Distribution of Metals in River Sediment from Open-Pit Coal Mine Activity

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Abstract

As a country rich in coal reserves and resources, Indonesia faces a potential problem of metal compounds polluting its river. Unfortunately, the quality standards for metals in Indonesia are only available in water, not sediment. This study aims to determine the distribution of metal contamination (Fe, Mn, Pb, Cr, Ni) in Lati River sediments, East Kalimantan Province, as drainage effluent from the mine wastewater treatment systems using ICP-MS. The highest to the lowest metal concentration is Fe>Mn>Cr>Pb>Ni and the highest accumulation of metals was found in streams that become drainage from the active mine wastewater treatment system.

Keywords: Metals, Acid Mine Drainage, Sediment

Introduction

Indonesia is a tropical country known for its rich resources, such as coal. Indonesian coal reserves reach 38.84 billion tons, with an annual average coal production of 600 million tons. Kalimantan island of Indonesia has the most significant potential, storing 62.1% of the country's total coal reserves and resources. The high potential of coal reserves supports demand, market forces, and politics that increases coal mining activities (ESDM 2021). Coal mining activities can cause acid mine drainage (AMD) due to the oxidation of sulfide minerals in open land, characterized by a pH lower than 3 and various concentrations of metals (Younger *et al*. 2012; Abfertiawan *et al*. 2013). Mine wastewater can cause metal pollution in aquatic ecosystems when not appropriately treated. The contamination of river sediments can also cause metal pollution in the waters. Sediment plays a vital role in the movement and accumulation of metals that can potentially cause toxicity to biota. The quality standards of metals in Indonesia are only available in water, define and monitored by government regulation No. 22/2021. Whereas, sediments have not been determined in Indonesia, even though metal compounds accumulate more in sediments than in water (Nasir *et al*. 2021).

One of the largest coal site mining in Kalimantan has the potential to form acid mine drainage (AMD) (Gunawan *et al*. 2014). AMD stored in the pit is channeled to the treatment and management system mine water treatment plant (MWTP). A previous study (Abfertiawan *et al*. 2016) showed that the Lati River, used as drainage from mining wastewater treatment effluents, is impacted by AMD and showed increased metal levels and acidic water.

This study aims to determine the distribution of metal contamination (Fe, Mn, Pb, Cr, Ni) in Lati River sediments, East Kalimantan Province, as drainage effluent from the mine wastewater treatment systems. The results of this study can hopefully provide historical information on the concentration of metal in Lati River sediments, and therefore better management scenarios can be formulated to fulfill the environmental standards.

Methods

Study Area

The study area is Lati River, Berau Regency, East Kalimantan Province, which is the effluent drainage from the mining wastewater treatment system. The sampling area is divided into 15 sampling points along 15.4 km. Sediment sampling locations are based on the 10 effluent of mine water treatment plant (MWTP) location as a mine wastewater treatment system. The study area map and illustration of the sampling point shows in Figure 1. Sediment samples were collected from the river in 5-10 cm depth using Ekman grab sampler with capacity around 250 gr (composite from left, middle, and right sides of the river) for each sampling point. All samples were stored in a cooler box at 4° during transportation from the field to the laboratory. The wet sediment samples were dried using oven until the weight was constant. The dry samples were pulverized and sieved using number 250 mesh. The measurement of metal concentration was carried out using ICP-MS under the near-total acid digestion method.

Data Analysis

Metal contamination was evaluated by comparing the concentration of metals with existing quality standards. Currently, there are no quality standards for sediment available in Indonesia. Therefore, a sediment quality guideline approach refers to the *Ontario Ministry of Environment and Energy* on *Sediment Quality Guidelines* (SQGs) (Hayton, 1993). The spatial distribution pattern of metal concentration in Lati river sediments was described by the Inverse Distance Weighted (IDW) spatial analysis tool in ArcGIS. The geo-accumulation index, Contamination Factor (CF), and Pollution Load Index (PLI) are applied to evaluate metal contamination in sediment. The background value (BKG) of metal concentration in this

