

# Assessment of Heavy Metal Contamination in Water and Sediment to Support Environmental Monitoring of a Mining-Affected River in Buper Waena, Papua, Indonesia

(Penilaian Kontaminasi Logam Berat pada Air dan Sedimen untuk Mendukung Pemantauan Lingkungan Sungai yang Terdampak Aktivitas Pertambangan di Buper Waena, Papua, Indonesia)

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## ABSTRACT

Artisanal mining activities are recognized as important sources of heavy metal contamination in river ecosystems. This study evaluated cadmium (Cd), lead (Pb), and mercury (Hg) concentrations in water and sediments of Kali Jembatan Dua, Jayapura, Papua, Indonesia, as baseline information for environmental monitoring. Water and sediment samples were collected from three stations representing upstream mining areas and downstream river sections in June 2025. Heavy metal concentrations were analyzed using Inductively Coupled Plasma-Optical Emission Spectrometry (ICP-OES). Concentrations in water ranged from 0.076-0.313 mg/L for Cd, 0.0032-0.0076 mg/L for Pb, and 0.0014-0.0039 mg/L for Hg. Cadmium exceeded the applicable Indonesian water quality standard, whereas Pb and Hg concentrations varied according to the designated water-use classification. Sediment concentrations ranged from 0.347-0.894 mg/kg (Cd), 0.721-2.234 mg/kg (Pb), and 0.0165-0.0277 mg/kg (Hg). Metal concentrations were generally higher at stations near mining activities and lower downstream. Sediments contained higher metal concentrations than the water column, indicating their role as sinks and potential secondary sources of contamination. These findings highlight the need for continuous monitoring and management of mining-affected river systems in Papua.

## Keywords:

Heavy metals; artisanal mining; cadmium; lead; mercury.

## ABSTRAK

Aktivitas pertambangan rakyat merupakan salah satu sumber penting kontaminasi logam berat pada ekosistem sungai. Penelitian ini bertujuan untuk mengevaluasi konsentrasi kadmium (Cd), timbal (Pb), dan merkuri (Hg) pada air dan sedimen di Kali Jembatan Dua, Jayapura, Papua, Indonesia, sebagai data dasar untuk pemantauan lingkungan. Sampel air dan sedimen dikumpulkan dari tiga stasiun yang mewakili area hulu yang terdampak aktivitas pertambangan hingga bagian hilir sungai pada bulan Juni 2025. Konsentrasi logam berat dianalisis menggunakan metode Inductively Coupled Plasma-Optical Emission Spectrometry (ICP-OES). Konsentrasi logam pada air berkisar antara 0,076-0,313 mg/L untuk Cd, 0,0032-0,0076 mg/L untuk Pb, dan 0,0014-0,0039 mg/L untuk Hg. Konsentrasi Cd melebihi baku mutu air yang berlaku di Indonesia, sedangkan interpretasi konsentrasi Pb dan Hg bergantung pada klasifikasi peruntukan badan air. Pada sedimen, konsentrasi Cd berkisar antara 0,347-0,894 mg/kg, Pb 0,721-2,234 mg/kg, dan Hg 0,0165-0,0277 mg/kg. Konsentrasi logam berat umumnya lebih tinggi pada stasiun yang berdekatan dengan area pertambangan dan menurun ke arah hilir. Sedimen mengandung konsentrasi logam yang lebih tinggi dibandingkan air, menunjukkan perannya sebagai tempat akumulasi sekaligus sumber kontaminasi sekunder. Hasil penelitian ini menunjukkan perlunya pemantauan dan pengelolaan berkelanjutan pada sistem sungai yang terdampak aktivitas pertambangan di Papua.

## Kata kunci:

Logam berat; pertambangan rakyat; kadmium; timbal; merkuri.

## Introduction

Heavy metal contamination is a major environmental concern in aquatic ecosystems because of the persistence, toxicity, and bioaccumulative characteristics of these pollutants. Metals such as cadmium (Cd), lead (Pb), and mercury (Hg) are non-biodegradable and can remain in the environment for long periods, accumulating in sediments and aquatic organisms through bioaccumulation and biomagnification processes. Even at relatively low concentrations, these metals may adversely affect aquatic biota, reduce ecosystem health, and pose risks to human populations through the consumption of contaminated water and aquatic resources (Sharma et al., 2025; Edo et al., 2024; Singh et al., 2022).

