



Sustainable Exploration of Mine Water Residuals for Drinking Water Resilience in Jahab, Tenggara, Kutai Kartanegara Regency

Ansahar¹, Yustina Hong Lawing², Misran³, Annisa Fitriwardani⁴, Febrian Nanendra⁵, Aldi Muhammad Miftahuddin⁶, and Tommy Andryan Tivianton⁷

¹Center for Research and Environmental Management Studies (PS-PPLH), Faculty of Engineering, University of Kutai Kartanegara, Tenggara, Indonesia

^{2,3,4,5,6}Faculty of Mining Engineering, University of Kutai Kartanegara Tenggara, Indonesia

⁷Faculty of Geography, University of Gadjah Mada, Yogyakarta, Indonesia

*Corresponding author Email: ansahar@unikarta.ac.id

The manuscript was received on November 17th, 2025, revised on December 3rd, 2025, and accepted on January 05th, 2026, date of publication February 02nd, 2026

Abstract

Mine water residuals (void) represent a potential raw water source for remote communities, such as in Kelurahan Jahab, Kecamatan Tenggara, Kabupaten Kutai Kartanegara. After more than ten years of inactivity, the former open-pit coal mine site operated by PT Multi Harapan Utama has undergone natural stabilization processes, resulting in neutral pH, low Total Dissolved Solids (TDS), and heavy metal concentrations below drinking water quality thresholds. However, laboratory analysis reveals extreme microbiological contamination, with Total Coliform reaching 1,240 MPN/100mL, although E. coli is <20 MPN/100mL. Currently, local residents extract water directly from the void using portable pumps and sell it to other households at IDR 65,000 per 1,500 liters. This practice lacks post-extraction treatment, posing significant risks of recontamination and adverse health impacts. This study aims to design a three-stage hybrid water treatment system—comprising aeration, multistage filtration, and ultraviolet (UV) disinfection—that is effective, affordable, and manageable by a Village-Owned Enterprise (BUMDes). The methodology integrates laboratory analysis, field surveys, in-depth interviews, and engineering design based on localized data. Water quality data were obtained from the official Environmental Laboratory Report by DLHK Kutai Kartanegara. Research findings demonstrate that the hybrid system effectively removes residual particulates, oxidizes volatile organic compounds, and eliminates pathogens without forming carcinogenic Disinfection By-Products (DBPs). Integration of a 2,500-watt solar power system ensures off-grid operation and enhances energy resilience. System sustainability is secured through a community Willingness to Pay (WTP) model ranging from IDR 50,000 to IDR 150,000 per month, transparently managed by BUMDes. These results prove that mine water residuals, once perceived as environmental liabilities, can be transformed into strategic drinking water assets.

Keywords: Acid Mine Drainage, BUMdes, Solar power system, Water resilience, WTP

1. Introduction

Clean water is a fundamental human right essential for health, sanitation, and quality of life [1]. In disaster-prone regions such as East Kalimantan, access to safe drinking water remains a major challenge due to environmental degradation, climate change impacts, and limited raw water infrastructure [2,3]. In this context, abandoned coal mine pits (voids) that have formed over more than a decade offer potential as strategic alternative sources if managed through innovative and sustainable approaches [4,5]. A void is an artificial basin created by open-pit mining activities, subsequently filled with rainwater, groundwater, and surface runoff [6]. If left unrehabilitated, such sites can become pollution sources through acid mine drainage (AMD)—a flow of acidic water rich in sulfates, heavy metals, and low pH [7]. However, after a long post-mining period (>10 years), certain voids exhibit natural neutralization processes, resulting in increased pH and significantly reduced metal content—classifying them as Type 5 AMD according to Skousen & Ziemkiewicz [1,8].

Chemical stabilization in these voids is influenced by geological, hydrological, and secondary vegetation factors surrounding the site [9]. These factors contribute to pyrite oxidation, iron precipitation, and decomposition of organic compounds, gradually improving water quality over time [10]. Global studies show that naturally neutralized voids can be utilized for irrigation, aquaculture, recreation, and even raw water supply [11,12]. In Kutai Kartanegara Regency, there are 264 abandoned coal mine voids scattered across Muara Badak,



Loa Janan, and Tenggara sub-districts. One such example is the void from PT Multi Harapan Utama located in Kelurahan Jahab, Km 14, with coordinates E: 116°53'12.2", S: 00°27'30.6". Currently, local residents directly extract water from this void using portable pumps and sell it to other households at IDR 65,000 per tank (1,500 liters). While this practice demonstrates economic value, it does not ensure microbiological safety [13,14]. Previous laboratory test results indicate that the void water has the physical and chemical parameters mostly compliant with Government Regulation No. 22/2021 (Class II). However, Total Coliform exceeds the parameter limit, although *E. coli* is below detection (<20 MPN/100mL). This indicates fecal contamination originating from domestic waste, septic tanks, or livestock entering the aquifer system.

The presence of high nitrate levels in the previous laboratory test further supports the likelihood of infiltration from agricultural runoff or organic fertilizers [15]. Nitrate in drinking water can cause methemoglobinemia ("blue baby syndrome") in infants and increase the risk of colorectal cancer if consumed long-term [16]. Therefore, despite its clear appearance, the water remains unsafe for consumption without further treatment. Drinking water treatment from non-traditional sources like mine voids requires appropriate, effective, affordable, and community-manageable technologies [17].

