

Potential use of a coal mine pit lake as a raw water source in Loa Ipuh Darat, Kutai Kartanegara, Indonesia

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ABSTRACT

Coal mine pit lakes (voids) can provide an alternative raw-water source in areas with limited access to conventional water supplies, but their use requires continuous assessment of water quality and appropriate treatment. This study evaluated the water quality of a more than 12-year-old former coal-mining void in Loa Ipuh Darat, Kutai Kartanegara, East Kalimantan, Indonesia, and assessed its potential and sustainability as a raw-water source. Water samples were collected from four sampling points and analyzed for physical, chemical, and microbiological parameters. Water quality status was evaluated using the Pollution Index (PI) and the National Sanitation Foundation Water Quality Index (NSF-WQI). Community perceptions were assessed using structured questionnaires and descriptive quantitative analysis. The PI value was 1.00, indicating that the water met the applicable quality standard and was classified as good. The NSF-WQI score was 87.34, also placing the water in the good category. Most measured parameters were within the Class I water-quality criteria, although microbiological indicators, total solids, BOD, turbidity, and several parameters approaching their respective limits require continued monitoring. Community acceptance was positive: 65.31% of respondents rated the treated water as good and 32.65% as very good, while the overall Likert-scale perception index was 86.12%. The findings indicate that the Loa Ipuh Darat pit lake has potential as an alternative raw-water source, provided that water treatment, routine quality monitoring, source-area protection, and community participation are maintained.

INTRODUCTION

Access to safe and adequate water is essential for human well-being. Increasing demand for clean water has encouraged the use of diverse raw-water sources, including springs, rivers, lakes and reservoirs, groundwater, and rainwater. In areas where conventional sources are limited or difficult to access, alternative sources require careful evaluation to ensure that their quality remains suitable for the intended use.

Under Government Regulation of the Republic of Indonesia No. 22 of 2021 on Environmental Protection and Management, water quality management is an important component of pollution prevention and environmental protection. Open-pit coal mining can leave deep excavations that subsequently fill with rainfall, surface runoff, and groundwater, forming permanent mine voids or pit lakes. If poorly managed, these water bodies may become pollution sources; however, with appropriate management, they may

provide opportunities for water supply, aquaculture, recreation, and ecosystem conservation (Munawar, 2017; Atkinson et al., 2008; Castendyk and Eary, 2009).

Water quality in coal-mine pit lakes is strongly influenced by the geochemical characteristics of surrounding materials. Oxidation of sulfide minerals, particularly pyrite (FeS_2), can generate acid mine drainage (AMD), characterized by low pH and elevated concentrations of dissolved metals such as Fe and Mn (Akcil and Koldas, 2006). Consequently, visually clear pit-lake water should not be assumed to be chemically safe without analytical verification (Gautama, 2014). Water quality is dynamic and must be evaluated in relation to its intended use (Effendi, 2003 and Hamdhani, 2024).

The Loa Ipuh Darat pit lake is more than 12 years old and has been used as a raw-water source for a local water-treatment facility serving surrounding communities. The site is therefore important both as an alternative water source and as a post-mining environmental asset. Under Government Regulation No. 22 of 2021, Class I water is intended, among other uses, as raw water for drinking-water supply. Continuous monitoring is consequently required to identify changes in physical, chemical, and microbiological quality and to protect the source from surrounding activities. Social acceptance is also important because the long-term use of alternative water sources depends not only on technical water quality but also on public trust in treatment and safety assurance (Dolnicar and Schäfer, 2009).

Previous studies have examined mine pit lakes for irrigation, recreation, and ecological conservation (McCullough & Lund, 2006), but studies integrating water-quality indices and community perception for pit-lake use as a raw-water source remain limited in Indonesia, particularly in East Kalimantan. This study addresses that gap by combining physical, chemical, and microbiological water-quality assessment, the Pollution Index (PI), NSF-WQI, and community perception.

The objectives were to: (1) assess the physical, chemical, and microbiological quality of pit-lake water in Loa Ipuh Darat; (2) determine its water-quality status using PI and NSF-WQI; and (3) assess community perceptions of its potential and sustainability as a raw-water source.