Among the various anthropogenic sources of heavy metals, artisanal and small-scale mining activities are recognized as important contributors to environmental contamination. These activities are often conducted with limited environmental management and inadequate waste handling practices, resulting in the release of metal-containing materials into nearby rivers and streams. In tropical regions, intense rainfall and surface runoff can further accelerate the transport of contaminants from mining sites to aquatic environments, increasing the spatial extent of pollution (Onyena et al., 2024; Githiria & Onifade, 2020).

Assessment of heavy metal contamination in river systems should include both water and sediment matrices. Water reflects recent contamination inputs and provides information on the immediate exposure of aquatic organisms, whereas sediments serve as long-term sinks for pollutants. Heavy metals adsorbed onto suspended particles tend to accumulate in bottom sediments, where they may persist for extended periods. Changes in environmental conditions such as pH, redox potential, and hydrodynamic disturbances can subsequently remobilize sediment-bound metals into the water column, making sediments a potential secondary source of contamination (Liu et al., 2023; Maqsood & Łobos-Moysa, 2025). Therefore, simultaneous analysis of water and sediments is essential for understanding the distribution and behavior of heavy metals in aquatic ecosystems.

In Indonesia, artisanal mining remains widespread and has been associated with environmental degradation in many regions (Meutia et al., 2022; Schwartz et al., 2021). Papua is one of the regions where community-based mining activities continue to occur, including along river corridors that are closely connected to local settlements and freshwater resources. These activities may increase the risk of heavy metal contamination in river ecosystems, particularly in small urban rivers that receive direct inputs from mining operations and other anthropogenic activities.

Despite the growing concern regarding mining-related pollution in Papua, information on heavy metal contamination in small urban rivers remains limited. Most previous studies have focused on large mining regions, while data on contamination levels, sediment accumulation, and metal distribution in rivers affected by community-scale mining activities in Jayapura are still scarce. This lack of baseline information constrains environmental monitoring and management efforts in the region.

Kali Jembatan Dua, located in the Buper Waena area of Jayapura City, is a small river system influenced by artisanal mining activities and increasing anthropogenic pressures. However, information regarding the occurrence and distribution of heavy metals in this river remains limited. Therefore, this study aimed to (1) determine the concentrations of Cd, Pb, and Hg in water and sediments of Kali Jembatan Dua, (2) evaluate contamination levels based on applicable environmental quality standards, and (3) examine the relationship between heavy metal concentrations in water and sediments. The findings are expected to provide baseline data to support environmental monitoring and management of mining-affected river systems in Papua.

## Methods

### Study Area

This study was conducted in Kali Jembatan Dua, located in the Buper Waena area, Jayapura City, Papua, Indonesia (2°35'23.1"S; 140°37'00.7"E). The river is influenced by artisanal mining activities, urban runoff, and other anthropogenic pressures. Three sampling stations were selected to represent different levels of mining influence along the river continuum. Station 3 was located upstream near the mining area, Station 2 represented the midstream section, and Station 1 was situated downstream. The sampling design was intended to evaluate spatial variations in heavy metal concentrations from the source area toward downstream sections. The location of the sampling stations is presented in [Figure 1](#).



Figure 1. Location of Kali Jembatan Dua, Jayapura, Papua, Indonesia, indicating the sampling site Station (2°35'23.1"S 140°37'00.7"E).

### Sample collection

Water and sediment samples were collected in June 2025 from three sampling stations. At each station, triplicate samples were collected for both water and sediment analyses. Surface water samples were collected approximately 20 cm below the water surface using acid-washed polyethylene bottles (500 mL). Immediately after collection, samples were preserved with concentrated nitric acid (HNO<sub>3</sub>) to pH < 2 and stored in a cooler box at approximately 4°C during transportation to the laboratory. Sediment samples were collected from the upper 0-5 cm layer using a stainless-steel scoop. Samples from each station were placed in clean polyethylene bags, transported to the laboratory, air-dried, and subsequently oven-dried at 105°C to constant weight. Dried sediments were homogenized and sieved prior to chemical analysis.

### Heavy metal analysis and Data Analysis

Concentrations of cadmium (Cd), lead (Pb), and mercury (Hg) in water and sediment samples were determined using Inductively Coupled Plasma-Optical Emission Spectrometry (ICP-OES) at the National Research and Innovation Agency (BRIN), Indonesia. Water samples were analyzed after preservation, whereas sediment samples were subjected to acid digestion using nitric acid prior to analysis. Quality assurance and quality control (QA/QC) procedures included the use of reagent blanks, certified standard solutions, calibration verification, and triplicate measurements. Instrument calibration was performed using multi-element standard solutions, and calibration curves showed coefficients of determination (R<sup>2</sup>) greater than 0.99.

