Physicochemical Characterization of Nickel Mine Wastewater in South Sulawesi, Indonesia: Seasonal Variations and Treatment Potential

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Abstract

This study utilized ten sampling locations from nickel mine wastewater. The primary pollutants identified were Fe, Mg, Ca, and Al, with the highest concentrations observed at screening stations and processing facilities. Wastewater from Mobile Equipment Maintenance areas exhibited elevated levels of Mg, Ca, Fe, and Na, while mining sites was augmented with Al and Ni. Analyses of particle size and zeta potential revealed larger particles with higher zeta potentials during the dry season, in contrast to smaller, colloidal particles prevalent in the wet season. This investigation contributes to the development of efficacious treatment strategies for nickel mine wastewater in Indonesia.

Keywords: Nickel mine wastewater, physicochemical properties, laterite nickel

Introduction

Indonesia is the world's largest nickel producer, holding 52% of global reserves and contributing 37.04% of world production with 1 million metric tons in 2021 (USGS, 2022). Nickel is an essential resource for many industries, such as stainless steel, batteries, alloys, and metal plating. However, its high output poses a major challenge in environmental management, especially in managing mine water.

In laterite mining, environmental conditions and rainfall can increase concentrations of nickel and other metals like chromium, manganese, magnesium, and iron in mine water. Open pit mining exposes chromium, which may oxidize to toxic hexavalent chromium (Cr(VI)) and leach into water (Nasrullah *et al.*, 2017). Furthermore, the energy-intensive pyrometallurgical smelting process used for laterite ore, which cannot be processed by grinding or norgate methods, produces runoff with high metal content, thus requires treatment and management before being discharged into water bodies (Keskinkilic, 2019)

Characterizing mine water is essential to understand its environmental behavior and determine the appropriate treatment alternatives to minimize pollution. Therefore, this study examines the physical and chemical characteristics of nickel mine water from both processing and mining activities to identify suitable treatment options and guide future research.

Methods

This study analyzed nickel mine water samples from both nickel ore processing and mining activities at an open-pit nickel mine in South Sulawesi, Indonesia. Sampling was conducted using the grab sampling method at 10 ponds that collect water from mining activities, processing plants, screening stations, and mobile equipment maintenance (Tab. 1). Samples were collected within two periods: the dry season and the wet season. To preserve the samples, nitric acid was added until the pH was below 2 before they were sent to the Water Quality Laboratory at the Bandung Institute of Technology for further analysis.

Characterization of nickel mine water in this study was carried out by testing physical characteristics such as measuring pH, temperature, conductivity, using a multimeter probe. Turbidity was also measured using a turbidimeter, total suspended solids (TSS) and total dissolved solids (TDS) using the gravimetric method, particle size with dynamic light scattering method and zeta potential using electrophoresis method. Additionally, chemical characteristics were identified by assessing total and dissolved metals using Inductively Coupled Plasma Mass

Table 1 *Sampling locations.*

Type of activity	Source of Overflow	Inlet Location
Mining	Mining A (East Area) Mining B (West Area) Mining (*Crushing Quarry Washing*)	18.10
Processing Plant	Processing (*Process Plant/Smelting*)	17.30
Screening Station	Processing (*Screening Station*) A (East Area) Processing (*Screening Station*) B (West Area)	<0.04
Mobile Equipment Maintenance	Processing (*Mobile Equipment Maintenance*) A (East Area) Processing (*Mobile Equipment Maintenance*) B (West Area)	<0.04

Results and Discussion

pH and Temperature Characteristics

The pH test results for all samples in both seasons showed that the pH of mine water tended to be stable within a range of 6.8–8.7 (Fig. 1A). This falls within the acceptable limits for nickel ore mining wastewater, which is 6–9, as per the Regulation of the Minister of Environment and Forestry No. 5 of 2022. However, slight differences in pH were observed across sampling locations, likely due to variations in rock types passed through during the runoff process (Amir *et al.*, 2021). Temperature measurements (Fig. 1B) revealed seasonal differences, with dry-season temperatures ranging from 25–27 °C, slightly higher than the wet season (24.5–25.3 °C). This variation can be attributed to reduced cloud cover during the dry season, allowing the sunlight to reach the soil and water surface more directly and heat it more effectively.

