Kuta Cot Glie district, Aceh Besar regency, as shown in Figure 2.

Figure 2. The study location

Measuring the Cross-Section of the River

Cross-section measurements show the planned excavation volume, distance, depth, and riverbank safety analysis based on the field observation. The observation results were analyzed and modeled using Autocad to obtain excavation data and a model for a safe mining plan related to riverbank safety. The river cross-sections were measured by dividing the river into several sections and generating river contours, width, depth, slope, and condition of the surrounding surface (Bagus et al., 2015). Measurements were made in detail for each height difference between ground levels at the 0.5 hectares of the study site, as shown in Figure 3, using a Total Station (Bagus et al., 2015). Topography measurements using the cross-section method detected details of changes in the river. The analysis was conducted by comparing the contour images from the observation and the initial

Aceh Int. J. Sci. Technol., 12(2) 197-207
August 2023
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contour data based on the license. Continuing mining and extending permits are not recommended if the research discovers damages.

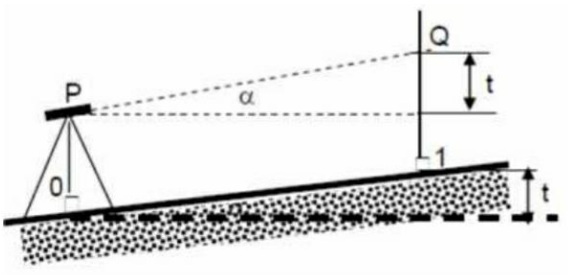

Figure 3. The method for measuring the cross-section of the river

Remarks:
T : Height difference between points 0 and 1
α : Oblique angle
P : 0 = Q1

Material Calculation

The material calculation at the study site was based on the affected area method and the average thickness of the sediment. It was then calculated using the Equation 1.

$$C = (L\ x\ t)\ x\ MgP\ x\ SG \quad (1)$$

(Source: (SNI), 1998)

Remarks:
C : Resource/reserve (tonnes)
L : Affected area (m^2)
t : Average thickness of sand and stone deposit (m)
SG : Type of rock (tonnes/m^3)

Based on SNI Number 13-4726-1998 regarding Mineral Resources, the Volume of river damage is obtained by comparing the Volume of excavated material from the river, including the riverbank, at each cross-section, to the acceptable Volume.

Measurements were made at each height difference at the material's surface and the river's cross-section with a cross-sectional distance of 25 meters. The results were cross-sectional images of river contours, width, depth, slope, and surrounding surface conditions (Bagus et al., 2015).

Change in Environmental Conditions

The study area is 0.5 hectares. It follows the IUP (*Izin Usaha Penambangan*) decree, which has a technical recommendation from the River Basin Regional Office in the form of a cross-sectional image of the river accompanied by data on the value of material reserves, the depth of the riverbed or original ground level, and the riverbank condition that are to be compared with the observed data. Comparing the technical recommendation and field data will show changes in the soil surface, from the original to the current condition, damaged riverbanks, Volume of damage, and the value of lost materials from the riverbed and riverbanks.

Laboratory Analysis

The quality of water around the research object was carried out at three points: upstream, precisely at the study location, and downstream. Water samples were taken using sampling media and brought to the laboratory to be tested for their quality. The testing parameters include temperature, DO (Dissolved Oxygen), TDS (Total Dissolved Solid), TSS (Total Suspended Solid), COD (Chemical Oxygen Demand), and BOD (Biologycal

Aceh Int. J. Sci. Technol., 12(2) 197-207
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Oxygen Demand). Water sampling points are conducted at the upstream and downstream parts of mining outside the surrounding area and in the middle of the mining site.