METHODOLOGY

Study Area and Time

The study was conducted at a former coal-mining void operated by PT Multi Harapan Utama (PT MHU) in Loa Ipuh Darat, Tenggarong District, Kutai Kartanegara Regency, East Kalimantan, Indonesia. The permanent water body covers approximately 18.05 ha and has an average depth of 24 m. Its location is within the service area of the Loa Ipuh Darat Water Treatment Plant, making it strategically relevant as a potential raw-water source.

The study was conducted over three months and included site reconnaissance, secondary-data collection, water sampling and laboratory analysis, community interviews/questionnaires, data processing, and interpretation.



Figure 1. Study area and water-sampling points.

Water Sampling and Handling

Water samples were collected from four sampling points selected to represent spatial conditions within the void, including locations near the highwall, the central area, and areas potentially influenced by surrounding activities. Grab and composite sampling followed SNI 6989.57:2008 for surface-water sampling. A water sampler was used at a defined depth below the surface. Sampling was conducted at approximately the same time of day to minimize temporal variation. Temperature, pH, and dissolved oxygen (DO) were measured in situ using calibrated portable instruments.

Physical and chemical samples were collected in 1,000-mL polyethylene bottles rinsed three times with sample water. Microbiological samples were collected in sterile 300-mL glass bottles. Equipment was cleaned and sterilized to minimize cross-contamination. Samples were transported in an ice-filled cooler at approximately 4 °C and delivered within 24 h to the KAN-accredited environmental laboratory of PT Laboratorindo Alam Bestari. Laboratory analyses followed APHA (2017) and relevant Indonesian National Standards (SNI).

Water-Quality Parameters

The analyzed parameters covered physical, chemical, and microbiological characteristics. Physical parameters included temperature, total dissolved solids (TDS), total suspended solids (TSS), turbidity, color, and odor. Chemical parameters included pH, BOD, DO, nitrate, nitrite, Cr(VI), Fe, Mn, As, Cd, Pb, fluoride, Al, H₂S, Hg, Cu, Ni, ammonia, and total phosphate. Microbiological indicators included *Escherichia coli*, fecal coliform, and total coliform.

Table 1. Water-quality parameters and analytical methods.

No.	Parameter	Analytical method	Analysis
1	Temperature	SNI 06-6989.23-2005	In situ
2	Total dissolved solids (TDS)	SNI 6989.27:2019	Laboratory
3	Total suspended solids (TSS)	SNI 6989.3:2019	Laboratory
4	Turbidity	SNI 06-6989.25-2005	Laboratory
5	Color	SNI 6989.80:2011	Laboratory
6	Odor	Organoleptic	Laboratory
7	pH	SNI 6989.11:2019	In situ
8	Biochemical oxygen demand (BOD)	SNI 6989.72:2009	Laboratory
9	Dissolved oxygen (DO)	IKM-06-DO-LAB (electrometry)	In situ
10	Nitrate (NO ₃ -N)	IKM/IPLAB/7.2.2	Laboratory
11	Nitrite (NO ₂ -N)	SNI 06-6989.9-2004	Laboratory
12	Hexavalent chromium [Cr(VI)]	SNI 6989.71:2009	Laboratory
13	Dissolved Fe	SNI 6989-84:2019	Laboratory
14	Dissolved Mn	SNI 6989-84:2019	Laboratory
15	Dissolved As	SNI 06-6989.54-2005	Laboratory
16	Dissolved Cd	SNI 6989-84:2019	Laboratory
17	Dissolved Pb	SNI 6989-84:2019	Laboratory
18	Fluoride (F ⁻)	SNI 06-6989.29-2005	Laboratory
19	Dissolved Al	SNI 06-6989.36-2005	Laboratory
20	Hydrogen sulfide (H ₂ S)	SNI 6989.70-2009	Laboratory
21	Dissolved Hg	SNI 6989-71:2019	Laboratory
22	Cu	SNI 6989-84:2019	Laboratory
23	Ni	SNI 6989-84:2019	Laboratory
24	Ammonia (NH ₃ -N)	SNI 06-6989.30-2005	Laboratory
25	Total phosphate (P)	SNI 6989-31:2021	Laboratory
26	<i>Escherichia coli</i>	SM APHA 24th ed. 9223 B (2023), IDEXX Colilert	Laboratory
27	Fecal coliform	SM APHA 24th ed. 9223 B (2023), IDEXX Colilert	Laboratory
28	Total coliform	SM APHA 24th ed. 9223 B (2023), IDEXX Colilert	Laboratory

Water-Quality Status

Pollution Index (PI)

