JOURNAL OF DEGRADED AND MINING LANDS MANAGEMENT
Volume 12, Number 1 (October 2024):6801-6808, doi:10.15243/jdmlm.2024.121.6801
ISSN: 2339-076X (p); 2502-2458 (e), www.jdmlm.ub.ac.id

Research Article

Model of environmental management due to coal mining on the Separi River in Tenggarong Seberang District, Kutai Kartanegara Regency, East Kalimantan Province

Nur Efendi[1], Eri Barlian[2], Nurhasan Syah[2], Indang Dewata[2], Dian Adhetya Arif[3], Iswandi Umar[2,3*]

[1] Doctoral Program of Environmental Science, Postgraduate Program of Universitas Negeri Padang, Jalan Prof. Dr. Hamka Airtawar Padang, Padang City, West Sumatra, Indonesia
[2] Environmental Sciences, Postgraduate Program of Universitas Negeri Padang, Jalan Prof. Dr. Hamka Airtawar Padang, Padang City, West Sumatra, Indonesia
[3] Department of Geography, Faculty of Social Sciences, Universitas Negeri Padang, Jalan Prof. Dr. Hamka Airtawar Padang, Padang City, West Sumatra, Indonesia

*corresponding author: iswandi_u@fis.unp.ac.id

Article history:
Received 28 April 2024
Revised 16 August 2024
Accepted 29 August 2024

Keywords:
coal mine
environment
ISM method
sustainability
water quality

Abstract

Coal mining has a significant impact on reducing river water quality. The decline in river water quality causes problems for human life and the environment. Therefore, this research aimed to evaluate river water quality and develop strategies for improving river water quality due to open pit coal mining activities in Tenggarong Seberang District and develop environmental improvement strategies. Several chemical parameters, including pH, TSS, Fe, and Mn, were observed through laboratory tests to determine water quality in the Separi River used in coal mining. The next step was determining environmental improvement strategies using the ISM approach. Twenty stakeholders from related agencies and institutions using FGD were involved in developing a policy strategy. The results of the analysis showed that there has been a decrease in river water quality standards due to mining activities in the research area, and the quality is still below the standard quality. Therefore, two significant strategies must be a priority for the environmental management of the Separi River. First, Conducting an environmental audit of the factors causing the decline in river water quality is necessary. Second, there must be warnings and legal sanctions for negligence in oil spills and oil used from coal mining.

To cite this article: Efendi, N., Barlian, E., Syah, N., Dewata, I., Arif, D.A. and Umar, I. 2024. Model of environmental management due to coal mining on the Separi River in Tenggarong Seberang District, Kutai Kartanegara Regency, East Kalimantan Province. Journal of Degraded and Mining Lands Management 12(1):6801-6808, doi:10.15243/jdmlm.2024.121.6801.

Introduction

Coal is one of the world's main energy sources. In recent years, there has been an increase in coal mining by 4.5% per year worldwide. Coal mining happens in several regions, spread across Asia, North America, Europe, CIS, Africa, South and Central America, Oceania, and the Middle East (Kirsanov et al., 2023). Coal mining is a mining activity that contributes to the environmental crisis, where acid mine drainage is one of the negative impacts caused by mining activities (Mdumela et al., 2021).

Mining wastewater and its management are a source of environmental problems for the global mining industry, not only for now but also for the future. The quality and quantity depend on the type of ore and mine (especially sulfide and open mold ores). This problem causes dangerous environmental damage if not properly managed. Globally, the waste produced by mining per year is estimated at 15 billion tons,

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which is ten times more than the global urban waste produced annually (Ojonimi et al., 2021).

Coal mining has both positive and negative impacts. The mining industry provides most of the materials needed to build infrastructure and obtain large amounts of energy. Mining practices nowadays can be summarized in a few steps: get a permit, dig up the ore, and sell the metal. Once the deposit is depleted, they leave the site and start another mine elsewhere. At the same time, mining is a human activity that disrupts the environment and is associated with many social impacts and inequality. It is not surprising that mining is one of the human activities with the highest potential for environmental and social impacts (Afkarina et al., 2019).

