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Analysis of the Impact of Coal Mine Acid Water on River Water Quality and Its Implications for River Water User Communities

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Abstract: This study aims to examine the impact of AAT on the water quality of the Purian River and its implications for communities that depend on this water source. Acid mine drainage, which is formed due to the oxidation of sulfide minerals, can reduce water quality, potentially affecting the health and economy of the user community. The research methods applied include quantitative and qualitative approaches. The analysis was carried out using a correlation test to measure the relationship between water quality between the point of compliance and the Parambahan River, and the Chi-Square test was used to evaluate the relationship between seasonal mining activities and health problems experienced by respondents. In addition, a survey was conducted to explore local community perceptions regarding the impact of river water. The results of the study indicated mild pollution in several water quality parameters, especially TSS and heavy metals, which exceeded the quality standard limits. Water quality status was measured using the Pollution Index based on PP No. 22 of 2021 and Kepmen LH No. 113 of 2003. The results showed that most samples were classified as mild pollution. Correlation analysis indicated that AAT was not the only factor causing pollution, due to seasonal mining activities and the contribution of water use for livestock farming practices. The conclusion is that waste management carried out by PT. AICJ meets government quality standards, at 66.67%, but respondents still feel negatively affected by mining activities.

Keywords: Acid mine drainage; Pollution index; Waste management; Water quality

Introduction

Water is one of the vital resources for human life and ecosystems. Water not only plays a role in maintaining the balance of climate and habitat, but also supports various sectors of life, such as agriculture, industry, and household needs (Lestari et al., 2021). However, various human activities, especially in the industrial sector, have significantly reduced water quality. One sector that contributes greatly to environmental pollution is the coal mining industry, which produces waste in the form of Acid Mine Water (AMD) (Arif, 2021). This waste, which often has low acidity levels and high heavy metal content, can pollute water sources and threaten aquatic ecosystems and the health of surrounding communities.

Mountaintop removal coal mining creates a waste problem, and piles of waste rock have literally buried valued ecosystems (Cooke et al., 2024). Coal mining activities often cause the formation of cavities and disrupt the balance of the natural environment, especially when using open mining techniques (Haryanto et al., 2022). One form of pollution produced is AMD, which is characterized by low pH and increased concentrations of heavy metals and sulphates (Widodo et al., 2019). AMD is dangerous because it can cause

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serious environmental damage and threaten biodiversity around the mining area. Moreover, contamination caused by AMD can flow into rivers, which are a source of water for the surrounding community, impacting public health and the environment (Pitaloka et al., 2024).

River water quality greatly affects the sustainability of the ecosystem and social welfare. The Purian River, located in the Bukit Bual Village area, Koto VII District, Sijunjung Regency, is one of the rivers that receives flow from coal mining activities. Research shows that the Purian River has experienced a decline in water quality, reflected in visual changes such as cloudy water, which makes it unsuitable for use by local communities (Desiana, 2021). This indicates the need for real action to address the impacts of AMD. This study aims to analyze the impact of AMD on water quality in the Purian River, as well as evaluate its impact on the health of the community that uses the water. Through the analysis of physical parameters such as Total Suspended Solids (TSS), pH, and heavy metal levels (Fe and Mn), this study is expected to provide a comprehensive picture of water quality conditions. In addition, this study will also explore public perceptions of river pollution, which is important in understanding the social impacts of mining activities.

Thus, this research is expected to not only contribute to the understanding of the environmental impacts of the mining industry, but also become a basis for making better and social policies to protect water resources and public health. This research is considered important for several reasons, namely making a study that integrates environmental and social impacts, this study highlights the technical aspects of how coal mine acid water affects river water quality, but also explores direct community action against river water users. The second reason this study is important is because the results of this study have the potential to be a solution for the authorities, Although not explicit in the title, the phrase "implications" can be interpreted as further discussion of how the results of the analysis can be used to formulate policies, mitigation strategies, or solutions that involve local communities.