Water-quality status was evaluated using the Pollution Index (PI), following Minister of Environment Decree No. 115 of 2003 and the applicable framework of Government Regulation No. 22 of 2021. The index was calculated from the measured concentration (C_i) relative to the applicable standard (L_{ij}), using the maximum and average concentration-to-standard ratios:

$$PI_j = \sqrt{\frac{(C_i/L_{ij})_M^2 + (C_i/L_{ij})_R^2}{2}}$$

where C_i is the measured concentration of parameter i , L_{ij} is the standard for designated use j , $(C_i/L_{ij})M$ is the maximum ratio, and $(C_i/L_{ij})R$ is the average ratio. PI values were interpreted as: 0–1.0 = meets the standard/good; >1.0–5.0 = lightly polluted; >5.0–10 = moderately polluted; and >10 = heavily polluted.

Table 2. Pollution Index classification

PI value	Water-quality status
$0 \leq PI \leq 1.0$	Meets standard / good
>1.0 to 5.0	Lightly polluted
>5.0 to 10	Moderately polluted
>10	Heavily polluted

NSF Water Quality Index

The National Sanitation Foundation Water Quality Index (NSF-WQI) was used as a composite assessment based on nine parameters: DO, pH, BOD, temperature change, total phosphate, nitrate, turbidity, total solids, and fecal coliform. The index was calculated as:

$$NSFWQI = \sum_{i=1}^n w_i I_i$$

where W_i is the weight assigned to parameter i and L_i is its sub-index value obtained from the corresponding rating curve. NSF-WQI values were classified as 91–100 = very good, 71–90 = good, 51–70 = medium, 26–50 = poor, and 0–25 = very poor.

Table 3. NSF-WQI classification (Brown et al., 1970).

NSF-WQI range	Classification
91–100	Very good
71–90	Good
51–70	Medium
26–50	Poor
0–25	Very poor

Community Perception

Community perception was assessed through a structured questionnaire administered to residents who used treated water produced from the pit-lake source. Respondents were selected purposively based on residence near the void and direct relevance to the use of the treated water. The questionnaire covered knowledge of the void, perceptions of current water quality, willingness to use treated pit-lake water, perceived health effects, and willingness to participate in source protection.

Data were analyzed descriptively using Likert and dichotomous scales. Likert responses assessed perceived water quality using five categories (very good, good, moderate, poor, and very poor). Dichotomous questions used “yes/no” responses for issues such as acceptance of pit-lake water, willingness to use treated water, and willingness to protect the source. Results were summarized as frequencies, percentages, and a Likert perception index.

RESULT AND DISCUSSION

Physical, Chemical, and Microbiological Water Quality

Water-quality results from the four sampling points are summarized in Table 4. Water temperature ranged from 31–32 °C, while TDS ranged from 70 to 220 mg/L. TSS varied from 2.67 to 30.71 mg/L, with the highest value at Point 1. Turbidity ranged from 3.62 to 5.51 NTU. Color ranged from 12.50 to 15.63 PtCo, and all samples were reported as odorless. Overall, the physical characteristics indicated relatively low dissolved and suspended solids, although localized differences suggest spatial variation within the void.

Chemical conditions were generally favorable. pH ranged from 7.44 to 7.52, remaining within the Class I range of 6–9. DO ranged from 6.30 to 6.65 mg/L, while BOD ranged from 2.68 to 2.98 mg/L. Dissolved Fe was below 0.03–0.09 mg/L and Mn was below 0.03 mg/L at all points. Most trace metals, including Cr(VI), As, Cd, Hg, Cu, and Ni, were below their respective detection limits or standards. These results indicate no evident acidification or pronounced metal enrichment at the time of sampling, which is important for a post-mining water body potentially affected by AMD.

Microbiological indicators were detected at all sampling points. *E. coli* ranged from 4.1 to 19.3 MPN/100 mL, fecal coliform from 5.2 to 25.0 MPN/100 mL, and total coliform from 24.1 to 137.6 MPN/100 mL. Although these values were relatively low compared with the applicable limits shown in Table 4, their presence confirms that treatment remains necessary before the water is supplied for domestic use. Microbial contamination may arise from surface runoff and human or animal activities around the water body (Edberg et al., 2000).

Table 4. Water-quality results at the four sampling points and applicable standards.

