ASTONJADRO

pISSN 2302-4240
eISSN 2655-2086

Volume 15, Issue 4, December 2026, pp.01247-01251
DOI: http://dx.doi.org/10.32832/astonjadro.v15i4.23849 http://ejournal.uika-bogor.ac.id/index.php/ASTONJADRO

Evaluation of Hexavalent Chromium (Cr^{6+}) Content in Nickel Mining Sediment Ponds of Morowali Using Atomic Absorption Spectrophotometry (AAS)

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| Submitted: May 26, 2026 | Revised: June 01, 2026 | Accepted: August 12, 2026 |

| Published: October 26, 2026 |

ABSTRACT

Nickel mining activities in Morowali have the potential to release hexavalent chromium (Cr^{6+}) into aquatic environments through runoff from mining areas into *sediment ponds*. Cr^{6+} is toxic, carcinogenic, and highly soluble in water, posing a serious threat to aquatic ecosystems and public health. This study aims to analyze Cr^{6+} concentrations in sediment pond water, evaluate compliance with the quality standard of Ministry of Environment and Forestry Regulation No. 5 of 2022, and formulate adaptive evidence-based management strategies. A quantitative descriptive approach was used, with water sampling conducted at three sediment pond locations in the Morowali nickel mining area, Central Sulawesi. Cr^{6+} concentrations were analyzed using *Atomic Absorption Spectrophotometry* (AAS) with the APDC-MIBK solvent extraction technique. Supporting parameters including pH, TSS, and Total Chromium were analyzed following applicable SNI standards. Results showed Cr^{6+} concentrations of 0.054 mg/L (54.0% of quality standard) at SedPond 1, 0.038 mg/L (38.0%) at SedPond 2, and 0.071 mg/L (71.0%) at SedPond 3, all below the 0.1 mg/L threshold of PermenLHK No. 5/2022. However, SedPond 3 warrants attention given its safety margin of only 29%. The Cr^{6+}/Total Cr ratio varied: 54.0% (SP-1), 15.2% (SP-2), and 18.7% (SP-3), indicating differences in geochemical conditions and the intensity of $Cr^{3+} \rightarrow Cr^{6+}$ oxidation among sampling locations. A management strategy based on regular monitoring and control of runoff sources is recommended as a priority mitigation measure.

Keywords: hexavalent chromium, sediment pond, nickel mining, atomic absorption, spectrophotometry.

INTRODUCTION

Mining is one of the industrial sectors that plays a significant role in Indonesia's economy, particularly in Central Sulawesi, which is rich in mineral resources such as nickel, gold, chromite, and other minerals. According to the Central Bureau of Statistics (BPS, 2022), the mining and quarrying sector contributed approximately 8.4% to national Gross Domestic Product (GDP). However, behind these economic benefits, mining activities also generate significant environmental impacts, particularly through heavy metal contamination of aquatic ecosystems and sediments.

One heavy metal of serious concern in the mining industry is chromium (Cr). Chromium exists in two main valence states in the environment: trivalent chromium (Cr^{3+}) and hexavalent chromium (Cr^{6+}). Of these, Cr^{6+} is known to be far more hazardous due to its toxic, carcinogenic, and mutagenic properties [1]. According to Sharma & Bhattacharya (2017), Cr^{6+} exhibits high mobility in water and sediments, enabling it to spread and accumulate in the environment, making it a serious threat to human health and aquatic biodiversity [2].

Nickel mining activities in Central Sulawesi have the potential to increase Cr^{6+} concentrations in the surrounding environment. The oxidation of chromium-bearing minerals exposed to air and water

during excavation processes can generate significant amounts of Cr^{6+} [3]. Waste from ore washing and mineral separation processes flows into *sediment ponds* that serve as mine wastewater management units before discharge to receiving water bodies [4]. Although functioning as contaminant barriers, sediment ponds can become accumulation reservoirs for heavy metals, including Cr^{6+}, threatening downstream water quality and aquatic ecosystems as a whole [5].