Today, the mining and quarrying sector plays a significant role in developing various sectors in countries worldwide. The industry ensures a sufficient and sustainable supply of raw materials for the construction, building, and manufacturing sectors in these countries' economic growth. Mining and quarrying activities produce raw materials that are further processed by the manufacturing industry as well as input materials and energy for production (Fugiel et al., 2017).

Sustainable development can be defined as a type of development that meets the needs of current generations while providing natural resources to meet the needs of future generations (Nishimatu, 2016). It is a tool that ensures that development benefits present and future generations through the integration of social, economic, and environmental factors in planning, implementation, and decision-making (Ojonimi et al., 2018). Mining water quality is a crucial environmental problem because mining activities often produce waste that pollutes water. This waste can include dangerous chemicals, heavy metals, and other particles that pollute water sources. As a result, this can threaten aquatic ecosystems, cause environmental damage, and impact human health. However, coal mining has become one of the major sectors in the economies of many countries, including Indonesia.

In mining leaching operations, acidic water is produced from water contact with sulfide-containing mining materials. This process is often referred to as acid mine drainage (AAT) or drainage mine acid (ATA). This acidic water has acidic properties and can damage the environment and natural resources. The pH of acidic water in mining leaching can vary depending on the type of mineral involved and the conditions at the mining site. The high acid conditions in acid mine drainage can increase the solubility of metals. It also worsens the toxic impact on water and soil ecosystems. The pH of acid mine water becomes unstable after being used to wash mineral rocks because of the complex interactions between water, rocks, and the minerals involved in the washing process. One of the significant impacts that can occur due to the formation of acid mine drainage is a decrease in the quality of public water bodies. Chemical elements and compounds of heavy metals, such as iron, manganese, and cadmium, come from soil and rocks, which are carried away during coal exploitation (Ferdian, 2020; Kiswanto et al., 2020).

Mining companies are closely related to the environment because their operational activities exploit natural resources. Because the environmental damage caused by this company's activities is quite impactful, the government must take responsibility and design social and environmental policies for mining companies (Ahadis et al., 2020). Without government policy, the ecosystem in the region will be endangered, and conflicts between communities and companies will increase. In this condition, government intervention must overcome problems from mining activities (Evana et al., 2020; Chowdhury and Oredo, 2022).

East Kalimantan Province has 1,403 coal mining companies with a mining area of around 5.2 million hectares and coal production reaching 207.44 million tons. Surprisingly, many mining companies and large production areas only have 12 mining inspectors. Apart from that, illegal coal mining has also been rampant since 2000, with 168 mining spots. This condition will certainly have a negative impact on the environment, especially acid mine drainage (Indrayanti, 2023).

This research aimed to evaluate the water quality of the Separi River in Kertabuana Village, Tenggarong Seberang District, Kutai Kartanegara Regency, East Kalimantan Province due to the impact of coal mining, and develop a strategy for water conservation policy direction.

Materials and Methods

Materials

The research was conducted in Kertabuana Village, Tenggarong Seberang District, Kutai Kartanegara Regency, East Kalimantan Province. This research focused on coal mine wastewater from PT ANSAF. PT ANSAF is one of the Separi Sub Block sites in Berambai. The research location has an area of 182 ha (Figure 1). Tenggarong Seberang District has a 443.4 km^2 area divided into 18 villages. Tenggarong Seberang subdistrict was an expansion of the Tenggarong Kota subdistrict in 1996. It is following Government Regulation/PP Number 38 of 1996. Demographically, the subdistrict has a population of 73,372 people with a density of 165 people/km^2. The research area is the largest coal mining-producing area in Kutai Kartanegara Regency. Apart from that, the Separi River in the research area functioned as the flow of coal mining water.

Methods

The method used to determine water quality was laboratory tests using several chemical parameters based on the Ministry of Environment decree No. 113

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of 2003 concerning wastewater standards for coal mining activities. The required chemical parameters include pH, TSS, Fe, and Mn. The assessment of water standard status was made according to the Minister of Environment Decree No. 115 of 2003 concerning Guidelines for Determining Water Quality Standard Status using the Pollution Index method. According to the Minister of Environment Decree No. 115 of 2003, the water quality standards are pH = 6-9, TSS = 300 mg/L, Fe = 7 mg/L, and Mn = 4 mg/L.