Conventional systems such as coagulation-flocculation with alum are often ineffective since the water is already clear, yet they fail to address microbiological threats [18]. Chlorine disinfection also carries risks of forming carcinogenic Disinfection By-Products (DBPs), such as trihalomethanes (THM) and haloacetic acids (HAA), particularly when the water contains dissolved organic carbon (DOC >1 mg/L) [19,20]. Therefore, non-chlorine disinfection methods such as ultraviolet (UV) irradiation become an ideal solution [21]. UV works by damaging pathogen DNA without forming disinfection by-products (DBPs), and it is easy to operate in remote communities [22]. The combination of UV and ozonation can remove viruses, bacteria, and protozoa with over 99.9% efficiency [23]. To address fine particulates and residual organic compounds, multistage filtration is highly recommended. Media such as quartz sand, granular activated carbon, and IRA-958 ion-exchange resin have been proven effective in removing hydrophilic NOM fractions and dissolved metals [24,25]. The IRA-958 resin specifically targets negatively charged organic anions that act as DBP precursors [25].

In addition to technology, system success is largely determined by local governance. A Village-Owned Enterprise (BUMDes) holds a strategic position as the managing institution due to its proximity to the community and ability to conduct daily monitoring [26]. The refill-gallon depot model managed by BUMDes has been shown to increase community satisfaction and generate local income [27]. A Willingness to Pay (WTP) survey involving 30 respondents in Jahab Subdistrict revealed that most residents are willing to pay IDR 50,000–150,000 per month for safe and affordable access to clean water [28]. This WTP value serves as a strong indicator that the community is economically ready to support a sustainable treatment system, provided that benefits are tangible and transparent. The integration of renewable energy, particularly a 2,500-watt Solar Power Plant (PLTS), is key to ensuring operational sustainability [29].

PLTS reduces dependence on diesel generators or unstable grid electricity, lowers long-term operational costs, and supports climate change mitigation efforts [30]. By minimizing carbon emissions and enhancing energy resilience, solar-powered systems contribute to green infrastructure development in rural areas. Such off-grid solutions ensure continuous operation during floods or fuel shortages—common challenges in tropical mining-affected regions. With proper design and maintenance, this hybrid approach combining UV disinfection, multistage filtration, and community-based management through BUMDes offers a viable pathway toward drinking water security using reclaimed mine water. The off-grid system is highly suitable for remote areas such as Jahab.

Transforming former mining land into productive assets aligns with the beneficial end use principle of the International Mine Water Association (IMWA) [5]. Studies show that mine water can be treated into high-quality drinking water using the HiPro® process [31]. Although originally designed for industrial-scale applications, this concept can be adapted for community-level systems through design modifications [31]. Pit lakes rehabilitated through ecosystem-based approaches provide dual benefits: ecological and social [12]. In Australia, reclaimed pit lakes have been successfully transformed into productive reservoirs, tourism destinations, and raw water sources [12,32]. Indonesia holds similar potential, especially in regions with thousands of unmanaged voids. However, technological sustainability depends not only on engineering design but also on local institutional capacity. Artificial reservoirs in Sleman, DIY, failed to remain operational due to insufficient operator training and lack of financial transparency [33]. This serves as a reminder that infrastructure investment without institutional support will ultimately fail.

A model integrating local human resources with regular technical training has proven successful in various rural clean water projects [34]. Operators trained from within the community are more responsive, cost-effective, and sustainable compared to external technicians [34]. Training programs should cover filter maintenance, UV calibration, and daily monitoring procedures. Utilizing locally available materials—such as zeolite, activated carbon derived from palm oil waste, or tropical clay—can reduce operational costs and enhance self-reliance [35,36]. Activated carbon has demonstrated effectiveness in removing humic and fulvic acids [35], while tropical clay soils exhibit strong natural organic matter (NOM) adsorption capabilities [36]. The success of the system is also influenced by its distribution model. Permanent piped networks are prone to corrosion, biofilm formation, and algal growth [27], whereas refill-gallon distribution proves more hygienic, flexible, and effective at preventing post-treatment recontamination [27]. Tropical climate conditions—with high rainfall (>200 mm/month) and average temperatures around 32°C—favor the proliferation of pathogenic microorganisms in stagnant water [37]. Therefore, treatment systems must be designed to handle both rainy and dry seasons, incorporating buffer storage capacity and adaptive standard operating procedures (SOPs) [37]. Based on these findings, transforming mining voids from environmental liabilities into strategic assets is entirely feasible. Through an integrated approach combining hybrid technology (aeration–filtration–UV), BUMDes-based governance, and solar energy integration, mine water residuals can become a resilient source of safe drinking water [38,39]. This approach also supports key Sustainable Development Goals (SDGs): SDG 6 (Clean Water and Sanitation), SDG 13 (Climate Action), and SDG 11 (Sustainable Cities and Communities) [40].

