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Contamination level of heavy metals and assessment of the ecologic risk in the surface water and sediments of Batanghari river, Dharmasraya region, Indonesia

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ABSTRACT

Heavy metals contamination in river surface water and sediments represents a critical environmental issue on a global scale. The Batanghari river in Dhamasraya region plays a main role in domestic water supply and agricultural activities, necessitating a comprehensive investigation into heavy metal contamination within its water and sediment. The aims of this study were to visualize the overview of the heavy metals concentration present in the Batanghari river and to assess the contamination degree using several ecological assessment tools, such as the enrichment factor (EF), geo-accumulation index (I_{geo}), contamination factor (C_f), contamination degree (CD), ecological risk index (E_r), and potential ecological risk index (RI). The samples of surface water and sediment were obtained from 15 locations along the Batanghari river. The heavy metal analysis in the water samples revealed that the Fe, Zn, and Cd concentrations exceeded the established safety thresholds. The mean concentrations observed in the water in the following descending order was, 1.030 mg/L, 0.380 mg/L, 0.005 mg/L, for Fe, Zn and Cd, respectively, while Cu and Pb concentration were not detected. Meanwhile, the concentrations in the sediment were significantly higher, with the following mean values: 14,422.37 mg/kg for FE, 53.05 mg/kg for Zn, 22.37 mg/kg for Cu, 18.00 mg/kg for Pb, and 0.13 mg/kg for Cd. Furthermore, EF, Igeo, Cf, and Er evaluations, Fe contamination was classified as high, while Pb and Cu showed low to moderate contamination levels, and Zn and Cd were categorized as low. Moreover, the contamination degree and potential ecological risk analyses indicated the highest pollution level were in downstream areas. Although pollution sources such as domestic effluents, road runoff, local mining, and agricultural activities were more prevalent in upstream and midstream regions, the mobilization of heavy metals through river flow led to their accumulation downstream.

Keywords: ecological risk, environmental evaluation, sediment quality, surface water pollution, toxic metals.

INTRODUCTION

The toxic heavy metal pollution of river water and sediments is a significant global concern due to the high toxicity, non-biodegradability, and potential for bioaccumulation in the environment, all of which threaten ecological health (Fadlillah et al., 2023; Hoang et al., 2020; Yu et al., 2021). Unlike many pollutants, heavy metals are not naturally degraded and instead undergo a continuous ecological cycle, primarily within natural water systems (Resongles et al., 2014; Vareda et al., 2019). Once introduced into a river system, heavy metals have the ability to travel across vast distances, settling into bottom sediments. Alterations in the conditions, for instance pH levels and hydrodynamics processes, can trigger the release of these metals into surface water, resulting in secondary contamination (Jia et al., 2021; Luo et al., 2024). Therefore, studying the distribution of heavy metals in river water and sediment is crucial for understanding and managing environmental pollution and ensuring the safety of river systems (Dey et al., 2021; Yu et al., 2021).

Rivers are vital for water conservation, providing drinking water for communities, and supporting diverse ecosystems and agricultural activities (Cosgrove and Loucks, 1969; Liu et al., 2019). Heavy metals in aquatic ecosystems originate from natural sources like soil erosion (Djordjević et al., 2012) and rock weathering (Santos-Francés et al., 2017), along with human activities like mining, agriculture, and industrial operations (Dey et al., 2021). Commonly found heavy metals like lead (Pb), copper (Cu), zinc (Zn), cadmium (Cd), and iron (Fe) contaminate surface sediments due to agricultural practices, metallurgical processes, and waste disposal (Fadlillah et al., 2023; Luo et al., 2024). The rapid expansion of industries poses a substantial risk of toxic heavy metal pollution in riverine environments (Chaparro et al., 2020; Hoang et al., 2020).