Results

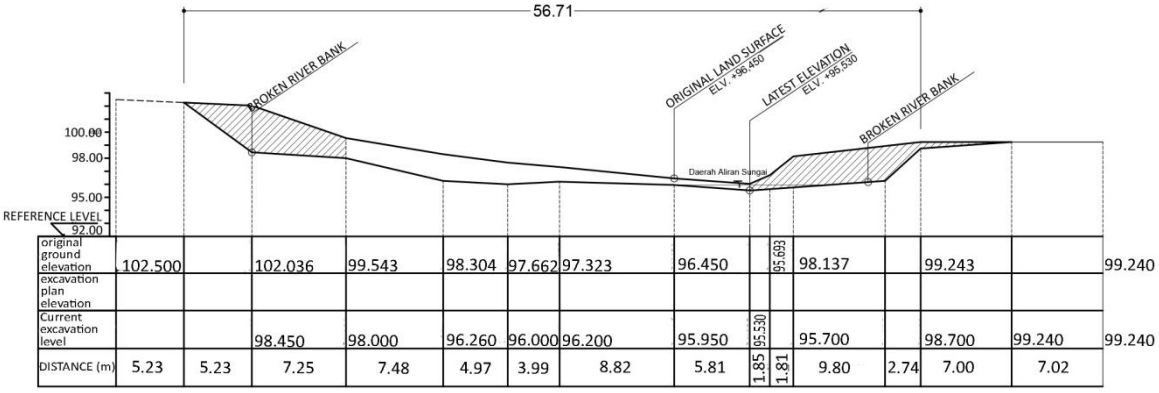
The Physical Impacts of Mining on the Environment

Table 1. The excavation volume in the BWS1 (*Balai Wilayah Sungai 1*) technical recommendation and the post-mining data

Name	Area (m^2)	Distance (m)	Excavated Volume (m^3)	Technical Recommendation Volume (m^3)
P0	94.49	25	2362.13	000
P1	104.95	25	2623.85	814.08
P2	234.57	25	5864.25	2331.03
P3	174.38	25	4359.50	3319.49
P4	268.52	25	6713.03	2136.04
P5	259.45	25	6486.30	1037.55
P6	251.87	25	6296.75	563.24
P7	246.23	25	6155.63	000
	Total		40861.43	10201.44

Table 2. The Volume of damage to the riverbank due to mining

Name	Area (m^2)	Distance (m)	Volume (m^3)	Avarage Depth (m)
P0	56.17	25	1404.13	0.92
P1	52.06	25	1301.40	1.38
P2	70.33	25	1758.15	3.54
P3	19.48	25	486.95	3.185
P4	40.71	25	1017.73	3.683
P5	37.45	25	936.25	3.458
P6	12.37	25	309.20	3.852
P7	14.10	25	352.53	2.995
Total	302.65		7566.33	



(a) Cross section P0

Aceh Int. J. Sci. Technol., 12(2) 197-207
August 2023
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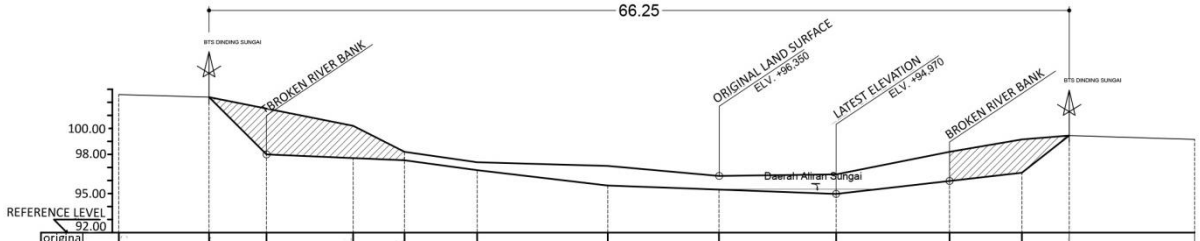
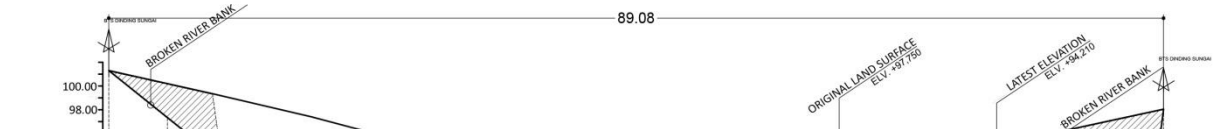