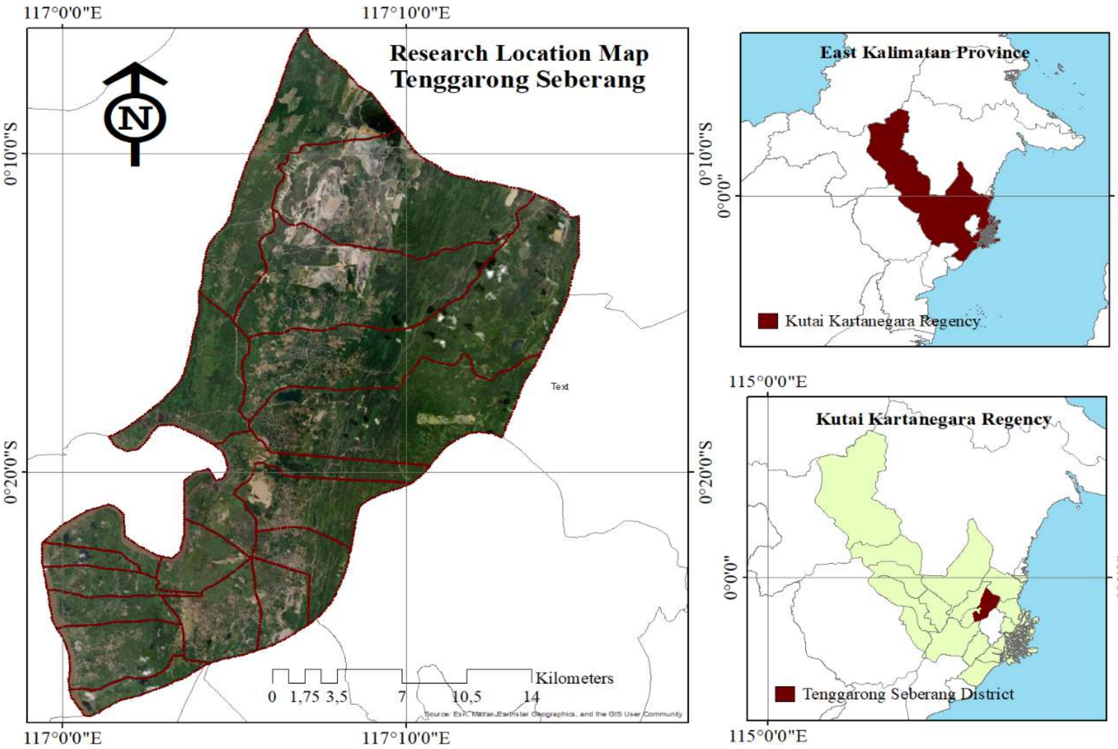

Figure 1. Research location map.

This research used the Interpretative Structural Modeling (ISM) approach to determine water quality conservation strategies from coal mining. The ISM approach was first introduced by Warfield (1974). This approach can structure very complex problems, thus helping in decision-making in many fields (Marimin et al., 2017; Umar et al., 2019; Arsiwi and Adi, 2020; Umar and Arif, 2023).

According to Marimin et al. (2014) and Umar and Triyatno (2024), there are several steps in the ISM method, i.e., (1) breaking down elements into several sub-elements, (2) establishing contextual relationships between sub-elements, (3) determining the Structural Self Interaction Matrix (SSIM), (4) creating a Reachability Matrix (RM), (5) doing transitivity, (6) determining the vertical hierarchical structure, and (7) determining the Driver Power (DP) and Dependence (D) relationship matrix. In creating an SSIM, pairwise comparisons were made using the VAXO symbols as follows:

a. V if Eij = 1 and Eji = 0; V = the i^{th} sub-element plays a more significant role than the j^{th} sub-element and not vice versa.
b. A if Eij = 0 and Eji = 1; A = the j^{th} sub-element plays a more significant role than the i^{th} sub-element and not vice versa.
c. X if Eij = 1 and Eji = 1; X = both sub-elements have the same role level value and are interrelated.
d. O if Eij = 0 and Eji = 0; O = the two sub-elements are not related to each other.