To accurately detect and quantify Cr^{6+} concentrations, a sensitive and reliable analytical method is required. *Atomic Absorption Spectrophotometry* (AAS) is one of the most widely used analytical techniques for heavy metal determination in various environmental matrices, including sediments, water, and soil. Advantages of AAS include low detection limits, high selectivity, and multi-element analysis capability, making it the primary instrument of choice in environmental heavy metal analysis in laboratories [6]-[7].

Evaluating Cr^{6+} content in nickel mining sediment ponds in Morowali is critically important given the potential ecological and health hazards posed. The quality standard for Cr^{6+} in mining wastewater is set at 0.1 mg/L [8]. This study aims to analyze Cr^{6+} concentrations in sediment pond water using AAS, evaluate regulatory compliance, and formulate adaptive evidence-based management strategies [9].

RESEARCH METHODS

Materials

This study was conducted at the nickel mining area of Morowali Regency, Central Sulawesi. Water sampling was performed on 12 March 2026 at three sediment pond locations with sample codes GLM-6301-19 (SedPond 1/SP-1), GLM-6301-20 (SedPond 2/SP-2), and GLM-6301-21 (SedPond 3/SP-3). SedPond 1 is located on the northern side, SedPond 2 on the eastern side, and SedPond 3 on the southern side of the operational mining area. Samples were collected using HDPE bottles with preservation according to SNI standards and immediately sent to an accredited laboratory for analysis.

Methods

The study employed a quantitative descriptive approach. Cr^{6+} concentration analysis was performed using *Atomic Absorption Spectrophotometry* (AAS) with the APDC-MIBK (ammonium pyrrolidine dithiocarbamate – methyl isobutyl ketone) solvent extraction technique for Cr^{6+} speciation in accordance with SNI 6989.71:2009. Supporting parameters analyzed included pH (SNI 06-6989.11-2004), Total Suspended Solids/TSS (SNI 06-6989.3-2004), Total Chromium (SNI 6989.71:2009), and other heavy metals (Cu, Cd, Zn, Pb, Ni, Fe, and Co). All analytical results were compared against quality standards [8], [10-13].

Data Analysis

Data analysis was performed using simple linear regression to examine the functional relationship between independent variables (pH, TSS, Total Cr) and Cr^{6+} as the dependent variable. The simple linear regression model used is expressed by the equation:

$$\hat{Y} = a + bX \quad \text{..} \quad (1)$$

Where: $\hat{Y}$ = predicted Cr^{6+} concentration (mg/L); a = constant (intercept); b = regression coefficient (slope); X = value of the independent variable. The coefficient of determination (R^2) was used to evaluate the strength of the relationship between variables.

RESULTS AND DISCUSSION

General Overview of Water Quality Testing Results

Water quality testing at the three sediment pond locations was conducted to characterize mine water, particularly regarding Cr^{6+} content as the primary parameter, as well as other supporting parameters. All testing followed relevant Indonesian National Standards (SNI) and results were compared against applicable wastewater quality standards. Complete results are presented in Table 1.

ASTONJADRO

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Table 1. Summary of Wastewater Quality Testing Results at Three Sediment Pond Locations [8]

Parameter	Sediment Pond 1 (GLM-6301-19)	Sediment Pond 2 (GLM-6301-20)	Sediment Pond 3 (GLM-6301-21)	Quality Standard*	Remarks
pH	7.49	7.82	6.75	6 – 9	Compliant
TSS (mg/L)	10	35	58	200	Compliant
Cu (mg/L)	<0.005	<0.005	0.009	2	Compliant
Cd (mg/L)	<0.005	0.012	<0.005	0.05	Compliant
Zn (mg/L)	<0.004	<0.004	0.006	5	Compliant
Pb (mg/L)	<0.005	<0.005	<0.005	0.1	Compliant
Ni (mg/L)	<0.004	0.008	<0.004	0.5	Compliant
Cr^{6+} (mg/L)	**0.054**	**0.038**	**0.071**	**0.1**	**Compliant**
Total Cr (mg/L)	0.10	0.25	0.38	0.5	Compliant
Fe (mg/L)	0.015	0.042	0.087	5	Compliant
Co (mg/L)	<0.004	<0.004	<0.004	0.4	Compliant