This study aims to propose a suitable water treatment system that is efficient, affordable, and manageable by local communities based on laboratory data and Willingness to Pay (WTP) survey results. This system is expected to serve as a replicable model for villages with abandoned mine voids across Indonesia.

2. Methods

This study employed a mixed-methods approach, integrating literature review, laboratory analysis, field survey, and engineering design to develop an effective and sustainable hybrid brackish water treatment system for Pulau Taddutan, Saliki Village, Muara Badak Subdistrict, Kutai Kartanegara Regency, East Kalimantan [41]. This methodological framework enabled the integration of quantitative data (laboratory results) and qualitative insights (in-depth interviews, Focus Group Discussions), ensuring that technical recommendations are not only academically sound but also socially and economically relevant.

Water sampling was conducted on December 3, 2023, at two strategic locations: (1) RT 7, Pulau Taddutan (E: 117°29'02.8", S: 00°27'04.0") (2) RT 8, Pulau Taddutan (E: 117°30'15.5", S: 00°25'41.5") Samples were collected using the grab sampling method in accordance with SNI 6989.57:2008, with 5 liters taken per site, then delivered to the Environmental Laboratory, UPTD DLHK Kutai Kartanegara [42]. Laboratory-based water quality analysis was performed based on physical, chemical, and microbiological parameters as specified in Government Regulation No. 22 of 2021 (Class II). The tested parameters included: temperature, Total Dissolved Solids (TDS), Total Suspended Solids (TSS), color, conductivity (DHL), turbidity, pH, BOD₅, COD, salinity, *E. coli*, and Total Coliform. All measurements followed standard methods such as SNI 6989.11:2019 (pH), SNI 6989.80:2011 (color), and SM 9223 B (microbiology) [43]. The raw and treated water quality data used in this analysis were obtained directly from official test results issued by the UPTD Environmental Laboratory, DLHK Kutai Kartanegara [44].

In addition to laboratory testing, in-depth interviews and questionnaire surveys were administered to 30 local community members to assess Willingness to Pay (WTP) and perceptions regarding clean water quality. Respondents were selected via purposive sampling, with criteria including household heads actively relying on local water sources [38]. Based on laboratory findings and field observations, a hybrid water treatment will be proposed while also considering its sustainability, which is ensured through a Village-Owned Enterprise (BUMDes)-based governance model, where operational costs are covered by monthly community contributions that determined based on the survey results. The system is designed to be operated and maintained by local residents, with technical training provided through BUMDes [12].

3. Result and Discussion

3.1 Characteristics of Abandoned Mine Water (Void) at Jahab, Km 14

The abandoned mine water (void) formed from the former coal excavation pit of PT Multi Harapan Utama has undergone natural processes for over ten years. This process has created a stable chemical and physical condition, classifying it as Type 5 Acid Mine Drainage (AMD)—referring to naturally neutralized acidic mining water [1]. Laboratory analysis conducted by DLHK Kutai Kartanegara on November 30, 2023, revealed the following characteristics: Neutral pH: 7.68 → compliant with Government Regulation No. 22/2021 (Class II), which specifies a range of 6–9 [44]. Low TDS: 135.7 mg/L (<1,000 mg/L) [44]. Very low turbidity: 0.12 NTU (meets the standard of ≤3 NTU). Colorless and odorless. Heavy metals: Iron (Fe) <0.03 mg/L and manganese (Mn) <0.032 mg/L both below regulatory limits. However, despite relatively safe physicochemical parameters, microbiological contamination remains a serious threat. Total Coliform levels reached 1,240 MPN/100mL, far exceeding the zero threshold in drinking water regulations, indicating fecal contamination originating from domestic waste or septic tanks [38]. Although *E. coli* was not detected (<20 MPN/100mL), the presence of high coliform levels still poses a potential risk of waterborne diseases such as diarrhea, dysentery, and cholera if consumed without adequate treatment [15]. Environmental factors further exacerbate recontamination risks. Average monthly rainfall reaches 201 mm, with approximately 14–18 rainy days per month, increasing surface runoff and the potential infiltration of pathogenic bacteria into water bodies [45]. Ambient temperatures around 32°C and humidity >60% support microbial growth in stagnant water [44].

Therefore, although the void water appears clear, it is not suitable for consumption without proper disinfection. Additionally, nitrate concentration was detected at 102 mg/L, surpassing the permissible limit of 20 mg/L [12]. Elevated nitrate levels in drinking water can cause methemoglobinemia ("blue baby syndrome") in infants and increase the long-term risk of colorectal cancer [46,47]. This strengthens the assumption that nitrate sources stem from domestic activities, agriculture, or livestock farming near the void area. The beneficial end-use approach promoted by the International Mine Water Association (IMWA) states that post-mining pit lakes should be utilized for productive purposes after the closure period [3,48]. In countries like Australia, Germany, and Canada, thousands of voids have been successfully rehabilitated into irrigation reservoirs, tourism destinations, and even raw water sources [10]. These rehabilitated pit lakes simultaneously provide ecological and social benefits [3]. Therefore, transforming environmental liabilities into strategic assets is highly relevant for Indonesia, particularly East Kalimantan, which hosts 264 unmanaged void sites. With appropriate technologies and local governance, these void waters can become a long-term solution for sustainable water security. The assessment of "compliant" or "non-compliant" status is based on Government Regulation No. 22/2021 (Annex VI – Class II). Microbiological parameters are the primary indicators of drinking water safety and are presented in Table 1.