Furthermore, Marimin et al. (2014), Ojha et al. (2023), and Umar and Triyatno (2024) classified element relationships into four categories (Figure 2), namely:

a. The first quadrant is called autonomous. The sub-elements in this quadrant have a driver power (DP) value ≤0.5. The sub-elements in the first quadrant can illustrated as the sub-elements that are not related/have little relationship with the system.
b. The second quadrant is called dependent, consisting of sub-elements with a driver power (DP) value ≤0.5.
c. Quadrant III: Linkage. In this quadrant, the sub-elements have a driver power (DP) value ≥0.5. The sub-elements in quadrant III need further analysis carefully because every action in one sub-element will affect other sub-elements in quadrants II and IV.
d. Quadrant IV: Driver (independent) consists of sub-elements that have a driver power (DP) value ≥ 0.5.

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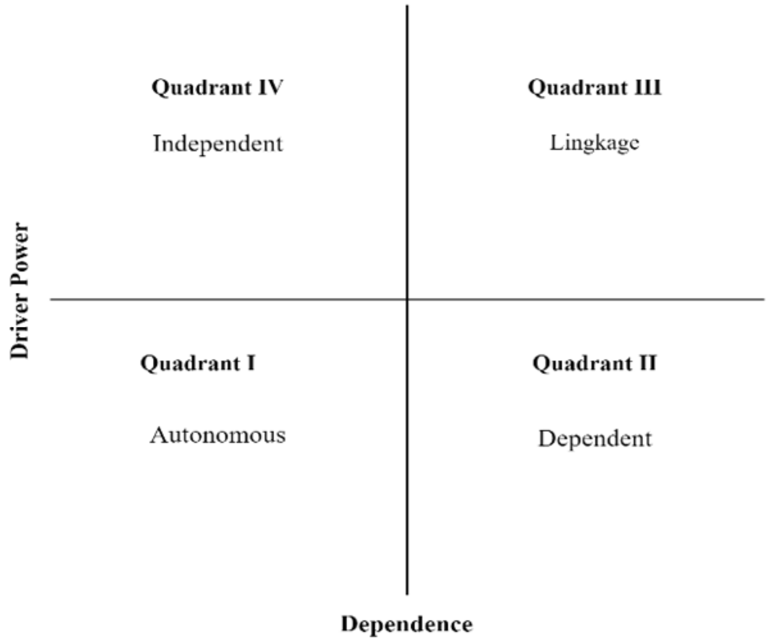

Figure 2. Driver power and dependence matrix in Interpretative Structural Modeling (ISM).

Results

Based on the results of data analysis from periodic environmental monitoring reports, the condition of chemical parameters, including pH, TSS, Fe, and Mn, as required in Minister of Environment Decree No. 113/2003, is below standard quality. Even though the chemical quality conditions of the Separi River still meet quality standards, they still experience impacts on the environment. The results of the analysis of the four chemical indicators are presented in Figure 3.

In determining the management strategy for river water quality due to mine acid, an expert system through FGD needs to be created. The results of the expert system analysis showed the following eight main problems in the Separi River,

(1) There is a decline in river water quality.
(2) Oil and used oil runoff from heavy mining equipment.
(3) Sediment material is carried away by water and enters rivers.
(4) Acid mine water enters water bodies.
(5) Disruption of aquatic biota habitat.
(6) Weak supervision and law enforcement.
(7) Less than optimal control and mitigation efforts
(8) Low public and company awareness of water conservation management.

Based on the eight main problems in the Separi River, a strategy to prevent the decline in river water quality is needed. For this reason, the ISM approach was used to develop the following seven strategies.

(E1) It is necessary to do an environmental audit of the factors causing the decline in river water quality.
(E2) Providing warnings and legal sanctions for negligence in oil and used oil spills.
(E3) Every coal mining company must make sediment tanks and acid mine water before releasing it into the river.
(E4) There is a need for conservation efforts to improve river quality.
(E5) Increased supervision and law enforcement against companies destroying the environment.
(E6) Cross-sectoral synchronization in supervision, control, and law enforcement against environmentally destructive mining companies.
(E7) Building mutual awareness between communities, mining companies, and the government in improving the environment.