original ground elevation	102.600	102.400		100.200	98.200	97.400	97.120	96.350	96.470	98.200	99.150	99.450
excavation plan elevation												
Current excavation level			98.000	97.720	97.550	96.800	95.620	95.300	94.970	95.960	96.590	99.450
DISTANCE (m)	6.94	4.43	6.67	3.96	5.59	10.06	8.56	9.03	8.73	5.57	3.65	9.66

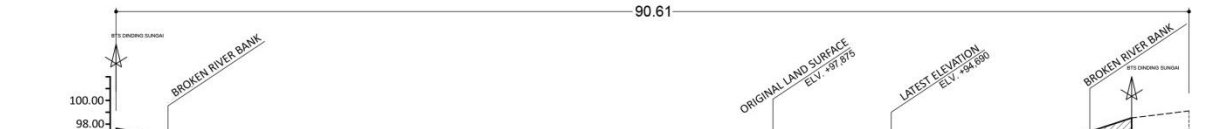
(b) Cross section P1

Figure 4. The riverbank damages in cross sections P0 and P1



ORIGINAL GROUND ELEVATION	102.300	101.235		98.402	96.206	96.268	96.865	97.160	97.750	96.015	97.629	98.436	99.050
EXCAVATION PLAN ELEVATION						95.930	95.930	95.930					
CURRENT EXCAVATION LEVEL			94.650	94.670	94.750	94.650	94.570	93.620	92.850	94.210	94.170	94.130	
DISTANCE (m)	4.96	3.81	0.75 7.59	8.30	9.37	7.14	10.75	8.65	13.33	3.94	4.29	5.34	3.40

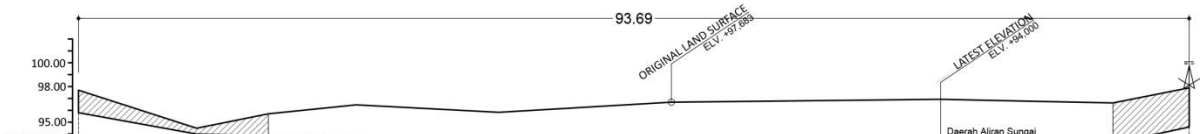
(a) Cross section P2



ORIGINAL GROUND ELEVATION	98.635	96.965	96.759	96.231	97.542	97.875	97.395	96.786	96.584	97.367	99.519	98.200
EXCAVATION PLAN ELEVATION												
CURRENT EXCAVATION LEVEL	97.500	96.070	95.500	95.290	95.000	94.770	94.720	94.690	94.980	95.610	97.800	98.200
DISTANCE (m)	9.23	3.90	5.69	8.14	28.51	6.11	3.89	6.37	7.35	7.35	4.84	2.05

(b) Cross section P3

Figure 5. Image of riverbank damages from sections P2 and P3



ORIGINAL GROUND ELEVATION	98.695	95.496	96.706	97.458	96.833	97.863	97.923	97.623	98.891
EXCAVATION PLAN ELEVATION			95.000	95.000	95.500	95.000			
CURRENT EXCAVATION LEVEL	96.800	95.500	94.820	94.600	94.300	94.280	94.000	94.200	95.600
DISTANCE (m)	9.97	6.05	7.40	12.04	14.55	22.70	14.55	6.43	