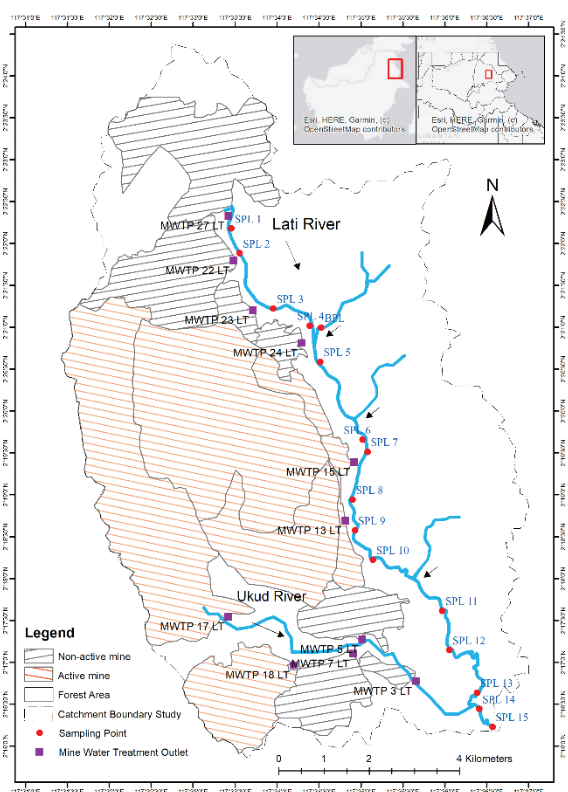

Figure 1 Map of the study area

study was based on areas with geological similarities, which the composition of heavy metals on freshwater sediments referring to Hákanson (1979).

Result and Discussion

Metal concentration

Five primary metals with the highest concentrations approaching or exceeding the limit background value in the sediment (Hákanson *et al*. 1979) in this study include Fe, Mn, Pb, Cr, and Ni. Concentrations of metals are summarized and compared with the *Sediment Quality Guidelines* (SQGs) based on the long-term toxic effects of contaminant on aquatic organism (Table 1).

The order of the highest metal concentrations in Lati River sediments was Fe > Mn > Cr > Ni > Pb. The result is in line with a study by Dlamini *et al*. (2013), where the order of metals with the highest concentration in acid mine drainage was Fe > Mn > Cr > Ni > Pb > Co > Cd > Cu > Zn.

Spatial distribution of metals in sediments

Concentrations of metals that exceed their background value can potentially act as a contaminating factor in river sediments. The distribution pattern of metal accumulation in river sediments at each sampling point is shown in Figure 2.

Based on the metal distribution in sediments of the Lati River data (Figure 2), SPL 10 (i.e., the effluent from the active mine wastewater treatment system) has the highest metal concentration, especially Mn, Cr, and Ni. An operational coal mine in the middle of the segment has the largest catchment area (1,900 hectares) of other mining sites. The larger mining area with a high Potential Acid Forming (PAF) layer will have more potential to form AMD containing various metals (Maharani *et al*. 2018). Based on the data gathered, the volume of PAF in active mining areas reached 69.76% of the total overburden layer. This partially explains the highest accumulation of metals found in the sediment of the middle river since it serves as the drainage of the mining waste treatment system with a high potential for forming AMD.

Accumulation of sediment bounded by metals can be affected by the transport and deposition of sediment on the riverbed, as well as physicochemical parameters in river water. The decrease in sediment rate can affect sediment deposition capacity in a river flow (Raposa *et al*. 2016; Asadi *et al*. 2021). In SPL 10, the sediment rate decreased (41.57 tons/day), indicating a decrease in suspended particles carried by river flows, as the potential for suspended particles to settle on the sediment surface increased (Sitorus and Susanto 2019).