pH Analysis and Its Relationship with Cr^{6+}

pH values at the three sediment pond locations ranged from 6.75 to 7.82. SedPond 1 showed a pH of 7.49 (neutral to slightly alkaline), SedPond 2 recorded the highest pH of 7.82, while SedPond 3 had the lowest pH of 6.75, approaching the lower limit of the 6–9 quality standard established by PermenLHK No. 5 of 2022. Water pH significantly influences Cr^{6+} solubility. Under low pH (acidic) conditions, Cr^{6+} mobility and solubility tend to increase, whereas at higher pH, Cr^{6+} tends to precipitate as CrO_4^{2-} adsorbed onto suspended particles.

Linear regression analysis between pH and Cr^{6+} concentration yielded the regression equation:

$$Cr^{6+} = -0.0295 \times pH + 0.2714 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

with a coefficient of determination $R^2 = 0.9604$ and p-value = 0.1275. The R^2 value of 0.9604 indicates that 96.04% of the variation in Cr^{6+} concentration can be explained by pH variation, indicating a very strong relationship between the two variables. The negative regression coefficient (−0.0295) confirms that each unit increase in pH is accompanied by a 0.0295 mg/L decrease in Cr^{6+} concentration. This pattern is consistent with geochemical theory, which states that at low pH, Cr^{6+} species in the form of $HCrO_4^-$ and H_2CrO_4 are more stable and difficult to precipitate [9].

TSS Analysis and Its Relationship with Cr^{6+}

TSS concentrations increased significantly from SedPond 1 to SedPond 3, recording values of 10 mg/L, 35 mg/L, and 58 mg/L respectively. Although all three values remain well below the 200 mg/L quality standard, the consistent increasing trend indicates differences in runoff characteristics and settling effectiveness at each sediment pond. Linear regression analysis between TSS and Cr^{6+} yielded the equation:

$$Cr^{6+} = 0.00034 \times TSS + 0.0427 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3)$$

with $R^2 = 0.2443$ and p-value = 0.6708. The considerably lower R^2 value (24.43%) indicates that the relationship between TSS and Cr^{6+} is not as strong as that between pH and Cr^{6+}. Most Cr bound to TSS particles exists in the form of Cr^{3+} (insoluble), not dissolved Cr^{6+} [10]. This finding confirms that pH is the primary controlling factor of Cr^{6+} mobility in the nickel mining sediment pond system in Morowali.

Distribution and Analysis of Hexavalent Chromium (Cr^{6+})

Cr^{6+} was detected at all three sediment pond locations with a valley-pattern concentration profile, with SP-2 as the lowest point. SP-2 showed the lowest Cr^{6+} (0.038 mg/L), SP-1 was intermediate (0.054 mg/L), and SP-3 recorded the highest value (0.071 mg/L). All three values remain below the national quality standard (0.1 mg/L); however, SP-3 has reached 71.0% of the quality standard with a safety margin of only 29%.

Spatial linear regression analysis between sediment pond sequence number (X) and Cr^{6+} concentration yielded:

$$Cr^{6+} = +0.0085 \times X + 0.0373 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (4)$$

with $r = +0.515$, $R^2 = 0.265$, and $p = 0.655$. The low R^2 (26.5%) indicates that the spatial position of the sediment pond is not a strong predictor of Cr^{6+} concentration. The observed valley pattern (SP-1: 0.054 → SP-2: 0.038 → SP-3: 0.071 mg/L) reflects local controlling factors, particularly differences in pH conditions between ponds. Comparison between the SP number → Cr^{6+} regression model ($R^2 = 0.265$) and the pH → Cr^{6+} model ($R^2 = 0.960$) clearly demonstrates that pH is a far superior predictor in explaining Cr^{6+} variation.