(a) Cross section P4

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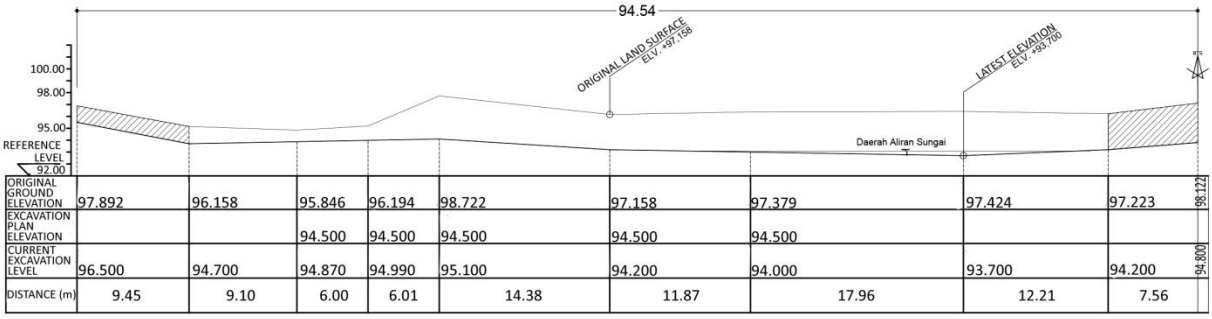
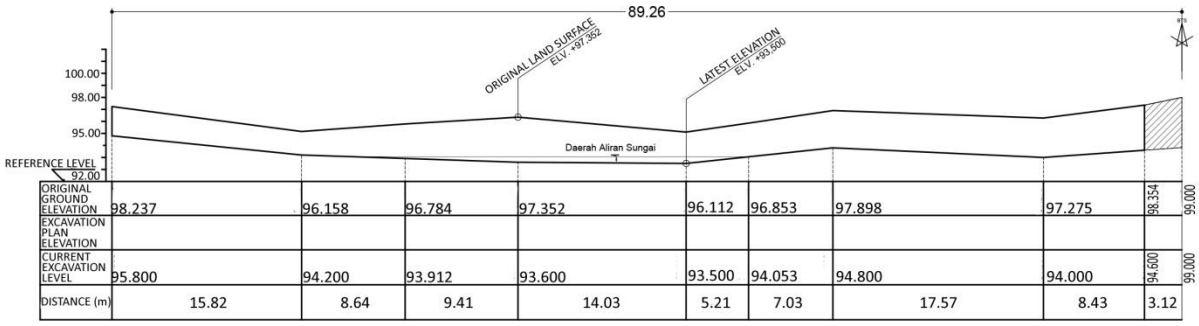


ORIGINAL GROUND ELEVATION	97.892	96.158	95.846	96.194	98.722	97.158	97.379	97.424	97.223	98.122
EXCAVATION PLAN ELEVATION			94.500	94.500	94.500	94.500	94.500			
CURRENT EXCAVATION LEVEL	96.500	94.700	94.870	94.990	95.100	94.200	94.000	93.700	94.200	94.800
DISTANCE (m)	9.45	9.10	6.00	6.01	14.38	11.87	17.96	12.21	7.56	