Parameter	Class I standard	Point 1	Point 2	Point 3	Point 4
Temperature (water), °C	Deviation 3	31	32	31	32
Temperature (air), °C	—	33	34	33	35
TDS, mg/L	1000	92.50	220.00	157.50	70.00
TSS, mg/L	25	30.71	5.17	4.32	2.67
Turbidity, NTU	—	5.51	3.62	4.52	5.31
Color, PtCo	15	12.50	13.75	13.75	15.63
Odor	—	No odor	No odor	No odor	No odor
pH	6–9	7.44	7.47	7.45	7.52
BOD, mg/L	2	2.80	2.68	2.90	2.98
DO, mg/L	≥6	6.50	6.30	6.45	6.65
Nitrate (NO ₃ -N), mg/L	—	0.729	0.698	0.743	0.767
Nitrite (NO ₂ -N), mg/L	—	0.01	0.01	0.01	0.01
Cr(VI), mg/L	0.05	<0.009	<0.009	<0.009	<0.009
Dissolved Fe, mg/L	0.30	<0.03	0.09	<0.03	<0.03
Dissolved Mn, mg/L	0.40	<0.03	<0.03	<0.03	<0.03
Dissolved As, mg/L	0.05	<0.002	<0.002	<0.002	<0.002
Dissolved Cd, mg/L	0.01	<0.002	<0.002	<0.002	<0.002
Dissolved Pb, mg/L	0.03	<0.03	<0.03	<0.03	<0.03
Fluoride, mg/L	1.00	<0.03	<0.03	<0.03	0.06
Dissolved Al, mg/L	—	<0.015	<0.015	<0.015	<0.015
H ₂ S, mg/L	—	0.004	0.002	0.004	<0.002
Dissolved Hg, mg/L	0.001	<0.0002	<0.0002	<0.0002	<0.0002
Cu, mg/L	0.02	<0.02	<0.02	<0.02	<0.02
Ni, mg/L	0.05	<0.04	<0.04	<0.04	<0.04
NH ₃ -N, mg/L	—	<0.03	<0.03	0.19	<0.03
Total phosphate (P), mg/L	0.01	0.01	0.04	0.10	0.01
<i>E. coli</i> , MPN/100 mL	—	4.1	6.0	9.2	19.3

Fecal coliform, MPN/100 mL	100	5.2	12.4	15.2	25.0
Total coliform, MPN/100 mL	1000	24.1	137.6	95.8	116.6

The overall chemical profile is consistent with a relatively stabilized pit lake. However, the interpretation should remain precautionary because pit-lake chemistry can change with hydrological inputs, sediment interactions, oxidation processes, and surrounding land use (Lottermoser, 2010 and Skousen et al., 2017). The measured values therefore represent the condition during the study period rather than a guarantee of long-term stability.

Pollution Index

The four-point dataset showed moderate spatial variation but generally low concentration-to-standard ratios. Using Class I criteria, the average ratio (C_i/L_{ij}) was 0.44 and the maximum ratio was 1.00, producing a PI value of 1.00. Under the adopted classification, the pit-lake water therefore met the water-quality standard and was classified as good.

Table 5. Pollution Index calculation

Parameter	Unit	Class I limit	P1	P2	P3	P4	Mean C_i	C_i/L_{ij}	Adjusted ratio
Color	PtCo	15	12.50	13.75	13.75	15.63	13.91	0.93	0.93
TDS	mg/L	1000	92.50	220.00	157.50	70.00	135.00	0.14	0.14
pH	—	6–9	7.44	7.47	7.45	7.52	7.47	1.00	1.00
Fluoride	mg/L	1	0.03	0.03	0.03	0.06	0.04	0.04	0.04
Dissolved Fe	mg/L	0.3	0.03	0.09	0.03	0.03	0.05	0.15	0.15
Dissolved Cu	mg/L	0.02	0.02	0.02	0.02	0.02	0.02	1.00	1.00
Dissolved Mn	mg/L	0.4	0.03	0.03	0.03	0.03	0.03	0.08	0.08
Dissolved Cd	mg/L	0.01	0.002	0.002	0.002	0.002	0.002	0.20	0.20
Dissolved Pb	mg/L	0.03	0.03	0.03	0.03	0.03	0.03	1.00	1.00
Cr(VI)	mg/L	0.05	0.009	0.009	0.009	0.009	0.01	0.18	0.18
Dissolved Hg	mg/L	0.001	0.0002	0.0002	0.0002	0.0002	0.0002	0.20	0.20
Dissolved As	mg/L	0.05	0.002	0.002	0.002	0.002	0.002	0.04	0.04
Dissolved Ni	mg/L	0.05	0.04	0.04	0.04	0.04	0.04	0.80	0.80
Fecal coliform	MPN/100 mL	100	5.2	12.4	15.2	25.0	14.45	0.14	0.80
Total coliform	MPN/100 mL	1000	24.1	137.6	95.8	116.6	93.53	0.09	0.09