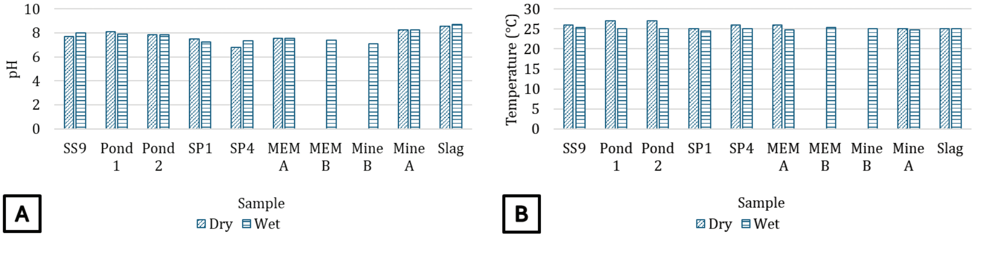

Figure 1 *Comparison of pH (A) and temperature (B) in each sample.*

Characteristics of Electrical Conductivity and Total Dissolved Solid (TDS)

Conductivity measurements revealed seasonal differences in nickel mine water quality, with wet season values (177–639 µS/cm) consistently exceeding dry season levels (150–418 µS/cm) (Fig. 2A). This increase is likely due to the higher amount of runoff in the wet season, enhancing the erosion of minerals from the surrounding soil and rocks, dissolving more minerals into the water (Loock *et al.*, 2015). The elevated mineral content directly raises the water's conductivity (Prihatno *et al.*, 2021). Among the sampled locations, the highest conductivity values were observed in water from the processing plant, screening station, then mining areas, while the lowest values were recorded in mobile equipment maintenance ponds. The higher value of conductivity at processing plants (SP1 and SP4) can be caused by the large number of dissolved substances, including metals, carried from the metal removal process at this location. Screening stations (SS9, Pond 1, and Pond 2) also exhibited high conductivity due to mineral and metal dissolution during ore crushing and grinding activity in this area, though to a lesser extent than processing plants. Mining areas (Mine A, Mine B, and Slag Dump Pond) showed moderate conductivity, likely from quarrying activities that release minerals into water. Meanwhile, mobile equipment maintenance areas (MEM A and MEM B) had the lowest conductivity, as fewer minerals and metals are introduced from heavy equipment washing compared to ore processing and mining sites.

Parallel trends were observed in TDS measurements (Fig. 2B), with wet season concentrations (89–319 mg/L) surpassing dry season levels (92–260 mg/L). This seasonal pattern results from rainfall-enhanced erosion and leaching of mining materials, which increases ionic constituents (Mg^{2+}, Ca^{2+}, Na^{+}, Cl^{-}) that contribute to both TDS and conductivity. The distribution of TDS mirrored conductivity patterns, confirming their interdependence as water quality indicators.

Characteristics of Turbidity and Total Suspended Solid

Turbidity levels in nickel mine water were generally higher in the wet season (66–115,200 NTU) than in the dry season (8.8–110,200 NTU) (Fig. 3A). This increase can be attributed to greater surface runoff, which intensifies soil and rock erosion, carrying more suspended particles into the water. The high levels of particles carried in this mine water then result in an increase in turbidity in mine water from mining activities, processing plants, and screening stations. Additionally, wet soil clinging to heavy equipment during the rainy season contributed to higher turbidity in water from equipment washing and maintenance activities.

TSS measurements using the gravimetric method (Fig. 3B) also indicated higher concentrations in the rainy season (6–136,964 mg/L) compared to the dry season (9–123,388 mg/L). This trend follows turbidity levels, as both are influenced by increased erosion and suspended particle transport. TSS quantifies the concentration