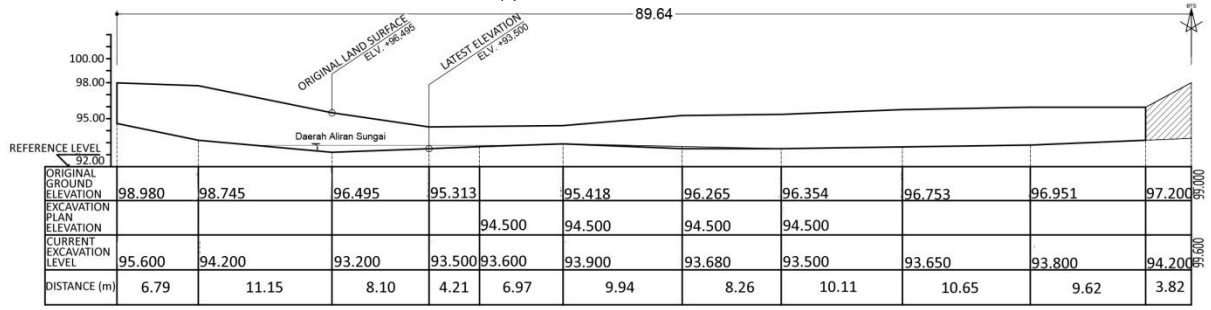
(b) Cross section P5

Figure 6. Image of riverbank damages in sections P4 and P5



ORIGINAL GROUND ELEVATION	98.237	96.158	96.784	97.352	96.112	96.853	97.898	97.275	98.354
EXCAVATION PLAN ELEVATION									
CURRENT EXCAVATION LEVEL	95.800	94.200	93.912	93.600	93.500	94.053	94.800	94.000	94.600
DISTANCE (m)	15.82	8.64	9.41	14.03	5.21	7.03	17.57	8.43	3.12

(a) Cross section P6



ORIGINAL GROUND ELEVATION	98.980	98.745	96.495	95.313		95.418	96.265	96.354	96.753	96.951	97.200
EXCAVATION PLAN ELEVATION					94.500	94.500	94.500	94.500			
CURRENT EXCAVATION LEVEL	95.600	94.200	93.200	93.500	93.600	93.900	93.680	93.500	93.650	93.800	94.200
DISTANCE (m)	6.79	11.15	8.10	4.21	6.97	9.94	8.26	10.11	10.65	9.62	3.82

(b) Cross section P7

Figure 7. Image of river damages in section P6 and P7

(a) Pre-mining condition

(b) Post-mining condition

Figure 8. The conditions of part of the Krueng Jreu sub-watershed riverbank (a) pre- (December, 2021) and (b) post-mining (September, 2022) (Source: research data and technical recommendation)

The Chemical Impacts of Mining on the Environment

Table 3. The quality of river water downstream (5°19'54"N 95°31'24"E) of the study location

No	Parameter	Test Method	Unit	Quality Standard	Limit of Detection	Result
1	Temperature	Thermometry	°C	Deviasi 3	0.01	28.80
2	DO	Winkler	Mg/L	4	0.01	6.75
3	TDS	Gravimetry	Mg/L	1000	0.01	72
4	TSS	Gravimetry	Mg/L	50	2	23
5	COD	Spectrophotometry	Mg/L	25	3.22	9.23
6	BOD	Winkler	Mg/L	3	-	1.98

Table 4. The quality of river water in the middle (5°19'53"N 95°31'39"E) of the study location

No	Parameter	Test Method	Unit	Quality Standard	Limit of Detection	Result
1	Temperature	Thermometry	°C	Deviasi 3	0.01	28.70
2	DO	Winkler	Mg/L	4	0.01	6.60
3	TDS	Gravimetry	Mg/L	1000	0.01	64
4	TSS	Gravimetry	Mg/L	50	2	21
5	COD	Spectrophotometry	Mg/L	25	3.22	10.26
6	BOD	Winkler	Mg/L	3	-	1.51

Table 5. The quality of river water upstream (5°19'53" N. 95°31'33"E) of the study location

No	Parameter	Test Method	Unit	Quality Standard	Limit of Detection	Result
1	Temperature	Thermometry	°C	Deviasi 3	0.01	28.50
2	DO	Winkler	Mg/L	4	0.01	6.42
3	TDS	Gravimetry	Mg/L	1000	0.01	62
4	TSS	Gravimetry	Mg/L	50	2	17
5	COD	Spectrophotometry	Mg/L	25	3.22	14.11
6	BOD	Winkler	Mg/L	3	-	2.17

Dicussion

The Physical Impacts

Based on the technical recommendation data from the River Basin Regional Office, there are limits to the permitted depth, area, distance of positions, and contours of the mining plan. The difference in the Volume of material excavated at the study site and the Volume recommended for mining based on the technical recommendation is presented in Table 1. The Volume of damage to the riverbank due to excavation after mining is shown in Table 2. Meanwhile, Figures 4, 5, and 6 show detailed contour changes in the riverbank and the river's depth and width in each cross-section based on field observation. In the research of Iriani & Bahtiar (Iriani & Bahtiar, 2013), damage to river banks and deepening has been found. Here found the deepening of the river with a measured volume with a comparison of measuring data and technical recommendations issued by the Balai Wilayah Sungai Sumatera 1.