Table 1. In-situ Water Quality of Mine Void at Jahab Village, Km 14

No	Parameter	Unit	Test Result	Regulatory Standard (PP 22/2021)	Status
A.	Physical Parameters				
1	Temperature*	°C	32.3	±3°C from ambient temperature	Compliant

2	Total Dissolved Solids (TDS)*	mg/L	135.7	< 1,000	Compliant
3	Total Suspended Solids (TSS)*	mg/L	2.47	< 50	Compliant
4	Color	TCU	Colorless	≤ 50	Compliant
5	Electrical Conductivity (EC)	µmhos/cm	291	(-)	-
6	Odor	-	Odorless	Odorless	Compliant
7	Turbidity	NTU	0.12	≤ 3	Compliant
B. Chemical Parameters					
8	pH*	-	7.68	6–9	Compliant
9	BOD ₅ *	mg/L	2.28	≤ 3	Compliant
10	COD	mg/L	9.37	≤ 25	Compliant
11	Salinity	%	0.12	(-)	-
12	Dissolved Oxygen (DO)	mg/L	6.48	(-)	-
13	Iron (Fe)	mg/L	<0.03	≤ 0.2	Compliant
14	Manganese (Mn)	mg/L	<0.032	≤ 0.1	Compliant
15	Fluoride (F ⁻)	mg/L	0.3	≤ 1.5	Compliant
16	Nitrate (as N)	mg/L	102	≤ 20	Non-compliant
C. Microbiological Parameters					
17	<i>E. coli</i>	MPN/100mL	<20	0	Non-compliant
18	Total Coliform	MPN/100mL	1,240	0	Non-compliant

3.2 Performance of Local Water Treatment System by the Community

In Kelurahan Jahab, residents currently extract water directly from the void using portable pumps and sell it to other households at IDR 65,000 per tank (1,500 liters). However, this system does not involve any treatment process beyond pumping and distribution. The water is consumed without disinfection, posing a significant risk of pathogen transmission. In-depth interviews with community leaders and the Head of Jahab Subdistrict revealed that there is no formal water treatment unit, such as PDAM or PAMSIMAS, operating in the area. Some households use only basic sand filters, which are ineffective in removing microorganisms [36]. Field surveys also indicate that while residents are aware of health risks, they continue consuming void water due to limited access and high bottled water prices. The fact that nitrate levels reach 102 mg/L—far exceeding the regulatory standard of 20 mg/L—suggests possible infiltration from domestic waste, organic fertilizer, or septic tanks [12]. High nitrate concentration in drinking water can cause methemoglobinemia ("blue baby syndrome") in infants and increase the risk of colorectal cancer if consumed long-term [46,47]. Moreover, although the water is physically and chemically safe, the presence of Total Coliform at 1,240 MPN/100mL indicates that the water is still unfit for consumption. Informal, non-standardized treatment systems are vulnerable to post-extraction recontamination, especially if pipes or storage tanks are not regularly sterilized [25].

Therefore, an independent, self-managed approach without proper technology and formal governance is insufficient to ensure sustainable and safe drinking water supply. A hybrid system that integrates multiple treatment stages—such as aeration, multistage filtration, and UV disinfection—is required: one that is integrated, reliable, and easily managed by the local community. Acid Mine Drainage (AMD) management must consider technological, social, and environmental aspects holistically to ensure truly sustainable solutions [2]. The refill-gallon depot model managed by Badan Usaha Milik Desa (BUMDes) has proven more hygienic than permanent piped networks, which are prone to corrosion, biofilm formation, and algal growth [35]. Gallon-based distribution allows treated water to be used immediately, preventing post-treatment recontamination [35]. This approach also supports improved sanitation, reduces maintenance costs, and promotes local economic development through job creation and income generation within the BUMDes framework.

3.3 Recommended Hybrid System for Mine Water (Void) Treatment

Based on the water quality characteristics and operational challenges, a three-stage hybrid treatment system is recommended, consisting of: (1) Aeration using an Aeration Tower: Aeration aims to increase dissolved oxygen (DO) levels and oxidize volatile organic compounds as well as residual iron and manganese [17]. In Jahab Village, initial DO reaches 6.48 mg/L; however, it needs to be maintained to ensure water freshness and prevent the growth of anaerobic bacteria [44]. A custom-designed aeration tower has been engineered with galvanized angle steel frame (70x70x6 mm), a height of 600 cm, and base diameter of 120 cm, in accordance with the Detailed Engineering Design (DED) specifications (Table 2) [45]. (2) Multistage Filtration (Silica Sand – Granular Activated Carbon – IRA-958 Ion Exchange Resin): Although the void water is no longer turbid, filtration remains necessary to capture fine particulates and remove hydrophilic organic compounds. The recommended filtration media sequence is as follows: Quartz and silica sand: Removes remaining suspended solids. Granular activated carbon: Adsorbs organic compounds, odors, color, and anthropogenic micropollutants such as detergents and boat lubricants [35]. IRA-958 ion-exchange resin: Eliminates hydrophilic Natural Organic Matter (NOM) fractions and dissolved metals [20]. The IRA-958 resin effectively removes negatively charged carbonyl and carboxyl groups, which are primary precursors of Disinfection By-Products (DBPs). The combination of activated carbon and ion-exchange resin enhances DOC rejection by over 86%, producing DBP-free drinking water [20]. (3) UV Disinfection: To address microbiological contamination, ultraviolet (UV) irradiation is applied using the Wonder UV Sterilizer 12 GP [21]. This technology eliminates up to 99.9% of pathogens—including viruses, bacteria, and protozoa—without forming carcinogenic disinfection by-products [32].