Heavy metal concentrations in water were expressed as mg/L, whereas sediment concentrations were expressed as mg/kg dry weight. Descriptive statistics were used to summarize spatial variations in heavy metal concentrations among sampling stations. Pearson correlation analysis was applied to evaluate relationships between metal concentrations in water and sediments.

Measured concentrations in water were compared with the Indonesian water quality standards stipulated in Government Regulation (PP) No. 22 of 2021. Sediment contamination levels were evaluated using the sediment quality guidelines proposed by IADC/CEDA (1997), with target values of 0.8 mg/kg for Cd, 85 mg/kg for Pb, and 0.3 mg/kg for Hg.

## Result

### Physicochemical characteristics of water

The physicochemical parameters of water in Kali Jembatan Dua are presented in Table 1. Water temperature ranged from 28.7 to 31.5°C, turbidity from 10.3 to 413 NTU, total dissolved solids (TDS) from 0.060 to 0.069 g/L, pH from 6.72 to 7.55, and dissolved oxygen (DO) from 0.045 to 5.45 mg/L. Station 3 exhibited the highest turbidity and the lowest dissolved oxygen concentration among all sampling stations.

Table 1. Physicochemical parameters of water in Kali Jembatan Dua

Station	Parameter				
	Temperature (°C)	Turbidity (NTU)	TDS (g/L)	pH	DO (mg/L)
1	28,7-31,2	12,9	0,062	7,55	4,46-5,45
2	31,1-31,5	10,3	0.060	6,94	4,21-5,21
3	29,9-30,0	413	0,069	6,72	0,045-0,82
Quality	28,0-30,0	<5	0,5-30	7,00-8,50	>5

### Heavy metal concentrations in water and sediments

The concentrations of Cd, Pb, and Hg measured in water and sediment samples are presented in Figures 2-4. In water, Cd concentrations ranged from 0.076 to 0.313 mg/L, Pb from 0.0032 to 0.0076 mg/L, and Hg from 0.0014 to 0.0039 mg/L. The highest Cd and Pb concentrations were recorded at Station 3, whereas Hg showed relatively small spatial variation among stations.

In sediments, Cd concentrations ranged from 0.347 to 0.894 mg/kg, Pb from 0.721 to 2.234 mg/kg, and Hg from 0.0165 to 0.0277 mg/kg. Similar to water samples, the highest Cd and Pb concentrations were generally observed at Station 3. Sediment samples consistently contained higher concentrations of heavy metals than the corresponding water samples.

### Cadmium (Cd) Distribution

Cadmium concentrations in both water and sediments showed a decreasing trend from upstream to downstream stations. The highest concentrations were recorded at Station 3, while the lowest concentrations were observed at Station 1 (Figure 2).

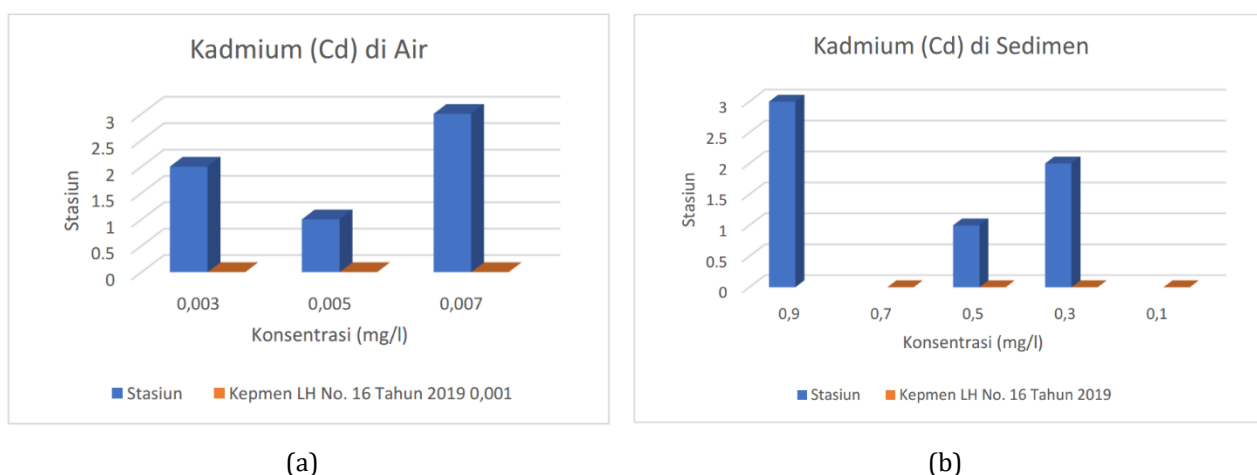


Figure 2. Spatial variation of cadmium (Cd) concentrations in (a) water and (b) sediments of Jembatan Dua River during the study period.