The ISM analysis used expert opinion through FGD. The experts were from community leaders, the Kutai Kartanegara Regency Environmental Service, NGOs, environmental observers, and the Indonesian Environmental Study Center. The results of expert opinions are presented in the form of a Structural Self Interaction Matrix (SSIM) (Table 1). The results of the analysis of the ISM approach show two crucial elements as a strategy for the environmental management of coal mining on the Separi River. The first strategy is doing an environmental audit of the factors causing the decline in river water quality. The second strategy is to provide warnings and legal sanctions for negligence in oil spills and used oil from coal mining. These two elements have a great driving force as a strategy for managing rivers caused by coal mining.

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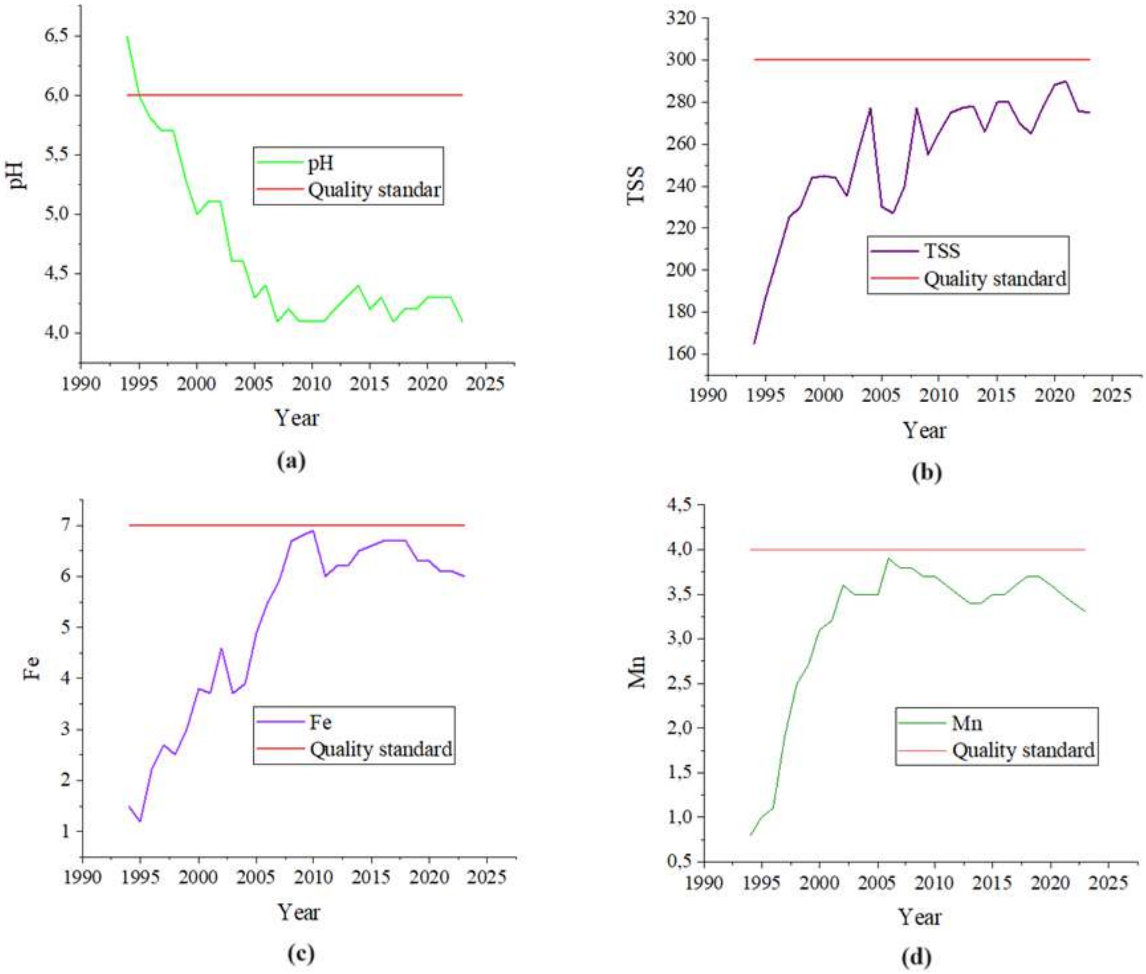

Figure 3. Chemical analysis of water quality in the Separi River for the 1994-2024. Notes: the Minister of Environment Decree No 113/2003 quality standards.