This approach is particularly important because the void water contains organic matter (COD = 9.37 mg/L; BOD₅ = 2.28 mg/L), making chlorine-based disinfection risky due to potential formation of trihalomethanes (THMs) and haloacetic acids (HAAs) [13]. The system is designed for a production capacity of 1,200 liters/hour, with an estimated daily energy requirement of 2,500 watt-hours/day [49]. Integration of a 2,500-watt solar power system (PLTS) ensures off-grid operation, enhancing energy resilience during floods or fuel supply disruptions [49]. Coagulation-flocculation is not mandatory due to the already low turbidity, but can be implemented optionally during rainy seasons if turbidity increases significantly [19].

Table 2. Component Details of the Hybrid Mine Water (Void) Treatment System

Component	Specification	Quantity	Function
Intake Pump	Shimizu Manual 125 Watt	1 unit	Water extraction from the void
Aeration Tower	Galvanized Angle Frame (70x70x6 mm), Height: 600 cm, Base Diameter: 120 cm	1 unit	Increases DO and oxidizes volatile organics and metals
Sedimentation Tank	Mpoin 1,200 L + Aero Agitator 0.5 HP	1 set	Optional pretreatment for flocculation
FRP Filter Unit	Nanotec 10-inch, 3-Way Head Valve	3 units	Sand, zeolite, and activated carbon filtration
Filtration Media	Quartz sand, silica, granular activated carbon, IRA-958 ion-exchange resin	2 bags @25 kg each	Adsorption of organics, metals, and color
UV Sterilizer	Wonder UV 12 GP	3 units	Non-chemical disinfection without DBP formation
Storage Reservoir	Mpoin 1,200 L tank	1 unit	Temporary storage before distribution
Solar Power System (PLTS)	Polycrystalline panel, 2,500 W total	1 system	Primary off-grid energy source
Generator	Honda 2,500 VA	1 unit	Backup power supply during night or prolonged rain

Note: Coagulation-flocculation is optional, only required if significant turbidity increase occurs during high-rainfall periods.

3.4 Operational Sustainability and Governance

The success of the system heavily depends on a governance model based on a Badan Usaha Milik Desa (BUMDes) and community economic support [38]. A Willingness to Pay (WTP) survey conducted with 30 respondents revealed that the majority of residents are willing to pay IDR 50,000–150,000 per month for safe and accessible drinking water [38]. This WTP value serves as a strong indicator that the community is economically ready to support a sustainable treatment system, provided its benefits are tangible and transparent. The recommended business model is a refill-gallon depot, not a piped distribution network. The reasons are: Higher hygiene: Gallons can be easily sterilized, whereas PVC pipes are prone to biofilm formation and algal growth [23]. Lower maintenance costs: Creation of local income through BUMDes [38]. BUMDes plays a strategic role in: Training local operators. Conducting routine maintenance. Distributing gallon containers. Ensuring financial transparency. Socializing the importance of clean water [38]. A study by Wilopo et al. shows that artificial reservoirs managed by local institutions significantly enhance water resilience in Sleman, Yogyakarta, due to strengthened community ownership and accountability [12]. Furthermore, integrating a 2,500-watt solar power system reduces electricity operational costs by up to 80%, making it a more sustainable solution [50]. Transforming former mining sites into productive assets is a core principle of sustainable development in disaster-prone areas [3][48]. In Kelurahan Jahab, the void is no longer just an abandoned mine; it can become a productive reservoir supporting water security, carbon farming, and greenhouse gas (GHG) offset programs [38].

4. Conclusion

This study has successfully identified the critical characteristics of mine water (void) at Jahab Village, Tenggara Subdistrict, Kutai Kartanegara Regency, which has neutral pH (7.68), low Total Dissolved Solids (TDS = 135.7 mg/L), excellent turbidity (0.12 NTU), and heavy metals such as iron (<0.03 mg/L) and manganese (<0.032 mg/L) already within drinking water quality standards (Government Regulation No. 22/2021), except for Total Coliform that reached 1,240 MPN/100mL, although E. coli was not detected or <20 MPN/100mL. These findings demonstrate that despite favorable physicochemical parameters and natural stabilization over more than ten years post-mining, the water is still not safe for consumption without further treatment, particularly due to potential health risks such as diarrhea, dysentery, and cholera from fecal contamination. Therefore, it fails to ensure drinking water safety.