Method

Types of Research

This study is a type of survey research that aims to collect data on a large population through smaller sampling (Barlian, 2016). The method used is a combination of quantitative and qualitative approaches to obtain complete and comprehensive data. The quantitative approach is used to measure such as water quality which is analyzed through laboratory measurements. The qualitative approach is applied to gain an in-depth understanding of community perceptions and experiences related to the impact of Acid Mine Water (AMD).

Research Sample

The water population includes AMD samples originating from mine surface water, as well as river water receiving waste flow from mining companies that flow into the Purian River. The human population includes people who use the Pandan River and Purian River water in their daily lives.

Data Collection and Instrument

Water samples were taken from three points in the river, including Parambahan River, Padan River, and Purian River. Measurements of water quality parameters, such as TSS, pH, and heavy metal content (Fe, Mn), were carried out on site and in the laboratory. In addition, interviews were conducted with residents who have lived around the river for more than a year and who use river water as a livelihood. Secondary data, including water quality monitoring results from companies and public health data, were obtained from sources such as Decree of the Minister of Environment No. 113 of 2003, Government Regulations No. 22 of 2021, Minister of Health Regulation No. 32 of 2017, and data from related Health Centers.

Result and Discussion

River Water Quality

River water sampling was conducted at three different locations to evaluate the quality of river water flowing by AMD. Water quality testing of the three samples taken was carried out using two approaches, namely, direct in situ testing and laboratory testing. The parameters measured include physical parameters such as TSS and chemical parameters such as pH and heavy metals (Fe & Mn), as in Table 1.

In accordance with Government Regulations No. 22 of 2021 and Decree of the Minister of Environment No. 113 of 2003, the level of pollution is calculated by comparing the results of laboratory tests for each parameter against the quality standards set by the government. The results of the PI calculation for each parameter at each sample point are used as the basis for determining the water quality status according to the categories regulated in Decree of the Minister of Environment No. 115 of 2003 (Romdania et al., 2018). The results of the calculation of the river water quality status based on the coal mining wastewater quality standards in Decree of the Minister of Environment No. 113 of 2003 are as shown in Table 2.

Table 1. River water quality test results

Parameter	Unit	Mark			Measurement method
		Sample 1	Sample 2	Sample 3	
pH	-	8.44	7.78	8.36	pH Metric
Fe	Mg/L	1.00	1.47	1.56	Spectrophotometry
Mn	Mg/L	0.24	0.38	0.24	Spectrophotometry
TSS	Mg/L	145.8	65	142.5	Gravimetry

Table 2. Wastewater quality standard IP results

Sample	IP	Water quality status
Sample 1	0.3896	Meet quality standards
Sample 2	0.0932	Meet quality standards
Sample 3	0.3441	Meet quality standards

Calculation of PI for class 2 river water with quality standards based on Government Regulations No. 22 of 2021, in Table 3.

Table 3. PI results for class 2 river water quality standards

Sample	PI	Water quality status
Sample 1	1.9333	Light pollution
Sample 2	0.8993	Meet quality standards
Sample 3	1.8988	Light pollution

Acid Mine Drainage Management

Acid Mine Drainage Management at PT. X is carried out using active management technology through the creation of sedimentation ponds as one of the main methods. Water flowing into the open pit area, either from seepage or rainwater, is directed first to the sedimentation pond before being released into the water body. Lime is added when the water pH is below the threshold set to maintain water quality, especially those related to acidity levels. The purpose of adding lime is to increase the pH of the water and prevent the release of acidic water, which can pollute the aquatic environment.

Acid Mine Drainage Monitoring by the company at the compliance point with the results as shown in Table 4.