Furthermore, the analysis shows three elements are highly dependent on other sub-elements. First, every coal mining company is obliged to build sediment tanks. Second, there is an obligation to make conservation efforts to improve river quality. Third, mutual awareness should be built between the community, mining companies, and the government to improve the environment. The illustration is presented in Table 2 of the final reachability matrix.

Figure 4a is the driver power and dependence relationship structure, where the decision elements are divided into four categories: autonomous, dependent, linked, and independent. The analysis shows that two elements fall into the independent category. The first one is doing an environmental audit of the factors causing the decline in river water quality (E1). The second one is the provision of warnings and legal sanctions for negligence in oil spills and used coal mining oil (E2). The independent quadrant is an element that has a high driving force and low dependence on other components.

Furthermore, Figure 4b is the hierarchical structure of the Separi River management strategy, where these two elements are the main priorities that must be carried out in improving the coal mining environment.

Table 1. Final results of expert assessment using SSIM.

Element	E1	E2	E3	E4	E5	E6	E7
E1		V	V	V	V	V	V
E2			V	V	V	V	V
E3				X	A	A	X
E4					A	A	X
E5						X	V
E6							V
E7							

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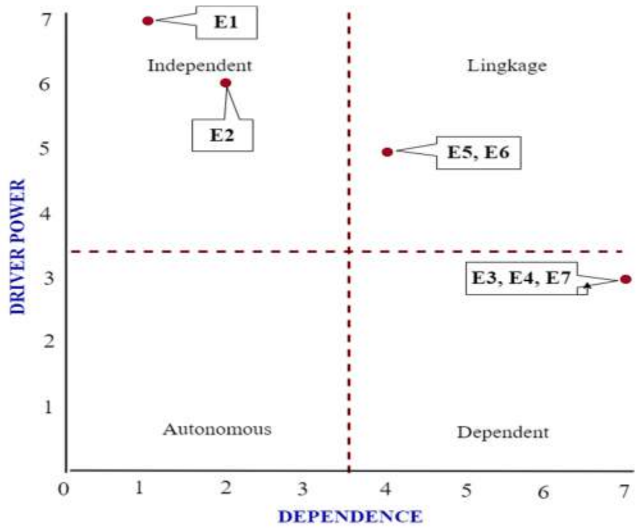
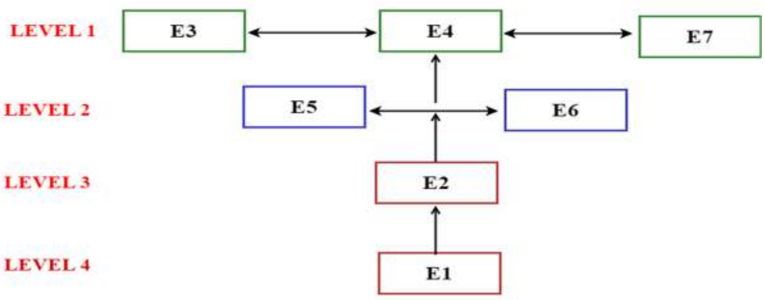
Table 2. Final reachability matrix.