Cr^{6+} to Total Chromium Ratio and Chromium Speciation

The Cr^{6+}/Total Cr ratios at the three locations were: SedPond 1 (0.054/0.10 = 54.0%), SedPond 2 (0.038/0.25 = 15.2%), and SedPond 3 (0.071/0.38 = 18.7%). The relatively high ratio at SedPond 1 (54%) indicates that the majority of chromium at that location exists in the highly hazardous hexavalent form, despite its absolute concentration not being the highest. This pattern is attributed to the lowest TSS at SP-1 (10 mg/L), resulting in the most limited particle adsorption capacity to bind and reduce Cr^{6+} to Cr^{3+} [10]. At SedPond 2 and 3, higher TSS acts as an effective adsorption medium, suppressing the dissolved Cr^{6+} ratio.

Implications for Environmental Health and Regulatory Compliance

Although all three sediment pond locations comply with the Cr^{6+} quality standard (0.1 mg/L), several aspects warrant serious attention. First, a narrow safety margin: SedPond 3 has already reached 71.0% of the quality standard. Under conditions of high rainfall or increased mining activity, Cr^{6+} concentrations could potentially exceed the permitted threshold. Second, stricter international standards: WHO Guidelines for Drinking Water Quality set a total Cr limit of 0.05 mg/L. Third, the carcinogenic nature of Cr^{6+}: IARC classifies Cr^{6+} compounds as Group 1 (proven human carcinogens) [8], such that the concentration of 0.071 mg/L at SedPond 3 must be addressed as a high priority 14]-[15].

Recommended Cr^{6+} Management Strategies

Based on the analytical results, three priority management strategies are recommended: (1) **Intensive monitoring at SedPond 3**: given that Cr^{6+} at SedPond 3 has reached 71% of the quality standard, high-frequency monitoring (at minimum monthly) is required with an early warning system triggered at a threshold of 0.08 mg/L (80% of quality standard); (2) **pH buffering and *sediment pond* optimization**: regression analysis demonstrates that pH is the strongest predictor of Cr^{6+} ($R^2 = 0.96$), therefore the addition of $Ca(OH)_2$ lime and evaluation of hydraulic retention time (HRT) are strongly recommended; (3) Implementation of the SPARING system: in accordance with No. P.93/2018, the immediate installation of electrochemical or optical sensors for real-time online Cr^{6+} monitoring at the SedPond 3 outlet point is highly recommended to fulfill regulatory obligations and demonstrate the company's environmental commitment to stakeholders.

CONCLUSION

Based on water quality testing results at three sediment pond locations in the Morowali nickel mining area, three main conclusions can be drawn. First, Cr^{6+} concentrations were detected above the reporting limit (RL = 0.0098 mg/L) at all sampling points, in the order SP-2 (0.038 mg/L) < SP-1 (0.054 mg/L) < SP-3 (0.071 mg/L), indicating SP-3 as the highest chromium accumulation point due to differences in geochemical conditions among locations. Second, all Cr^{6+} concentrations remain below quality standard (0.1 mg/L); however, SP-3 has reached 71% of the standard with the lowest pH (6.75), which positively correlates with increasing TSS (58 mg/L) and Total Chromium

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(0.38 mg/L), indicating active $Cr^{3+} \rightarrow Cr^{6+}$ oxidation intensity and potential increasing ecological risk. Third, Cr^{6+} management in sediment ponds should be conducted adaptively with three priorities: application of pH buffering and reduction of high-Cr material input rates at SP-3; periodic monitoring of SP-1 and SP-2 at minimum once per quarter using accredited AAS methods; and establishment of an early warning system at a threshold of 0.08 mg/L (80% of quality standard) in accordance with sustainable mining principles and AMDAL/RKL-RPL obligations.

ACKNOWLEDGEMENT

The authors express their deepest gratitude to all parties who contributed to this research, particularly to the two supervisors Prof. Dr. Ir. Erniati, S.T., M.T. and Dr. Eris Nur Dirman, S.T., M.T., as well as the management of the nickel mining company in Morowali for granting permission and facilitating field sampling activities. This study was conducted as part of the Master's Program in Infrastructure and Environmental Engineering, Faculty of Postgraduate Studies, Universitas Fajar Makassar.

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