Table 4. Wastewater monitoring results compliance point 1

Parameter	Unit	Mark				
		April	May	June	July	August
TSS	Mg/L	1.40	1.96	40.8	42.8	7.52
Fe	Mg/L	0.25	0.25	0.35	0.25	0.42
Mn	Mg/L	0.27	0.72	0.27	0.27	0.27
pH	-	6.89	7.39	7.09	7.85	8.19

There are two compliance points in the company, the results of acid mine drainage monitoring at compliance point 2 are shown in Table 5.

Table 5. Wastewater monitoring results compliance point 2

Parameter	Unit	Mark				
		April	May	June	July	August
TSS	Mg/L	1.56	1.20	21.3	34.5	11.5
Fe	Mg/L	0.26	0.25	0.35	0.25	0.29
Mn	Mg/L	0.27	0.65	0.27	0.27	0.27
pH	-	6.90	7.42	6.58	7.43	7.46

Mann-Whitney test was conducted between the quality standards based on the Decree of the Minister of Environment No. 113 of 2003 with the results of wastewater monitoring that had been processed with pH, Fe, Mn and TSS parameters. The results for the pH parameters were obtained as in Table 6.

Table 6. Mann-Whitney pH test and quality standards

Test Statistics[a]	pH monitoring
Mann-whitney U	.000
Wilcoxon W	78.000
Z	-4.442
Asymp. Sig. (2-tailed)	.000
Exact Sig. [2*(1-tailed Sig.)]	.000[b]

a. Grouping variable: baku mutu pH
b. Not corrected for ties

Mann-Whitney test on Fe parameters with results as in Table 7.

Table 7. Mann-Whitney Fe test and quality standards

Test Statistics[a]	Fe Monitoring
Mann-Whitney U	.000
Wilcoxon W	78.000
Z	-4.466
Asymp. Sig. (2-tailed)	.000
Exact Sig. [2*(1-tailed Sig.)]	.000[b]

a. Grouping Variable: Baku Mutu Fe
b. Not corrected for ties

Mann-Whitney test on Mn parameters with results as in Table 8. Mann-Whitney test on TSS parameters with results as in Table 9.

Table 8. Mann-Whitney Mn test and quality standards

Test Statistics[a]	Mn monitoring
Mann-whitney U	.000
Wilcoxon W	78.000
Z	-4.538
Asymp. Sig. (2-tailed)	.000
Exact Sig. [2*(1-tailed Sig.)]	.000[b]

a. Grouping variable: baku mutu Mn
b. Not corrected for ties

Table 9. Mann-Whitney Mn test and quality standards

Test Statistics[a]	TSS monitoring
Mann-Whitney U	.000
Wilcoxon W	78.000
Z	-4.442
Asymp. Sig. (2-tailed)	.000
Exact Sig. [2*(1-tailed Sig.)]	.000[b]

a. Grouping Variable: Baku Mutu TSS
b. Not corrected for ties

From the monitoring results of compliance points 1 and 2, calculations were carried out to see the quality status of coal mining wastewater using the IP method, the results obtained were as in Table 10.

Table 10. PI compliance point 1 and 2

Month	Compliance Point 1		Compliance Point 1	
	PI	Water Quality Status	IP	Water Quality Status
March	0.369766	Meet quality standards	0.145061	Meet quality standards
April	0.272844	Meet quality standards	0.268188	Meet quality standards
May	0.115804	Meet quality standards	0.106385	Meet quality standards
June	0.172502	Meet quality standards	0.41093	Meet quality standards
July	0.145144	Meet quality standards	0.044419	Meet quality standards
August	0.30708	Meet quality standards	0.037542	Meet quality standards

To see whether coal mining wastewater affects Sample 1, a correlation test was carried out, and the results obtained were as in Table 11. The results of the correlation test of monitoring compliance point 2 with Sample 1, as in Table 12.