In Indonesia, assessment reports from the Ministry of Public Works and Housing indicate concerning levels of heavy metal contamination in rivers and groundwater. Only a fraction of these water sources meets the standards for irrigation and drinking water quality (Rahayu et al., 2014). Batanghari River, the longest river on Sumatra Island, is particularly affected (Gusri et al., 2022). It flows through West Sumatra and Jambi provinces and is part of the Batanghari Watershed, the second largest in Indonesia. Research has identified excessive pollution in the Dharmasraya cluster along the Batanghari River, attributed to intense human activities such as traditional mining, agriculture, and domestic practices (Narsan et al., 2023). However, limited research exists on the spatial distribution of the ranging concentrations of heavy metals distributions and the ecological risks they pose in this region.

Comprehensive monitoring and assessment are essential for a thorough understanding on the state of heavy metals presence in Batanghari River water and sediment. Surface sediment metal concentrations alone cannot discern natural background levels from anthropogenic enrichment (Dey et al., 2021; Fadlillah et al., 2023; Luo et al., 2024). Therefore, methods like Metal EF, Igeo, Cf, Cd, Er, and RI are employed to evaluate contamination levels and potential ecological risks regarding the heavy metals distribution. This study aims to identify the sources of heavy metals in the Dharmasraya cluster of Batanghari River, focusing on traditional mining, agriculture, and residential activities. By applying these indices, the study seeks to assess the exposure and the potential ecological risks posed by lead (Pb), cadmium (Cd), iron (Fe), copper (Cu), and zinc (Zn) in the Dharmasraya cluster of Batanghari River.

MATERIAL AND METHODS

Sampling sites

This study was carried out on the Batanghari River, located in Dharmasraya Regency, West Sumatra Province, Indonesia (Fig. 1). The total length of the study area spans approximately 14.81 km, with geographic coordinates ranging from 101º43’0”,1º 7’0” to 101º46’0”, 1º10’0”. The region experiences a tropical climate, with average temperature of 26.7 °C and annual rainfall of 2795.67 mm (2018–2020) (BPS Dharmasraya, n.d.; BPS Provinsi Sumatera Barat, n.d.). The samples of water and sediment were collected from fifteen sampling sites along the Batanghari River in Dharmasraya Regency. Sampling locations were strategically chosen based on land use patterns, agricultural practices, and anthropogenic activities, particularly those involving heavy metal contamination, such as traditional mining exploration and residential zones. These selections were intended to capture representative concentrations of heavy metals across various land use types.

Samples collection and heavy metal analysis

Sampling of river water and sediment samples were carried out at the 15 sites (Figure 1), during the dry season in November 2023. The sites were chosen based on the land use areas. Water samples were collected in three different dept of river for each site, which resulting in 45 five samples. The average for each site were the presented in the results. Meanwhile, a grab sampler was used for the sediment sampling. The samples were obtained at a depth range of 0–5 cm. During the transfer from the location to the laboratory for analysis, sediment samples were placed in plastic bags while water samples in dark bottles with black covered and acidified with nitric acid (HNO_3). All samples were kept in an isolated icebox during the delivery to the laboratory analysis within 24 hours (Fadlillah et al., 2023). Filter paper (Whatman 42) was used to filter the