### Lead (Pb) Distribution

Lead concentrations exhibited a spatial pattern similar to that of Cd, with elevated concentrations at the upstream station and lower concentrations toward downstream areas. Sediment concentrations were consistently higher than water concentrations across all stations (Figure 3).

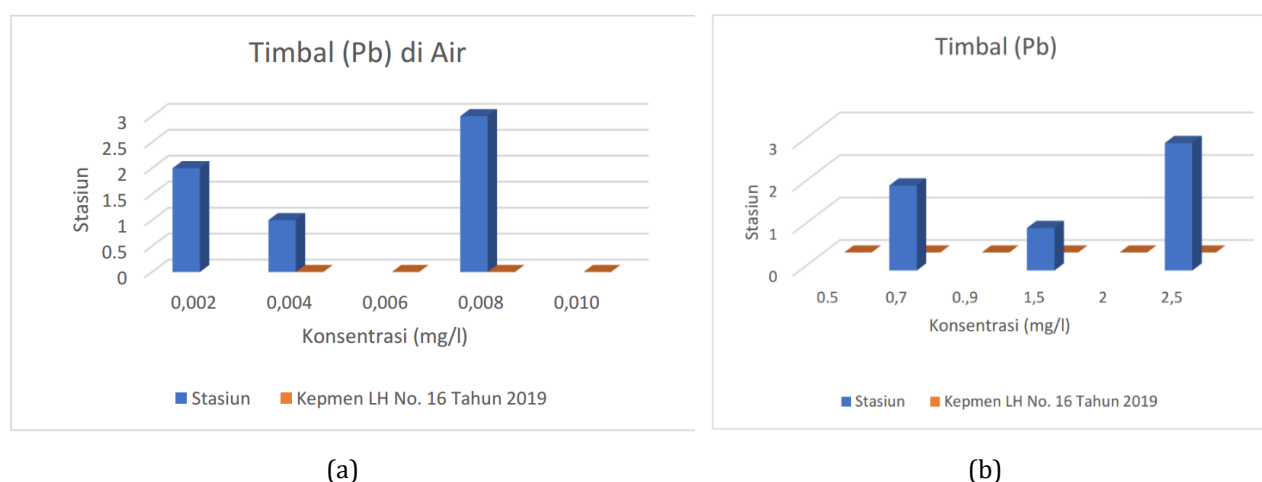


Figure 3. Spatial variation of lead (Pb) concentrations in (a) water and (b) sediments of the Jembatan Dua River during the study period.

### Mercury (Hg) Distribution

Mercury concentrations in water ranged from 0.0014 to 0.0039 mg/L and showed less pronounced spatial variation than Cd and Pb. Sediment Hg concentrations ranged from 0.0165 to 0.0277 mg/kg and were relatively uniform among sampling stations (Figure 4).