Table 11. Correlation test between compliance point 1 and sample 1

Correlations		Compliance Point 1	Sample 1
Compliance Point 1	Pearson Correlation	1	.568
	Sig. (2-tailed)		.432
	N	4	4
Sample 1	Pearson Correlation	.568	1
	Sig. (2-tailed)	.432	
	N	4	4

Table 12. Correlation test between compliance point 2 and sample 1

Correlations		Compliance Point 2	Sample 1
Compliance Point 2	Pearson Correlation	1	.824
	Sig. (2-tailed)		.176
	N	4	4
Sample 1	Pearson Correlation	.824	1
	Sig. (2-tailed)	.176	
	N	4	4

Impact of Acid Mine Drainage on Society

This study involved 30 respondents who were the people of Bukit Bual Village, from the total respondents, 80% of respondents did additional work as seasonal miners. It was found that there were health problems in seasonal miners, with complaints of itching in the foot area. A Chi-Square test was conducted for the relationship between seasonal miners and health problems, as in Table 13.

Table 13. Chi-Square test of seasonal miners and health problems

	Value	df	Asymptotic Significance (2-sided)
Pearson Chi-Square	11.250[a]	1	.001
Continuity Correction[b]	8.342	1	.004
Likelihood Ratio	13.389	1	.000
Fisher's Exact Test			
Linear-by-Linear Association	10.875	1	.001
N of Valid Cases	30		

a. 2 cells (50.0%) have expected count less than 5. The minimum expected count is 2.40
b. Computed only for a 2x2 table

Based on the test results, an Asymptotic Significance of < 0.05 was obtained, so it is said that seasonal mining activities have a significant relationship with health problems. With the health problems of seasonal miners who are in direct contact with river water, calculations are carried out with the status of river water quality using the pollution index (PI) method. The parameters calculated are pH, Fe and Mn with quality standards according to Regulation of the Minister of Health No. 32 of 2017 as in Table 14.

Table 14. River water IP with quality standards of Minister of Health Regulation No. 32 of 2017

Sample	PI	Water Quality Status
Sample 1	0.418	Meet quality standards
Sample 2	1.108	Light Pollution
Sample 3	1.151	Light Pollution

The community considers that coal mining activities have an impact on the quality of river water, which is indicated by changes in the color of the river water. A correlation test was conducted between the impact of river water quality by coal mining activities and the color of river water, the results were as shown in Table 15.

Table 15. Correlation test of the impact of river water quality with river water color

		Impact of Mining on River Water Quality	River Water Color
Impact of Mining on River Water Quality	Pearson Correlation	1	-.487**
	Sig. (2-tailed)		.006
	N	30	30
River Water Color	Pearson Correlation	-.487**	1
	Sig. (2-tailed)	.006	
	N	30	30

**. Correlation is significant at the 0.01 level (2-tailed)

Figure 2. The color of the river water is muddy

From the results of the correlation test, a significance value of 0.006 was obtained, which is smaller than α, which is 0.05, meaning that the impact of the quality of this river water has a significant relationship with changes in the color of river water. It is said that the impact of declining river water quality makes the water color increasingly turbid, as in Figure 2.

One of the biotic components that play a significant role in a river ecosystem is periphyton (Bahri et al., 2023). Rivers have always been important suppliers of water for a variety of social uses. As industries developed, so did the impact of their activities on how rivers functioned. Regrettably, one common use of rivers has been as landfills for trash, particularly from major industrial enterprises. Industrial waste's organic and inorganic components have a negative impact on river ecosystems, producing environmental harm and imbalances (Azhar et al., 2024).