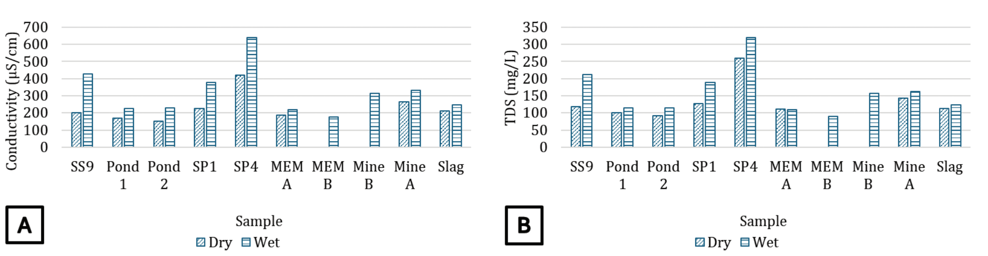

Figure 2 *Comparison of conductivity (A) and TDS (B) in each sample.*

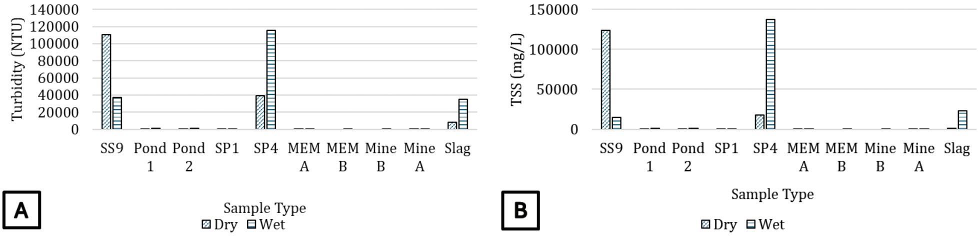

Figure 3 Comparison of turbidity (A) and TSS (B) in each sample.

of suspended solids in water, while turbidity measures light scattering by these particles. Their interdependence causes these two parameters to have the same tendency and positive correlation.

Particle Size and Zeta Potential

The results of the zeta potential and particle size measurements on nickel mining water samples show clear variations between the dry and rainy seasons, as well as between different sampling locations. During the dry season, the particle sizes are generally larger, ranging from 246.98 nm to 7,532.65 nm, with larger average sizes observed in Pond 2 and Slag Dump Pond. In contrast, during the wet season, the particle sizes tend to be smaller, with some samples, such as MEM A and Mine B Pond, showing particle sizes below 1000 nm, indicating colloidal behaviour. The zeta potential in all samples falls within a relatively high range, but not far from zero, indicating that the repulsive forces between particles are not very strong, causing the particles to aggregate and settle more easily. Larger particles (>1000 nm) tend to settle more easily, while colloidal particles require additional treatment, such as the addition of coagulants, to accelerate settling. This analysis shows that particle size and zeta potential influence mining water management processes, especially in settling strategies and further treatment. The particle size and zeta potential of each sample can be seen in the (Tab. 2).

Characteristics of Total and Dissolved Metals

Screening stations (Pond 1, Pond 2, and SS9) generally exhibited the highest levels of Mg, Fe, Ca, Ni, Al, and Cr (Fig. 4 and Fig. 5). During the dry season, Fe (9–2,468.59 mg/L) and Al (0.65–74.67 mg/L) were predominantly suspended, making them treatable via pond sedimentation. In contrast, Mg (19–169.25 mg/L) and Ca (6.36–9.62 mg/L) were mainly dissolved, requiring additional treatment such as coagulation which allow the binding of bind metal particles to form flocs that are easier to settle. During the wet season, metal concentrations were higher for Fe (413.39–5,869.59 mg/L), Mg (61.89–236.53 mg/L), and Al (26.63–168.24 mg/L). Most of these metals remained in suspended form, making sedimentation a viable treatment option.

Mine water from processing plants (SP1 and SP4) during the dry season contained high Fe, Mg, Al, and Ca levels (Fig. 4). Fe and Al metals tend to be suspended with a concentration range of 37.25–909.01 mg/L and 1.85–33.76 mg/L, respectively, allowing for sedimentation treatment. Mg (27.22–78.86 mg/L) and Ca (4.66–12.53 mg/L) were mostly dissolved, indicating the needs of coagulation process. Figure 5 shows that wet season samples exhibited increased metal concentrations for Fe (146.62–1,135.56 mg/L), Mg (69.03–110.14 mg/L), and Al (6.48–78.84 mg/L), with most metals in suspended form, making sedimentation an effective method. Additionally, Ni was detected at a fairly high levels (15.39–39.64 mg/L).