Figure 4 shows the post-mining P0 section with a volume of riverbank damage of 1,404.13 m^3, which caused the river's width to stretch from 38.94 to 56.71 meters, a growth of 17.77 meters. In the cross-section of stake 0, there is an increase in the river's depth from 96.029 to 95.530 meters above sea level due to mining using heavy equipment.

In section P1, the Volume of damage at the riverbank is 1,301.40 m^3, increasing the river's width from 20.32 to 66.25 meters. The condition is accompanied by decreased material in the river, damaging the riverbanks and supporting plants above it. In the cross-section of stake P1, the river's depth, or the original ground level, is 94.970 meters above sea level, while the pre-mining depth is 96.350 meters.

Figure 5 shows a cross-sectional river map of P2. The Volume of riverbank damage is 1,758.15 m^3 which increased the river's width by 18.90 meters, from 70.18 to 89.08 meters. In addition, the depth of the original

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ground level or riverbed due to sediment excavation increased to 92.850 meters above sea level. An inundation was also observed at the location of P2, which had a significant additional depth of 4.9 meters. Figure 5 also shows that the Volume of riverbank damage in section P3 is 486.95 m^3. This damage resulted in the river widening by 27.06 meters, from 63.55 to 90.61 meters. The river's depth changed to 94.686 meters above sea level from 97.875 meters above sea level. This change happened on the east side of the observation site.

Figure 6 shows the P4 section with a volume of riverbank damage of 1,017.73 m^3, which resulted in an additional 22.45 meters of river width, a change from 71.24 to 93.69 meters. There was an elevation of the river's depth or the original ground level to 94.000 meters above sea level from the previous position of 97.683 meters above sea level or an additional depth of 3.683 meters. Figure 6 also shows that section P5 had a volume of riverbank damage of 936.25 m^3. The river's width increased by 17.01 meters, from 77.53 to 94.54 meters. There is also an increase in the river's depth from 97.158 to 93.700 meters above sea level. At this stake, the depth increased by 4.158 meters.

As shown in Figure 6, the Volume of riverbank damage post-mining in section P6 is 309.20 m^3. After mining the sand and stone or collecting accumulated materials from the river, the river depth was 93.500 meters above sea level from 97.352 meters. These findings indicate a 3.12-meter-long damage to the riverbank and an increase in river width from 86.14 to 89.26 meters. Figure 6 also shows that the Volume of riverbank damage reached 352.53 m^3 with a damage length of 3.82 meters; the river's width stretched from 85.82 to 89.64 meters. At P7, it was found that the river's depth was 2.15 meters deeper than previously. Its initial depth was 93.200 meters above sea level, which increased to 95.350 meters above sea level.

Figure 8 is an actual condition of the damaged Krueng Montala river, Krueng Jreu sub-watershed, i.e., the river deepened, the riverbanks were damaged, and the flow pattern changed due to sand and stone mining. The figures include the pre and post-mining conditions.

The Chemical Impacts

The chemical impacts of mining in rivers were analyzed by taking samples at three points: upstream of the research location, exactly at the research location, and downstream of the research location. Table 3 displays the results of laboratory tests for water quality downstream from the research location. Table 4 presents the results of water quality tests for samples exactly at the study site, while Table 5 presents the results of laboratory tests for water quality upstream of the study location. Samples were collected from three sampling points to obtain representative data on water quality around the study site. The research location is far from residential areas, so there were no household waste disposals around the research location.