Discussion

River conditions cannot be separated from human activities (Mangallo & Oktaviani, 2023; Supardiono et al., 2023b; Supardiono et al., 2023a). Drinking water contaminated with different chemicals and heavy metals, released from different natural and anthropogenic sources (Melo et al., 2024). Water plays a crucial role in sustaining livelihood and maintaining various sectors of the economy both in the urban and rural areas (Purba et al., 2023; Semy & Singh, 2021). Utilization and management of water resources must be carried out wisely by taking into account the interests of present and future generations (Monica et al., 2023). Coal mining, including of the mining process itself, mineral processing operations, mine dewatering, seepage of contaminated leachates, flooding of mine workings, and discharges of untreated water, will influence on the water resources, both surface and groundwater at various stages of the life cycle of mining and even after its closure (Moyo et al., 2024; Wolkersdorfer et al., 2022; Zhou et al., 2020). Coal mining is one of the core industries that contribute to the economic development of a country but deteriorate the environment (Tiwary, 2001; Ray & Dey, 2020; Ngamlana et al., 2024). Mine water is a major source of heavy metals contaminating surface and groundwater pollution, posing serious threats to ecological environment and human health (Hujun et al., 2024; Kaharapenni & Noor, 2015; Kausher et al., 2023; Liu et al., 1991). Coal mining activities produce huge amounts of water that may contain trace metals, including heavy metals and metalloid, which could be toxic to the public (Maidie et al., 2022; Wahyudin et al., 2018). Its existence, close to anthropological activities, puts pressure on the water quality. Various types of waste pollute river water bodies, so rivers have an additional role as distribution pathways for pollutant materials (Dhea et al., 2023). One way that can be done in monitoring environmental conditions is to use biomarkers. Biomarkers are one way to monitor the quality of river waters by looking at biological markers on organisms (Anasiru et al., 2024). Pollution index calculation was carried out to determine the status of river water quality, based on the quality standards stipulated in the Decree of the Minister of Environment No. 113 of 2003, the results obtained were as in Table 2 where Sample 1, Sample 2 and Sample 3 were in the good category or met the quality standards. However, based on the Quality Standards stipulated in Government Regulations No. 22 of 2003 for Class 2, the PI analysis whose test parameters were aligned with the parameters of mining wastewater obtained the results as in Table 3, in the results of this calculation only one sample was in the category meeting the quality standards, namely Sample 2 and two samples in the light pollution category, namely Sample 1 and Sample 3.

The light pollution category in Sample 1 and Sample 3 is influenced by a fairly high TSS value, where the TSS value in Sample 1 is 148.5 mg/L and in Sample 3 is 142.5 mg/L. Most of the existing literature shows that AMD tends to affect water quality by increasing physical parameters such as Total Suspended Solids (TSS), which in turn has an impact on increasing water turbidity. Anggraini (2024) noted that increasing TSS can disrupt the balance of aquatic ecosystems.

It can be seen in Table 11, the results of the correlation test between Compliance Point 1 and Sample 1, the Pearson Correlation value is 0.568 and the significance (Sig.) 0.432 > 0.05 there is a possibility of the influence of other variables or additional factors that cause an influence from the Location of Compliance Point 1 to Sample 1. Because the Company has two compliance points, a correlation test was also carried out for Compliance Point 2 with Sample 1, with the results in Table 12 with a Pearson Correlation value of 0.824 and a significance value (Sig.) 0.176 > 0.05, which means that there are other external factors that affect the water quality in Sample 1, such as contributions from other sources along the river flow.

Based on the correlation test of the Compliance Point with Sample 1, the significance value (Sig.) > 0.05 as well as the results of the correlation test of Compliance Point 2 with Sample 1, there is no sufficient evidence to show that the AMD flow from coal mining activities at PT. X has a significant effect on water quality at the measurement point of Sample 1. This condition is the same as the research conducted by Yang et al. (2024), in his research it was emphasized that there are other factors that affect groundwater quality including carbonate dissolution, microbial activity, and precipitation.

Overall, the management of Acid Mine Drainage by PT. X is in accordance with the Regulation of the Minister of Environment and Forestry No. 5 of 2022 concerning Wastewater Management for Mining Businesses and/or Activities using the Wetland Method. AMD management using wetlands can meet quality standards according to research conducted by Maulida & Purwanti (2023). This is evidenced by the results of water tests at the compliance point which have met the quality standards of the Minister of Environment Decree No. 113 of 2003, as seen in Table 10, the testing of wastewater quality status was carried out using the IP method with the results of the wastewater quality status in the category of meeting quality standards.