In general, nickel mine water from mobile equipment maintenance (MEM A and MEM B) had high levels of Mg, Ca, and Fe (Fig. 4 and Fig. 5). During the dry season, Fe (3.573 mg/L) was mostly suspended, allowing for sedimentation treatment, while Mg (19.29 mg/L) and Ca (10.75 mg/L) were dissolved, requiring coagulation. The concentrations of the three metals tend to be increase during the wet season, with a range of Fe metal 3.7–

Table 2 *Particle Size and Zeta Potential.*

Sample Type	Season	Particle Size Distribution (nm)	Average Particle Size (nm)	Zeta Potential Range (mV)	Average Zeta Potential (mV)
Pond 1	Dry	837.07 – 1,068,52	924.3	-56.5 – 3.53	-26.4
	Wet	1,068.52 – 6,667.1	2,282.3		
Pond 2	Dry	246.98 – 7,532.65	4,777.7	-43.38 – 1.54	-20.9
	Wet	2,511.05 – 5,901.02	3,576.7		
SS9	Dry	246.98 – 1,541.04	818.4	-90.32 – 53.18	-67.5 / 37.5
	Wet	4,091.63 – 7,532.65	5,433.5		
SP1	Dry	315.27 – 7,532.65	3,197.6	-28.74 – 1.23	-16.2
	Wet	2,837.04 – 6,667.1	3,896.6		
SP4	Dry	580.41 – 7,532.65	3,284.3	-44.4 – 8.42	-14.2
	Wet	402.44 – 7,532.65	3,600.8		
MEM A	Dry	39.58 – 5,901.02	3,458.9	-35.43 – 2.06	-16.1
	Wet	454.69 – 1,068.52	679.3		
MEM B	Dry	–	–	–	–
	Wet	105.1 – 6,667.1	2,870.7		
Mine A	Dry	134.16 – 7,532.65	1,982.3	-38.65 – 1.54	-11.5
	Wet	1.66 – 3,205.35	2,185.2		
Mine B	Dry	–	–	–	–
	Wet	134.16 – 193.48	155.2		
Slag	Dry	5,901.02 – 8,510.56	6,140.1	-44.89 – 3.53	-19.3
	Wet	513.71 – 8,510.56	1,847		

4.99 mg/L, Mg 22.81–23.39 mg/L, and Ca 4.71–7.53 mg/L. A fairly high concentration of Na metal was also found with a range of 5.76–6.54. Most types of Fe and Na metals are suspended metals, so the four metals have the potential to be processed using a simple pond sedimentation method. Meanwhile, Mg and Ca metals tend to be in dissolved form so that additional processing is required.

Nickel mine water from mining activities (Mine A, Mine B, Slag) contains very high concentrations of Fe, Mg, Ca, and Zn during dry season. Fe (0.14–193.18 mg/L) and Zn (0.78–0.23 mg/L) were primarily suspended, making sedimentation a viable treatment option. Meanwhile, Mg (29.42 mg/L) and Ca (3.19 mg/L) were dissolved, requiring coagulation. During the wet season, the concentration of Fe, Mg, and Al increased, with the range of Fe metal 146.62–1135.56 mg/L, Mg 69.03–110.14 mg/L, and Al 6.48–78.84 mg/L. A fairly high concentration of Ni metal was also found with a range of 15.39–39.64 mg/L. Most metals remained in suspended form, making sedimentation effective.

Conclusions

The results of the physical characterization analysis showed that the nickel mine water studied in the dry season had a pH range of 6.8–8.7, temperature 25–27 °C, conductivity 150–418 µs/cm, turbidity 8.8–110,200 NTU, TDS 92–260 mg/L, TSS 9–123,388 mg/L. Meanwhile, in the wet season it had a pH range of 6.8–8.7, temperature 24.5–25.3 °C, conductivity 177–639 µs/cm, turbidity 66–115,200 NTU, TDS 89–319 mg/L, TSS 6–136,964 mg/L mg/L. Analysis of the particle size and zeta potential in nickel mining water samples reveals variations based on season and location. During the dry season, the samples exhibit larger particles and higher zeta potentials. Conversely, in the wet season, smaller, colloidal particles with lower zeta potentials are prevalent, necessitating additional chemical treatments (e.g., using coagulants to destabilize colloids). Dry season water, with inherently more settleable particles, may only require gravity-based separation (e.g., sedimentation ponds), reducing chemical costs. Meanwhile, the results of chemical characterization analysis