Based on laboratory findings and current literature, a three-stage treatment system is recommended: Aeration using an aeration tower → enhances dissolved oxygen (DO) and oxidizes volatile organic compounds. Multistage filtration (quartz sand – granular activated carbon – IRA-958 ion-exchange resin) → removes fine particulates, adsorbs anthropogenic organic pollutants (e.g., detergents, boat lubricants), and eliminates hydrophilic NOM fractions. UV disinfection (Wonder UV Sterilizer 12 GP) → a non-chlorine solution effective in inactivating viruses, bacteria, and protozoa without forming carcinogenic Disinfection By-Products (DBPs) such as trihalomethanes (THMs) and haloacetic acids (HAAs). This integrated system holistically addresses all critical parameters—microbiological safety, organic content, and chemical stability—while preventing hazardous by-product formation. The process has been proven to reduce DBP formation potential by over 90% in similar systems.

Sustainability of the system depends not only on technology but also on local governance. A Badan Usaha Milik Desa (BUMDes) plays a strategic role as the managing institution because of its proximity to the community and understanding of local social dynamics. Willingness to Pay (WTP) surveys involving 30 respondents showed that most residents are willing to pay IDR 50,000–150,000 per month for safe and affordable drinking water access, which serves as a strong foundation for long-term operational financing, creating a sustainable local economic cycle. In addition, this approach creates local jobs, improves purchasing power, and strengthens community

resilience (disaster resilience) against clean water crises. Transforming degraded land into productive assets is a core principle of sustainable development in disaster-prone areas. The findings prove that mine water voids can be transformed from environmental liabilities into strategic assets. Appropriate hybrid technologies are effective at the community scale. BUMDes-based governance and WTP are key sustainability drivers. Solar integration supports energy resilience and climate adaptation. Key recommendations from this study are: Implement a hybrid treatment system (aeration – multistage filtration – UV disinfection). Operate and manage the system through BUMDes with a refill-gallon depot model. Train local operators for routine maintenance and troubleshooting. Conduct regular monitoring by environmental laboratories..

Acknowledgement

The authors formally declare that this research was conducted independently and remains entirely free from any conflict of interest. No financial, institutional, commercial, or personal relationships exist that could have influenced, biased, or compromised the objectivity of the study design, data collection, analysis, or interpretation of results. The authors affirm full academic integrity and take sole responsibility for the scientific content presented in this manuscript.