Table 1 *Metal concentration in Lati River sediment*

	Metal concentration (mg/kg)				
	Fe	Mn	Pb	Cr	Ni
Mean	33,856	1,615	17.11	162.80	56.60
SD	11,466	2,664	2.11	32.63	41.38
Median	32,400	705.50	17.00	161.50	48,.0
Max	65,800	10,000	21,2	241	173.70
Min	21,700	81.5	13.75	114.50	17.05
LEL[1]	20,000	460	31	26	16
SEL[2]	40,000	1100	250	110	75
BKG[3]	40,000	860	20	49	50

[1]LEL = *Lowest Effect Level*
[2]SEL = *Severe Effect Level*
[3]BKG = *Background Value*

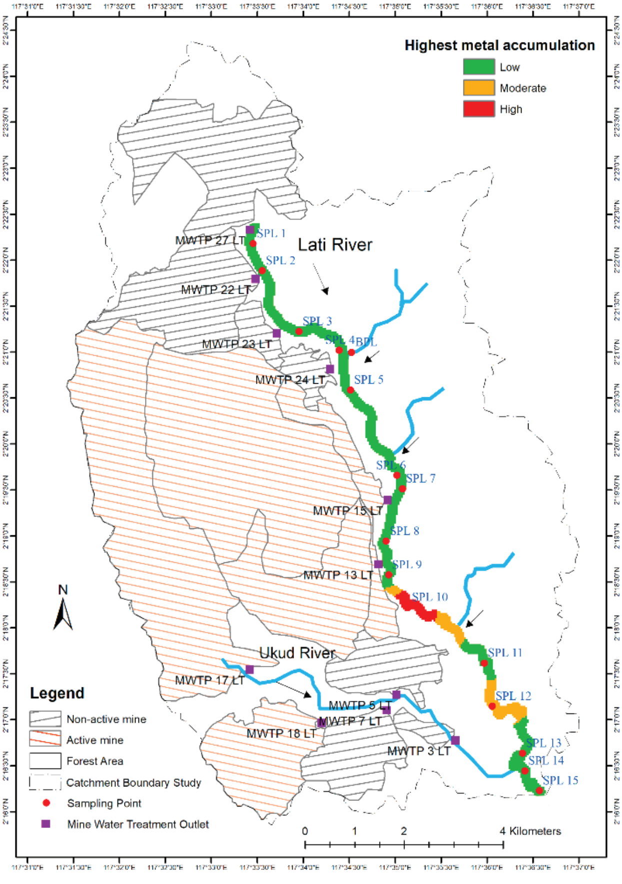

Figure 2 Accumulation of metal contamination in the sediment of Lati River

High velocity can cause more sediment particles carried by river flow (Erwanto and Sugata 2019). Sediment deposition is greater in areas with low gradient slopes or elevations (Wang *et al.* 2016). The velocity in SPL 10 has decreased to 0.4 m/s, with a downward slope gradient of <0.01%. This result is related to the highest accumulation of metals found in sediment at this site, where the sediment rate decreases, and the slope gradient is low so that the sediment carried in the flow decreases and has the potential to settle on the sediment surface. Physico-chemical parameters can also influence metal concentration in sediments of river water. High concentrations of the Total Dissolved Solid (TDS) in river water and a pH below 6 can indicate metal contaminants, e.g., iron, manganese, sulphate, bromide, and arsenic in river water (Alanazi *et al.* 2021).

On the other hand, the upstream segment between SPL 1 to SPL 3, which is the drainage of non-active mine wastewater treatment, showed the highest iron (Fe) concentration of 65,800 mg/kg. According to SQGs, the concentration of metal Fe at SPL 1 to 3 has exceeded the *Severe Effect Level* (SEL). The results of monitoring the outlet of the non-active mine wastewater treatment system show that the Fe concentration of 5.17 mg/L or below the quality standard. However, Fe concentration in the ex-mining pond was still high (11.58 mg/L). The runoff from the catchment area can act as a source of diffuse pollution to the river ecosystem (Debska *et al.* 2022). The catchment area from the non-active mine wastewater treatment in the upstream river was the second largest area (1,153 ha). This condition shows that, although the metal concentration from the mine wastewater treatment outlet (as point sources) is still below quality standard, the high concentration of Fe in the ex-mining pond and runoff water from the non-active mine catchment area can be a diffuse source of Fe in river sediment. The flow rate can affect the high concentration of Fe in the sediment. A decrease in the flow rate indicates that suspended particles carried by the river flow decrease, so the particles settle on the sediment surface (Raposa *et al.* 2016; Asadi *et al.* 2021). SPL 1 to SPL 3 has a low flow rate compared to other sampling points, which ranges from 0.1 to 0.4 m^3/second.