The result supports the potential use of the void as a raw-water source, but it does not imply that the untreated water is directly suitable for consumption. Parameters approaching the Class I limit, particularly pH, Cu, Pb, and Ni in the index calculation, warrant routine monitoring. Changes in runoff, sedimentation, or human activities could alter the water-quality profile.

NSF-WQI

The NSF-WQI provided a composite assessment of nine parameters and yielded a score of 87.34, corresponding to the good category. High sub-index values were obtained for total phosphate (98.40), nitrate (97.08), DO (93.54), and pH (93.42), indicating favorable conditions for these parameters. Lower sub-index values were associated with fecal coliform (75.55), total solids (77.86), temperature change (80.50), and BOD (81.28).

Table 6. NSF-WQI calculation

Parameter	Unit	P1	P2	P3	P4	Mean	Ci	Sub-index Li	Weight Wi	Wi×Li
DO	mg/L	6.50	6.30	6.45	6.65	6.48	87.92	93.54	0.17	15.90
pH	—	7.44	7.47	7.45	7.52	7.47	7.47	93.42	0.11	10.28
BOD	mg/L	2.80	2.68	2.90	2.98	2.84	2.84	81.28	0.11	8.94
Temperature change	°C	2.00	—	—	—	—	2.25	80.50	0.10	8.05
Total phosphate	mg/L	0.01	0.04	0.10	0.01	0.04	0.04	98.40	0.10	9.84
Nitrate	mg/L	0.729	0.698	0.743	0.767	0.73	0.73	97.08	0.10	9.71
Turbidity	NTU	5.51	3.62	4.52	5.31	4.74	4.74	88.62	0.08	7.09
Total solids	mg/L	30.71	5.17	4.32	2.67	10.72	10.72	77.86	0.07	5.45
Fecal coliform	MPN/100 mL	5.2	12.4	15.2	25.0	14.45	14.45	75.55	0.16	12.09

The NSF-WQI result reinforces the PI classification, but the two indices serve different purposes. PI emphasizes compliance with designated standards, whereas NSF-WQI summarizes the combined condition of selected water-quality variables. The relatively lower sub-index for fecal coliform is particularly relevant for raw-water use because microbiological contamination requires effective treatment even when the overall index remains in the good category.