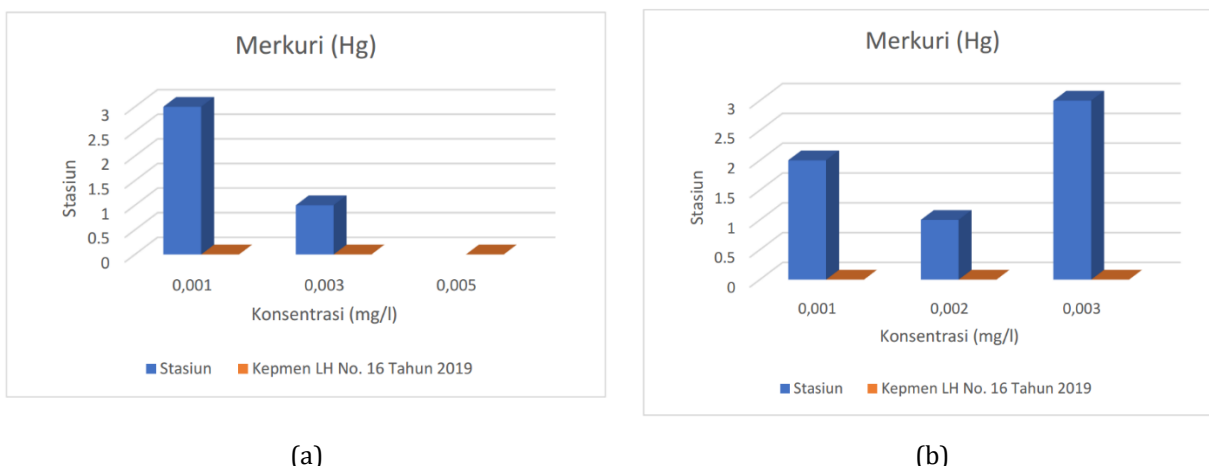


Figure 4. Spatial variation of mercury (Hg) concentrations in (a) water and (b) sediments of the Jembatan Dua River during the study period.

### Relationship Between Water and Sediment Concentrations

Pearson correlation analysis indicated different relationships among metals between water and sediment matrices. Pb showed a strong positive correlation ( $r = 0.729$ ), whereas Cd ( $r = 0.311$ ) and Hg ( $r = 0.201$ ) exhibited weak positive correlations.

## Discussion

### Influence of Artisanal Mining on Heavy Metal Distribution

The spatial distribution of heavy metals observed in Kali Jembatan Dua indicates the influence of artisanal mining activities on river environmental quality. The highest concentrations of Cd and Pb were recorded at Station 3, located closest to the mining area, and decreased toward downstream stations. This pattern suggests that mining activities represent a major source of heavy metal inputs to the river system. Similar trends have been reported in other mining-affected rivers, where elevated concentrations of heavy metals occur near mining sites and gradually decrease downstream due to dilution, sedimentation, and dispersion processes (Wei et al., 2022; Wichman et al., 2024).

### Role of Sediments in Heavy Metal Accumulation

Sediment samples contained higher concentrations of Cd, Pb, and Hg than the water column, confirming the role of sediments as important sinks for heavy metal contaminants. Heavy metals transported by suspended particles tend to accumulate in bottom sediments through adsorption and deposition processes. Once deposited, these metals may persist for long periods and can be remobilized under changing environmental conditions, including fluctuations in pH, redox conditions, and flow dynamics (Liu et al., 2023; Maqsood & Łobos-Moysa, 2025).

### Cadmium as the Most Critical Contaminant

Among the analyzed metals, Cd showed the greatest exceedance relative to the applicable water quality standard. Elevated Cd concentrations are commonly associated with mining activities because cadmium frequently occurs as an impurity in mineral ores. The decreasing Cd concentration from upstream to downstream sections suggests dilution and sedimentation processes; however, the observed levels still indicate potential ecological concerns because cadmium is highly toxic and can bioaccumulate in aquatic organisms (Oros, 2025).

### Water-Sediment Relationships

The strong positive correlation observed for Pb ( $r = 0.729$ ) indicates a close relationship between Pb concentrations in water and sediments. This finding suggests active exchange processes between these environmental compartments and highlights the importance of sediments as both repositories and potential secondary sources of Pb contamination. In contrast, weaker correlations for Cd and Hg indicate that their distributions may be influenced by additional environmental factors such as hydrological variability, particle characteristics, and geochemical conditions (Miranda et al., 2022).

### Environmental Implications

The occurrence of Cd, Pb, and Hg in both water and sediments demonstrates the presence of heavy metal contamination in Kali Jembatan Dua. Although Pb and Hg concentrations require interpretation according to the designated water-use classification, the elevated Cd concentrations and the accumulation of metals in sediments indicate potential ecological risks. Continuous environmental monitoring is therefore necessary to evaluate long-

term trends and support management strategies aimed at reducing contaminant inputs from artisanal mining activities in Papua.

## Conclusions

This study confirmed the presence of cadmium (Cd), lead (Pb), and mercury (Hg) in both water and sediments of Kali Jembatan Dua, Jayapura, Papua. Among the analyzed metals, Cd was identified as the most critical contaminant because its concentration exceeded the applicable Indonesian water quality standard. Heavy metal concentrations were generally higher at the upstream station located near artisanal mining activities and decreased toward downstream areas, indicating the influence of mining-related inputs on river water quality. Sediments consistently contained higher metal concentrations than the water column, highlighting their role as long-term sinks and potential secondary sources of contamination. The strong correlation between Pb concentrations in water and sediments suggests active interactions between these environmental compartments. Overall, the findings provide baseline information for environmental monitoring and support the implementation of regular assessments and management strategies for mining-affected river systems in Papua.

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## Conflict of Interest

The authors declare that they have no competing interests that could have influenced the work reported in this study.

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