Element	E1	E2	E3	E4	E5	E6	E7	Driving Power	Rank
E1	1	1	1	1	1	1	1	**7**	1
E2	0	1	1	1	1	1	1	**6**	2
E3	0	0	1	1	0	0	1	**3**	4
E4	0	0	1	1	0	0	1	**3**	4
E5	0	0	1	1	1	1	1	**5**	3
E6	0	0	1	1	1	1	1	**5**	3
E7	0	0	1	1	0	0	1	**3**	4
Dependence	**1**	**2**	**7**	**7**	**4**	**4**	**7**		
Level	4	3	1	1	2	2	1		



(a)



(b)

LEGENDS

E1. It is necessary to do an environmental audit of the factors causing the decline in river water quality.
E2. Providing warnings and legal sanctions for negligence in oil and used oil spills.
E3. Every coal mining company must make sediment tanks and acid mine water before releasing it into the river.
E4. There is a need for conservation efforts to improve river quality.
E5. Increased supervision and law enforcement against companies destroying the environment.
E6. Cross-sectoral synchronization in supervision, control, and law enforcement against environmentally destructive mining companies.
E7. Building mutual awareness between communities, mining companies, and the government in improving the environment.

Figure 4. Structure of the relationship between driver power and dependence (a), and policy hierarchy (b) of environmental management strategies for the Separi River.

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Discussion

Throughout the world, coal mining activities have posed a long-term threat to aquatic ecosystems due to the flow of acidic drainage water containing various heavy metals in high concentrations. Acid mine drainage in coal mining is mainly caused by the exposure of sulfide minerals in coal seams or layers above to weathering. This causes oxidation, which is then spread through indirect oxidation by iron ions produced mainly by chemolithotrophic. Chemical reactions such as hydrolysis and oxidation can convert sulfide minerals into sulfuric acid, lowering the water pH at mine sites (Luis et al., 2021).

The influence of unstable pH in acidic mine-leaching water has crucial impacts on the environment and ecosystem sustainability. Unstable pH conditions, especially if they tend to be low or acidic, can increase the corrosivity of water, accelerate the release of heavy metals, and damage the surrounding aquatic and soil ecosystems. High acidity can poison living organisms in water, inhibit vegetation growth, and reduce the sustainability of life in the river ecosystem (Zaki et al., 2023). An unstable pH can also exacerbate the toxic effects of heavy metals dissolved in acidic water, such as mercury, zinc, and aluminum, harming living organisms and humans. Therefore, maintaining and managing the pH of acid mine-leaching water, such as regular monitoring and proper water treatment, is necessary to ensure the pH remains within a safe range (Parjono et al. 2019; Ramadhan 2020).

Treatment and pH stabilization of acid mine drainage (AAT) is also a significant aspect of environmental management in the mining industry. Efforts to maintain pH at a stable level can positively affect environmental impact mitigation. pH stabilization measures can involve a range of strategies, including using chemicals that can neutralize the acidity of mine water (Setiawan et al., 2018; Mencho, 2022). The importance of pH stabilization is also related to reducing the release of heavy metals associated with acidic water. Under stable pH conditions, the tendency of heavy metals to dissolve can be reduced, which helps prevent environmental contamination. In addition to chemical methods, preventive measures involve careful handling of mining waste.

Environmental management is an essential component of coal mining. In coal mining exploration, several activities produce waste, namely development, production, transportation, reclamation, and mine closure. So, mining companies must identify and control critical environmental aspects in the entire coal mining process. For this reason, commitment from the government, companies, and law enforcement is essential to prevent damage to the mining environment (Ruokonen and Temmes, 2019). Apart from that, to monitor environmental damage, it is necessary to carry out periodic environmental audits (Woźniak and Jurczyk, 2020). Furthermore, the results of environmental audits require strict legal action and sanctions in an effort to have a deterrent effect on perpetrators of environmental damage (Fitryarini, 2018; Anaafo et al., 2023).

Conclusion

Coal mining activities in the Separi watershed have been proven to comply with quality standards based on Minister of Environment Decree No. 113/2003. Even though it is below standard quality, there has been a decline in river water quality due to coal mining. Furthermore, two significant strategies must be a priority for the environmental management of the Separi River. The first one is that it is necessary to do an environmental audit of the factors causing the decline in river water quality. The second one is to provide warnings and legal sanctions for negligence in oil spills and oil used from coal mining.

Acknowledgments

The first author would like to express his sincere gratitude to the Doctoral Program of Environmental Science, Postgraduate Program of Universitas Negeri Padang, for providing the opportunity to open up environmental insight. Furthermore, the first author would like to thank the East Kalimantan Province Environmental Service for contributing to providing data for this research.

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