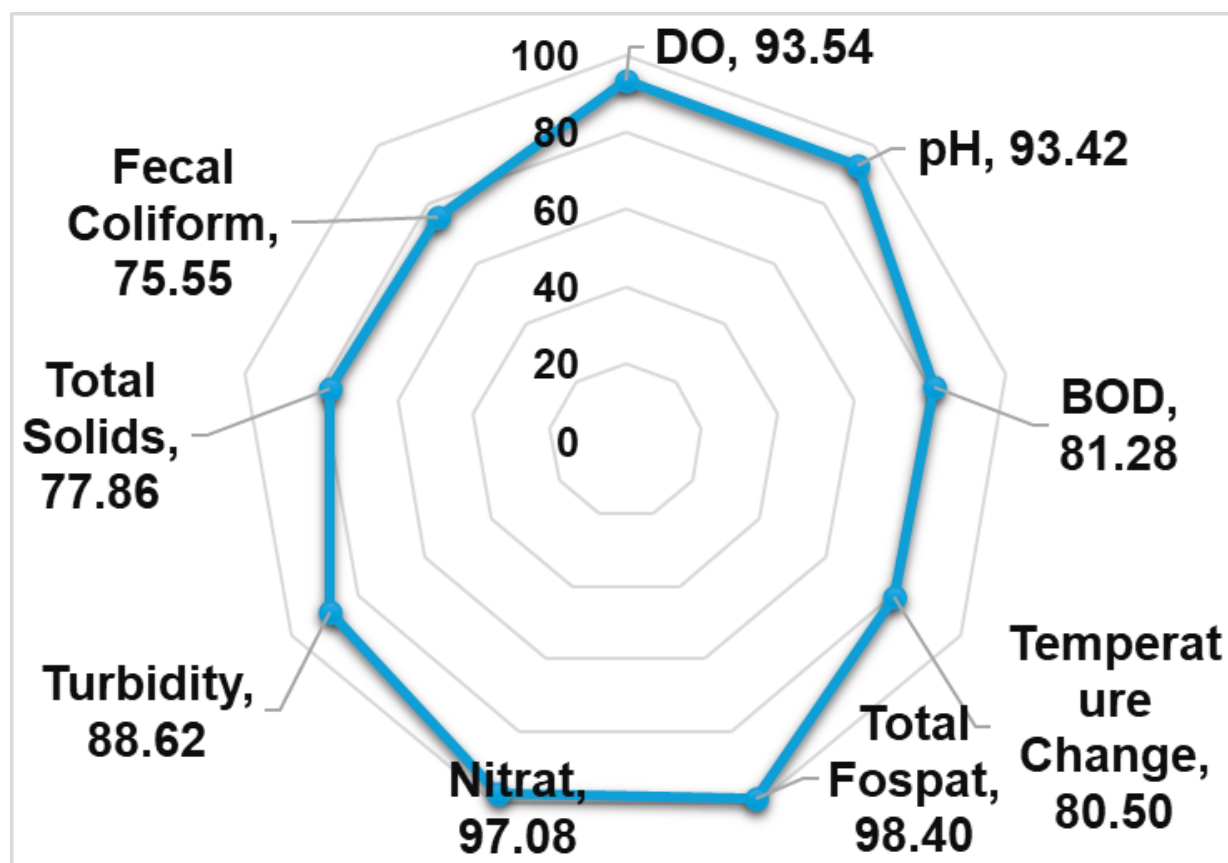


Figure 2. Water-quality profile based on NSF-WQI sub-index values

Community Perception

All respondents reported that treated water was continuously available and that they no longer experienced difficulty obtaining clean water. Most respondents expressed uncertainty about drinking the water directly without boiling, but none reported health complaints associated with consuming the treated water supplied through the water-treatment facility. All respondents knew of the existence of the former

coal-mine void, agreed with its use as a raw-water source, and expressed willingness to use the water after adequate treatment.

Overall acceptance was positive but conditional. Respondents emphasized the importance of scientifically verified treatment, periodic water-quality testing, a trusted treatment-plant operator, and transparent communication of monitoring results. This pattern is consistent with the concept of social acceptance in alternative-water management, where confidence in treatment performance and safety assurance strongly influences public acceptance (Dolnicar and Schäfer, 2009).

The highest perception category was good (65.31%), followed by very good (32.65%) and moderate (2.04%); no respondents selected poor or very poor. The overall Likert-scale perception index was 86.12%, classified as very good. These findings indicate strong acceptance of the treated water, while also highlighting the need to maintain treatment performance, distribution quality, monitoring, and public communication.

CONCLUSION

The Loa Ipuh Darat former coal-mine pit lake shows good potential as an alternative raw-water source for the surrounding community. The measured physical, chemical, and microbiological parameters generally indicated favorable water quality, with pH, DO, dissolved metals, and most other parameters remaining within the applicable Class I criteria. The Pollution Index was 1.00, placing the water in the good category and indicating that, at the time of sampling, the measured pollutant concentrations did not exceed the adopted water-quality criteria.

The NSF-WQI score of 87.34 independently classified the water as good and supported the PI assessment. Nevertheless, the presence of *E. coli* and coliform bacteria, together with relatively lower NSF-WQI sub-index values for fecal coliform, total solids, BOD, and temperature change, demonstrates that the pit-lake water should be treated before domestic distribution and should not be regarded as directly potable. Routine monitoring should prioritize microbiological indicators and parameters that may respond to runoff, sedimentation, surrounding activities, or changes in pit-lake geochemistry.

Community acceptance was strongly positive, with 65.31% of respondents rating the treated water as good, 32.65% as very good, and an overall perception index of 86.12%. Thus, the long-term use of the pit lake as a raw-water source is technically and socially promising, provided that treatment performance, periodic water-quality testing, protection of the source area, control of potential pollution inputs, and transparent communication with the community are maintained. Continued monitoring is essential because a single sampling period cannot establish long-term water-quality stability.

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