The geoaccumulation index value (Figure 3) shows that the sediment is not contaminated (class 0) by Pb metals. Moderate contamination in sediment (class 1) was demonstrated by several metals, i.e., Fe (SPL 1), Ni (SPL 10 and 12), also Mn and Cr (several sampling points). Several sampling points tend to be highly contaminated (class 3) by Mn metals (SPL 10 and SPL 12). Another study (Wang *et al.* 2021) also showed high sediment contamination by the metal Mn, mainly from industrial waste.

The Contamination Factor (CF) load (Figure 4) differs between metals, i.e., relatively moderate at some sampling points for Fe, Mn, Cr, and Ni; high for Cr and Mn; and low for Pb. These features indicate that the Lati River sediment is high to moderately polluted with Mn and Cr metals.

Mn easily moves and dissolves in water under acidic conditions (low pH values). On the contrary, the movement of this metal in water decreases with increasing pH; thus, the metal‘s potential to precipitate on the sediment surface is higher. This is consistent with the results of water pH measurements in the upstream river segment, which tend to be low (ranging from 3-4), with high concentrations of Mn (1.5–2.7 mg/L) in river water and low in river sediments. Meanwhile, in the middle

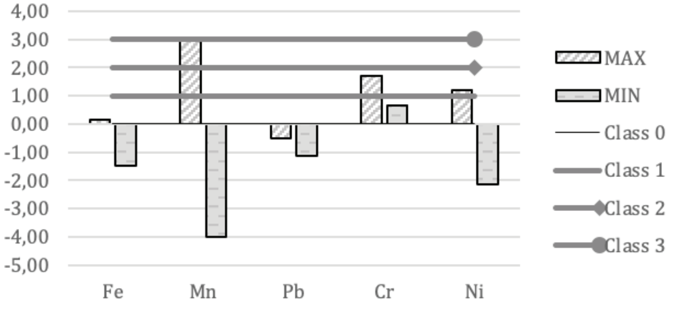

***Figure 3** Geoaccumulation index in Lati River sediment*

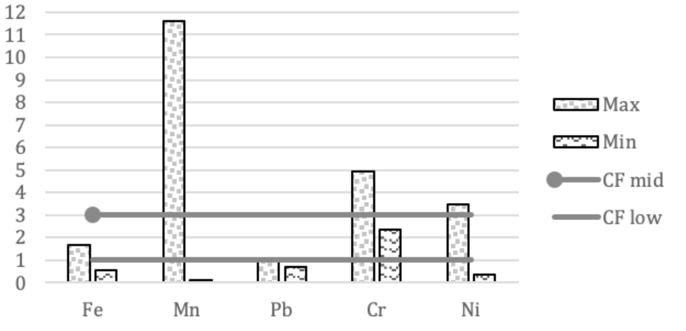

***Figure 4** Contamination factor in Lati River sediment*

part of the river, the pH of the water tends to be high (6.75), with the concentration of Mn in the river water decreasing, reaching 0.01–0.2 mg/L (HEM 2009; Aigberua 2020).

Pollution *Load Index* (PLI) was used to estimate the level of metal pollution load at the research site. PLI values at 15 sampling points showed a value of PLI < 1 (0.72 ± 1.79), indicating a basic pollutant level in the Lati River sediment. Therefore, the metal contamination did not cause a progressive decline in sediment quality. Nevertheless, regular monitoring must be done to assess the accuracy of the metal pollution load index in Lati River sediments.

Conclusions

Open-pit coal mine activity produces AMD, which has the potential to cause metal sedimentation along river sediment. Metal concentration from open-pit coal mining activities in Lati River sediment is Fe > Mn > Cr > Ni > Pb from the highest to the lowest. Based on I-geo, CF, and PLI, the river sediment surface is moderately contaminated by Fe and Ni metals; highly contaminated by Mn and Cr metals. Cr and Mn metals are high contamination factors in sediments. Overall, metal contamination in Lati River sediment has not caused a progressive decline in sediment quality. Fe, Mn, Cr, and Ni are potential metals contaminating the Lati River sediment. The highest accumulation of metals in Lati River sediments is found in streams that become drainage from the active mine wastewater treatment system.

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