References

- [1] J. G. Skousen and P. F. Ziemkiewicz, *Acid mine drainage control and treatment*. West Virginia, US: National Research Center for Coal and Energy, 1996.
- [2] R. S. Gautama, *Formation, Control, and Treatment of Acid Mine Drainage*. Bandung, Indonesia: ITB, 2014.
- [3] C. McCullough, M. Schultze, and J. Vandenberg, "Realizing beneficial end uses from abandoned pit lakes," *Minerals*, vol. 10, no. 2, p. 133, 2020. [Online]. Available: <https://doi.org/10.3390/min10020133>
- [4] A. S. Basuki, *Impact of the existence of coal mining activities by PT Viktor Dua Tiga Mega on the socio-economic conditions of surrounding communities*. ResearchGate, 2007.
- [5] C. G. Down and J. Stocks, *Environmental impacts of mining*. London, UK: Applied Science Publishers, 1978.
- [6] H. Fitrah, *Acid mine drainage and soil fertility*. Mataram, Indonesia: Penerbit Lafatz Jaya, 2019.
- [7] K. K. Kefeni, T. A. M. Msagati, and B. B. Mamba, "Acid mine drainage: Prevention, treatment options, and resource recovery," *Journal of Cleaner Production*, vol. 151, pp. 475–493, 2017. [Online]. Available: <https://doi.org/10.1016/j.jclepro.2017.03.081>
- [8] J. O. Ighalo et al., "A review of treatment technologies for the mitigation of the toxic environmental effects of acid mine drainage (AMD)," *Process Safety and Environmental Protection*, vol. 157, pp. 37–58, 2022. [Online]. Available: <https://doi.org/10.1016/j.psep.2021.10.065>
- [9] V. Masindi and M. Gitari, "An overview of the utilization of lignite and its derivatives in the treatment of acid mine drainage," *Chemosphere*, vol. 203, pp. 250–261, 2018. [Online]. Available: <https://doi.org/10.1016/j.chemosphere.2018.03.183>
- [10] E. Karakatsanis and V. Cogho, "Drinking water from mine water using the HiPro® process—Optimum coal mine water reclamation plant," in *IMWA Annual Conference*, Sydney, Australia, 2010.
- [11] E. T. Tuheteru, G. J. Kusuma, K. Pranoto, Y. Palingi, and R. S. Gautama, "Water quality study and potential utilization of former mining lake JVoid PT Kaltim Prima Coal, East Kalimantan," *Indonesian Mining and Energy Journal*, vol. 4, no. 1, pp. 52–59, 2021.
- [12] W. Wilopo, H. Setiawan, and D. P. Eka Putra, "Evaluation of artificial reservoir management in Sleman Regency, Yogyakarta Special Region," *Jurnal Presipitasi*, vol. 17, no. 3, pp. 205-214, 2020. [Online]. Available: <https://doi.org/10.14710/presipitasi.v17i3.205-214>
- [13] M. Qadafi, S. Notodarmojo, and Y. Zevi, "Effects of microbubble pre-ozonation time and pH on trihalomethanes and haloacetic acids formation in pilot-scale tropical peat water treatments for drinking water purposes," *Science of the Total Environment*, vol. 747, p. 141540, 2020. [Online]. Available: <https://doi.org/10.1016/j.scitotenv.2020.141540>
- [14] M. Elma et al., "Combination of coagulation, adsorption, and ultrafiltration processes for organic matter removal from peat water," *Sustainability*, vol. 14, no. 1, p. 370, 2021. [Online]. Available: <https://doi.org/10.3390/su14010370>
- [15] K. Khayan et al., "Integrated water treatment system for peat water treatment," *CLEAN – Soil, Air, Water*, vol. 50, no. 3, p.2100404, 2021. [Online]. Available: <https://doi.org/10.1002/clen.202100404>
- [16] Y. Zevi, M. Qadafi, and S. Notodarmojo, "The presence of trihalomethanes and haloacetic acids in tropical peat water," *Journal of Engineering and Technological Sciences*, vol. 54, no. 3, p. 220314, 2022. [Online]. Available: <https://doi.org/10.5614/J.ENG.TECHNOL.SCI.2022.54.3.14>
- [17] J. P. Ritson et al., "Simulated climate change impact on summer dissolved organic carbon release from peat and surface vegetation: for drinking water treatment," *Water Research*, vol. 67, pp. 66–76, 2014. [Online]. Available: <https://doi.org/10.1016/j.watres.2014.09.015>
- [18] J. K. Edzwald and J. E. Tobiason, "Enhanced coagulation: US requirements and a broader view," *Water Science and Technology*, vol. 40, no. 7, pp. 63–70, 1999. [Online]. Available: [https://doi.org/10.1016/S0273-1223\(99\)00641-1](https://doi.org/10.1016/S0273-1223(99)00641-1)
- [19] R. Sudoh et al., "Removal of dissolved humic acid from water by coagulation method using polyaluminum chloride (PAC) with calcium carbonate as neutralizer and coagulant aid," *Journal of Environmental Chemical Engineering*, vol. 3, no. 1, pp. 770–774, 2015. [Online]. Available: <https://doi.org/10.1016/j.jece.2015.04.007>
- [20] H. Y. Cai et al., "Adsorption of neutral and negatively charged low-molecular-weight carbonyls in reverse osmosis permeates by ion-exchange resins," *Water Cycle*, vol. 3, pp. 1–7, 2022. [Online]. Available: <https://doi.org/10.1016/J.WATCYC.2021.12.001>
- [21] I. G. Wenten et al., "Preparation of antifouling polypropylene/ZnO composite hollow fiber membrane by dip-coating method for peat water treatment," *Journal of Water Process Engineering*, vol. 34, p. 101158, 2020. [Online]. Available: <https://doi.org/10.1016/j.jwpe.2020.101158>
- [22] K. Padmaja, J. Cherukuri, and M. A. Reddy, "A comparative study of the efficiency of chemical coagulation and electrocoagulation methods in the treatment of pharmaceutical effluent," *Journal of Water Process Engineering*, vol. 34, p.101153, 2020. [Online]. Available: <https://doi.org/10.1016/J.JWPE.2020.101153>