Table 3 shows that the water temperature at the downstream point is 28.80°C, below the quality standard in the 2021 PP RI concerning Environmental Protection and Management-River Water Quality Standards. The DO is 6.75 mg/L, exceeding the quality standard of 4 mg/L. Based on the analysis, the downstream water sample's total dissolved solids (TDS) is 72 mg/L, which is still safe because it is below the quality standard of 1000 mg/L. Similarly, the TSS is 23 mg/L, below the TSS quality standard of 50 mg/L. COD analysis of the downstream sample resulted in a value of 9.23 mg/L, below the quality standard of 25 mg/L. The BOD value of 1.98 mg/L also meets the requirement (below the 3 mg/L quality standard).

Table 4 shows that the sample in the middle of the river flow had a temperature of 28.50 ºC with a dissolved oxygen content of 6.42 mg/L, above the quality standard of 4 mg/L. The TDS of this sample is 64 mg/L, below the quality standard of 1000 mg/L. Meanwhile, the TSS is 21 mg/L, indicating that the river's TSS is still safe because it is below the 50 mg/L standard. The COD is 10.26 mg/L, below the quality standard of 10.26 mg/L. The BOD is 1.51 mg/L and relatively safe (below the 3 mg/L standards).

Like the other sampling points, the upstream water sample was also tested for its temperature, TDS, TSS, BOD, and COD, as presented in Table 5. The analysis shows that water at this location had a temperature of 28.50ºC and dissolved oxygen of 6.42 mg/L. The test results of these two parameters were similar to the condition at the downstream and middle sampling points. The TDS parameter is 62 mg/L, which is a safe value because it is below the quality standard of 1000 mg/L. The TSS of 17 mg/L is also under control from the quality standard of 50 mg/L. The COD and BOD values at this sampling point are 14.11 mg/L and 2.17 mg/L, respectively. Both values indicate that the upstream COD and BOD are below the quality standards (25 mg/L for COD and 3 mg/L for BOD).

Conclusion

This research was conducted by measuring the width, depth, and situation of the river based on the topography divided into eight measuring stakes. This study revealed the riverbank's damage on the cross-sections of stakes P1, P2, P3, P4, P5, P6, and P7. The Volume of riverbank damage after mining in the section of P0, P1, P2, P3, P4, P5, P6, and P7 was 1,404.13 m^3, 1,301.40 m^3, 1,758.15 m^3, 486.95 m^3, 1,017.73 m^3, 936,25 m^3, 309.20 m^3, and 352.53 m^3, respectively. The total Volume of riverbank damage at the study site was 7,566.33 m^3. One of the proper mining management is to calculate and compile technical recommendations for excavation position and Volume of excavation so that safe mining limits can be known and complied with during implementation. In this case, mining technical limitations and recommendations were violated, causing damage to the river.

Recommendation

1. Mining should stop because the riverbank is already severely damaged.
2. The operating license or issuing a new licens at the location should not be extended to any parties.

References

(SNI), S. N. I. (1998). Mineral Resources (Patent No. 13–4726).

Arsal, T., Sumartono, Basri, & Anam, M. (2018). Effect of Sand Mining on Socio-Economic and Ecology of Communities in Lukulo River Areas Kebumen Central Java. International Journal of Indonesian Society Culture, 10(2), 270–278.

Bagus, D., Awaluddin, M., & Sasmito, B. (2015). Analisis Pengukuran Penampang Memanjang Dan Penampang Melintang Dengan Gnss Metode Rtk-Ntrip. Jurnal Geodesi UNDIP, 4(2), 43–50.