In Table 6, the significance value of the Mann-Whitney pH test and quality standards is 0.000 < smaller than 0.05, there is an effect of adding lime to the water of the AMD management process on the pH value. Table 7 shows the results of the Mann-Whitney test between Fe and the quality standard, the results obtained are Asymptotic Sig. (2-tailed) 0.000 < smaller than 0.05, it can be said that AMD management in KPL affects the Fe value. The results of the Mann-Whitney test between Mn and the quality standard in Table 8, the Asymptotic Sig. (2-tailed) value 0.000 < smaller than 0.05, it means that AMD management affects Mn levels. While in Table 9, the Asymptotic Sig. (2-tailed) value for the Mann-Whitney test between TSS and the quality standard is 0.000 < smaller than 0.05, it means that AMD management by the Company in the sedimentation pond affects the TSS value. This condition is the same as the research conducted by Kiswanto et al. (2020) by adding lime, the metal content such as Fe and Mn which initially exceeded the quality standard was reduced.

From the results of the Mann-Whitney test on pH, Fe, Mn and TSS with quality standards, these four parameters have an Asymptotic Sig. (2-tailed) value of 0.000 < 0.005, this indicates that there is sufficient evidence to state that the management of AMD by mining companies is in accordance with government regulations. In accordance with research by Andrawina et al. (2020) the efficient and effective artificial wetland method can increase the pH value of water and play a role in reducing the content of Fe and Mn metals and Total Suspended Solids (TSS).

The calculation of the quality status with the river water quality standards based on Regulation of the Minister of Health No. 32 of 2017, obtained the results as in Table 14 where Sample 1 meets the quality standards, Samples 2 and 3 are in the light pollution category. The Chi-Square test for the relationship between seasonal miners and health problems obtained the results in Table 13, with an Asymptotic Significance value of 0.001 < 0.05. The results of this test indicate that there is a significant relationship between the influence of AMD and the health problems of the community that uses the river water. This shows that seasonal miners/illegal miners who come into direct contact with river water have a higher risk of health problems. This condition is relevant to research by Yoga et al. (2020) that polluted water can have an impact on the health of the exposed community.

Based on the interview results, respondents argued that mining activities have an impact on river water quality, and said that changes in the color of river water indicate pollution of river water quality due to mining activities. A correlation test was carried out on the impact of river water quality with river water color, the results were obtained as in Table 15 with a significance (Sig.) of 0.006 < 0.05 and Pearson Correlation –0.487. With the negative value in Pearson Correlation, it can be interpreted that the greater the impact of mining on river water quality (pollution or decreased river water quality), the cloudier/darker the color of the river water. In a study conducted by Djaja (2024) the community believed that mining activities had a negative impact and polluted river water. The statistical analysis of the research results shows that mine waters impact on the chemical composition of soil-water extracts. The analysis of the ecological conditions in areas of the aban- doned coal mines confirms the considerable negative environmental impact (Arefieva et al., 2019).

Conclusion

Based on the research conducted, the results of the analysis using the Pollution Index (IP) method show that the quality of river water still meets the quality standards of the Minister of Environment Regulation No. 113 of 2003 for coal mining waste. However, when analyzed using the quality standards of the Minister of Environment Regulation No. 5 of 2022 for class 2 river water and the Minister of Health Regulation No. 32 of 2017 for health, there were two sample points that fell into the lightly polluted category. In addition, there is a significant relationship between exposure to river water polluted with AMD and public health problems, especially for seasonal miners who often come into direct contact with river water. These results indicate that mining activities have the potential to pollute river water. Therefore, there needs to be better management of AMD, as well as community involvement in monitoring water quality to prevent negative impacts on health and the surrounding ecosystem.

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