- [23] Hamzar, A. Suprpta, and A. Amsar, "Analysis of shallow groundwater quality for drinking water purposes in Bontonpomp Village," *Jurnal Environmental Science*, vol. 3, no. 2, pp. 131–142, 2021.
- [24] U. Mangidi, H. Djahir, and J. Deriansah, "Design of clean water treatment at PDAM Unit Wangu Kendari," *Jurnal Stabilita*, vol. 2, no. 1, pp. 69–84, 2014.
- [25] M. J. LeChevallier and K. K. Au, *Water Treatment and Pathogen Control: Process Efficiency in Achieving Safe Drinking Water*. London, UK: IWA Publishing, 2004.
- [26] M. Sillanpää, M. C. Ncibi, and A. Matilainen, "Advanced oxidation processes for the removal of natural organic matter from drinking water sources: A comprehensive review," *Journal of Environmental Management*, vol. 208, pp. 56–76, 2018. [Online]. Available: <https://doi.org/10.1016/j.jenvman.2017.12.009>
- [27] N. A. Rahman et al., "Desalination of Borneo tropical brackish peat water with adsorption process in continuous electrocoagulation treatment," *Desalination*, vol. 527, p. 115574, 2022. [Online]. Available: <https://doi.org/10.1016/J.DESAL.2022.115574>
- [28] H. S. Peavy, D. R. Rowe, and G. Tchobanoglous, *Environmental engineering*. New York, US: McGraw-Hill, 1985.
- [29] W. Viessman and M. J. Hammer, *Water supply and pollution control*, 4th ed. New York, US: Harper & Row, 1985.
- [30] A. Siddique et al., "Multi-pathways human health risk assessment of trihalomethane exposure through drinking water," *Ecotoxicology and Environmental Safety*, vol. 116, pp. 129–136, 2015. [Online]. Available: <https://doi.org/10.1016/j.ecoenv.2015.03.011>
- [31] S. Notodarmojo, A. Mahmud, and A. Larasati, "Adsorption of natural organic matter (NOM) in peat water by local Indonesian tropical clay soils," *International Journal of GEOMATE*, vol. 13, no. 38, pp. 111–119, 2017. [Online]. Available: <https://doi.org/10.21660/2017.38.30379>
- [32] J. Kong et al., "The virus removal in UV irradiation, ozonation and chlorination," *Water Cycle*, vol. 2, pp. 23–31, 2021. [Online]. Available: <https://doi.org/10.1016/J.WATCYC.2021.05.001>
- [33] M. Qadafi et al., "Characteristics and treatment methods for peat water as clean water sources: A mini review," *Water Cycle*, vol. 4, pp. 60–69, 2023. [Online]. Available: <https://doi.org/10.1016/J.WATCYC.2023.02.005>
- [34] C. Postigo et al., "A step forward in the detection of byproducts of anthropogenic organic micropollutants in chlorinated water," *Trends in Environmental Analysis and Chemistry*, vol. 32, p. e00148, 2021. [Online]. Available: <https://doi.org/10.1016/J.TEAC.2021.E00148>
- [35] A. Matilainen, N. Vieno, and T. Tuhkanen, "Efficiency of the activated carbon filtration in the natural organic matter removal," *Environment International*, vol. 32, no. 3, pp. 324–331, 2006. [Online]. Available: <https://doi.org/10.1016/j.envint.2005.06.003>
- [36] J. Muhammad, "Peat water purification by hybrid of slow sand filtration and coagulant treatment," *Journal of Environmental Science and Technology*, vol. 13, no. 1, pp. 22–28, 2020. [Online]. Available: <https://doi.org/10.3923/jest.2020.22.28>
- [37] D. Bing-zhi et al., "Effect of coagulation pretreatment on the fouling of ultrafiltration membrane," *Journal of Environmental Sciences*, vol. 19, no. 3, pp. 278–283, 2007. [Online]. Available: [https://doi.org/10.1016/S1001-0742\(07\)60045-X](https://doi.org/10.1016/S1001-0742(07)60045-X)
- [38] M. Andriani and M. Yusuf, "Community participation in Saliki Village: Water Supply System program in fulfilling clean water needs," *Jurnal Sosial dan Sains*, vol. 1, no. 8, pp. 819–826, 2021. [Online]. Available: <https://doi.org/10.59188/jurnalsosains.v1i8.178>
- [39] R. W. Cahyani et al., "Identification Of Eco-Tourism Potential In Muara Enggelam Village Muara Wis District, Kutai Kartanegara Regency, East Kalimantan Province," *Jurnal Penelitian Ekosistem Dipterokarpa*, vol. 8, no. 1, pp. 67–82, 2022. [Online]. Available: <https://doi.org/10.20886/JPED.2022.8.1.67-82>
- [40] A. J. Tonks et al., "Impacts of conversion of tropical peat swamp forest to oil palm plantation on peat organic chemistry, physical properties and carbon stocks," *Geoderma*, vol. 289, pp. 36–45, 2017. [Online]. Available: <https://doi.org/10.1016/j.geoderma.2016.11.018>
- [41] J. W. Creswell and V. L. Plano Clark, *Designing and conducting mixed methods research*. California, US: Sage Publications, 2017.
- [42] National Standardization Agency (BSN), *Water and wastewater – Part 57: Guidelines for surface water sampling*, SNI 6989.57:2008, 2008.
- [43] Government of Indonesia, *Government Regulation of the Republic of Indonesia Number 22 Year 2021 concerning Environmental Protection and Management*, 2021.
- [44] UPTD Laboratory DLHK, "Report of surface water quality testing (No. LHU 660.1/177/UPTD.Lab/LHU/DLHK)," 2023.
- [45] University of Kutai Kartanegara, "Final report: Development and engineering in the field of technology and innovation of water treatment technology into safe consumable water," Center for Research and Environmental Management Studies, Faculty of Engineering, University of Kutai Kartanegara, Tenggarong, Indonesia, 2023.
- [46] T. M. Addiscott and Z. Benjamin, "Nitrate in drinking water and methemoglobinemia in infants: a reappraisal," *Nutrition and Health*, vol. 18, no. 4, pp. 359–373, 2004. [Online]. Available: <https://doi.org/10.1177/026010600401800405>
- [47] IARC, "Some drinking-water contaminants and flavouring agents. IARC Monographs on the Evaluation of Carcinogenic Risks to Humans," vol. 94, Lyon, France, 2010.
- [48] M. L. Blanchette and M. A. Lund, "Pit lakes are a global legacy of mining: An integrated approach to achieving sustainable ecosystems and value for communities," *Current Opinion in Environmental Sustainability*, vol. 23, pp. 28–34, 2016. [Online]. Available: <https://doi.org/10.1016/j.cosust.2016.11.012>
- [49] UPTD Laboratory DLHK, "Report of surface water quality testing (No. LHU 660.1/174/UPTD.Lab/LHU/DLHK)," 2023.