Bendixen, M., Iversen, L. L., Best, J., Franks, D. M., Hackney, C. R., Latrubesse, E. M., & Tusting, L. S. (2021). Sand, gravel, and UN Sustainable Development Goals: Conflicts, synergies, and pathways forward. One Earth, 4(8), 1095–1111. https://doi.org/10.1016/j.oneear.2021.07.008

Darwin, Syahrul, B., & Hairul. (2021). Analisa Karakteristik Hidrologi DAS Krueng Aceh, Provinsi Aceh (Studi Kasus Sub DAS Krueng Jreu dan Sub DAS Krueng Khea). Jurnal Rona Teknik Pertanian, 14(1), 58–72.

Du, C., Guo, W., Li, G., Bai, M., Zhu, Q., Tian, Z., Li, M., Zhao, C., & Zhang, L. (2023). Biomanipulation as a Strategy For Minimizing Ecological Risks in River Supplied with Reclaimed Water. Environmental Research, 228, 115801. https://doi.org/https://doi.org/10.1016/j.envres.2023.115801

Iriani, D., & Bahtiar, R. (2013). Analisis Nilai Ekonomi Manfaat dan Dampak Negatif Penambangan Pasir Illegal Di Sungai Brantas Kelurahan Semampir Kota Kediri. Institut Pertanian Bogor.

Joseph, A. (2023). Chapter 5 - Extremophiles—Organisms that Survive and Thrive in Extreme Environmental Conditions (A. B. T.-W. W. in the S. S. Joseph (ed.); pp. 201–254). Elsevier. https://doi.org/https://doi.org/10.1016/B978-0-323-95717-5.00009-8

Kartiwa, B., & Sutrisno, N. (2006). Alih Fungsi Lahan dan Perubahan Karakteristik Debit DAS Krueng Aceh. Warta Penelitian Dan Pengmebangan Pertanian, 28(1).

Maulidah, S., & Brata, N. . (2019). Struktur Organisasi Kerja Di Kalangan Penambang Pasir Dan Dampak Terhadap Lingkungan, Ekonomi Dan Sosial Di Segitiga Pertambangan Pasir. Journal of Education, Society, and Culture, 7(2).

Nasare, L. I., Opoku, S. A., Amponsah, A., Tom-Dery, D., Asante, W. J., & Baatuuwie, B. N. (2023). Effect of Sand Mining on Riparian Landcover Transformation in Dallung-Kukou Catchment of the White Volta Basin, Ghana. Heliyon, 9(8), e18428. https://doi.org/10.1016/j.heliyon.2023.e18428

Pitchaiah, P. . (2017). Impacts of Sand Mining on Environment – A Review. SSRG International Journal of Geo Informatics and Geological Science, 4(1), 1–5.

Rangel-Buitrago, N., Neal, W., Pilkey, O., & Longo, N. (2023). The Global Impact of Sand Mining on Beaches and Dunes. Ocean & Coastal Management, 235, 106492. https://doi.org/https://doi.org/10.1016/j.ocecoaman.2023.106492

Rentier, E. S., & Cammeraat, L. H. (2022). The Environmental Impacts of River Sand Mining. Science of the Total Environment, 838(March), 155877. https://doi.org/10.1016/j.scitotenv.2022.155877

Sunarsih, S. S. (2021). Pengaruh Pertambangan Pasir Terhadap Erosi Dan Sedimentasi Sungai (Studi Kasus Di Desa Tanjung Alam Kecamatan Sei Dadap Kabupaten Asahan). Eksergi, 18(2), 65. https://doi.org/10.31315/e.v18i2.5290

doi: 10.13170/aijst.12.2.31526

Vandana, M., John, S. E., Maya, K., & Padmalal, D. (2020). Environmental Impact Of Quarrying Of Building Stones and Laterite Blocks: a Comparative Study of Two River Basins in Southern Western Ghats, India. Environmental Earth Sciences, 79, 1–15.

Zahra, A. ., Sylviana, M., & Kusuma, M. (2018). Kajian Aktivitas Penambangan Batu dan Pasir di Sungai Gung Desa Kajen Kecamatan Lebaksiu melalui Pendekatan SETS. Jurnal Pendidikan MIPA Pancasakti, 2(1).