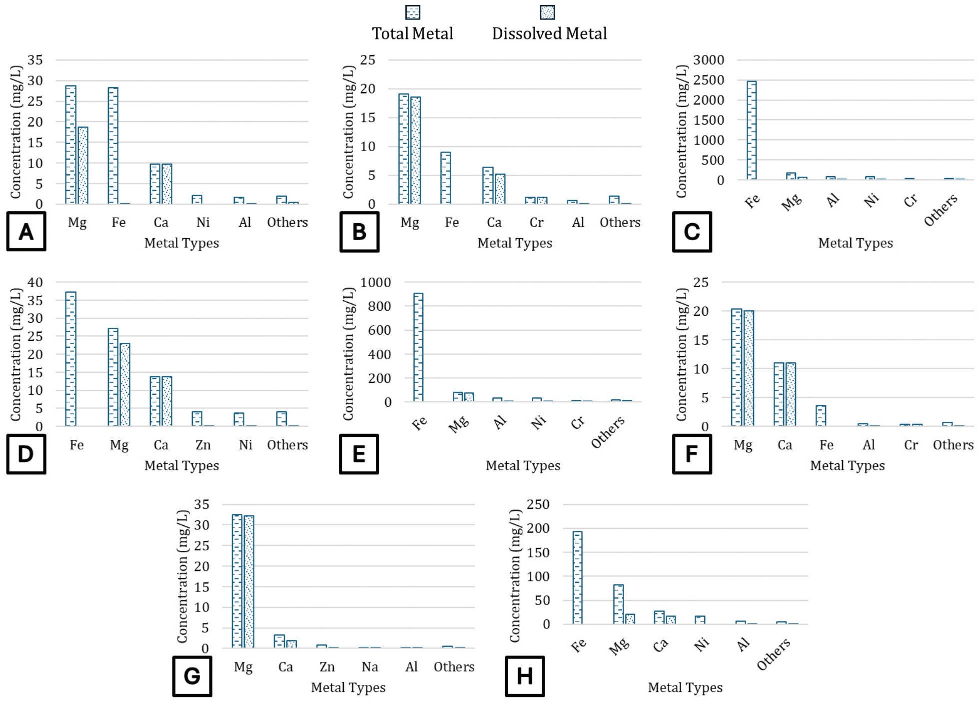

Figure 4 *Characteristics of Total Metals in the Dry Season: Pond 1 (A), Pond 2 (B), SS9 (C), SP1 (D), SP4 (E), MEM A (F), Mine A (G), and Slag (H).*

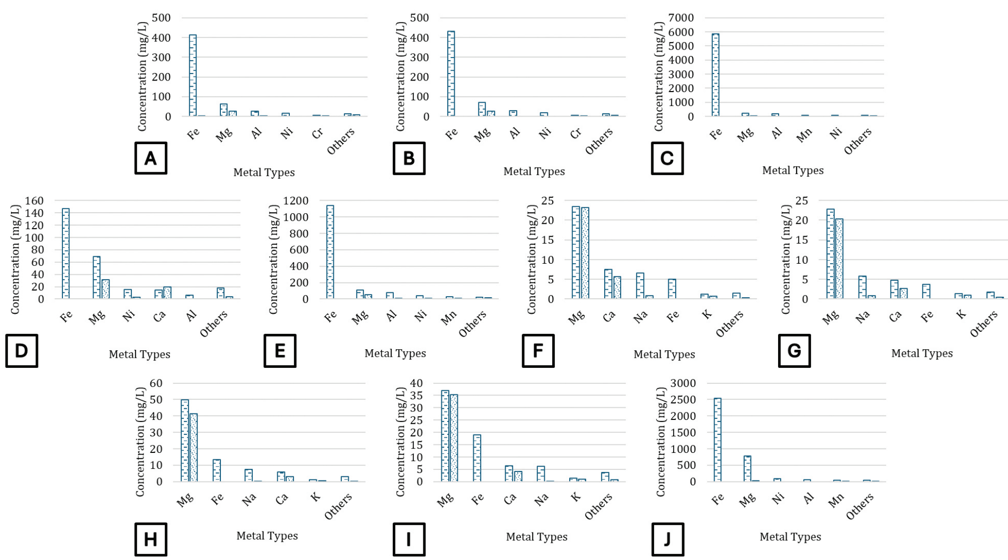

Figure 5 *Characteristics of Total Metals in the Wet Season: Pond 1 (A), Pond 2 (B), SS9 (C), SP1 (D), SP4 (E), MEM A (F), MEM B (G), Mine A (H), Mine B (I), and Slag (J).*

showed that the nickel mine water studied showed high concentrations of Fe, Mg, Ca, and Al metals in mine water from screening station and processing plant activities, Fe, Mg, Ca and Na metals in mine water from mobile equipment maintenance activities, and Fe, Mg, Ca, Zn, Al, and Ni metals in mine water from mining activities.

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