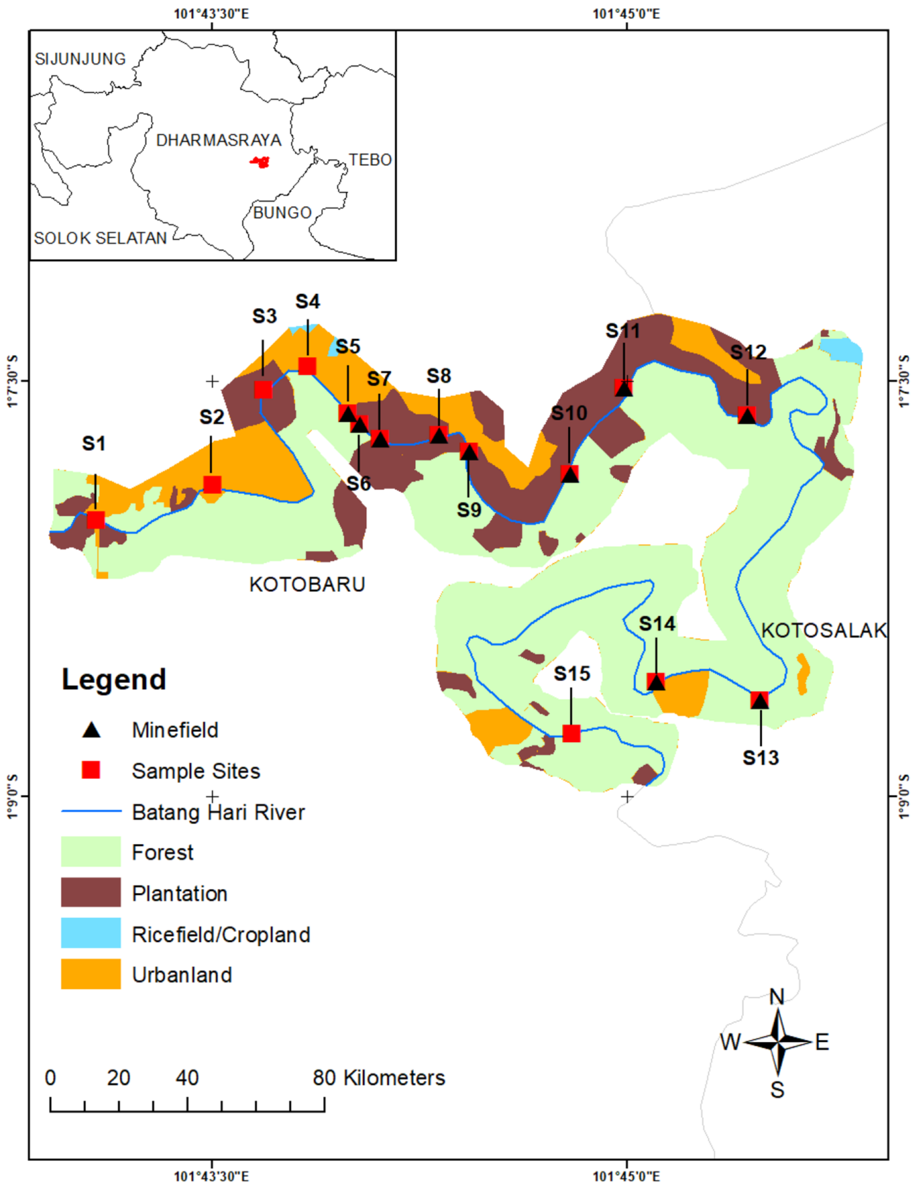

Figure 1. Study sites

water samples prior to the analysis of Pb, Cd, Fe, Al, Cu, and Zn as the targeted heavy metals, using an atomic absorption spectrophotometer (AAS) (Shimadzu AAS-7000).

Sediment samples were under went digestion before the heavy metals measurement. 0.3 g of dried samples of each site were digested after being air-dried for four weeks at room temperature (28 °C) in the laboratory. The digestion used 25 ml of nitric acid (HNO_3). The mix of the acid and sediment sample was heated at 100 °C for 10–15 until the samples were thoroughly diluted and the solution is totally clear (Fadlillah et al., 2023). The solution was cooled into room temperature before the addition of 10 mL of HNO_3, and afterward were filtered through filter paper (Whatman 42). The final solution was diluted into a volume of 50 mL with distilled water prior to AAS analysis.

Quality control measures were employed during the AAS analysis to ensure accuracy, including the use of calibration curves derived from the dilution of a 1000 mg/L stock solution with bidestillation water and the use of blank samples. Nitric acid (HNO_3) sulfuric acid (H_2SO_4), and heavy metal stock solutions ($Pb(NO_3)_2$, $Cd(NO_3)_2$, $FeNO_3$, $Al(NO_3)_3$, $Cu(NO_3)_2$, and Zn $(NO_3)_2$) were purchased from a certified local supplier (MERCK) in Indonesia. Data analysis followed the operational procedures of the national standard laboratory (SNI 8995:2021), in accordance with ISO 17025:2017 standards.

Assessment of the heavy metals pollution

The evaluation of pollution level was based on the concentrations in the surface water and was conducted by evaluating the concentration of the targeted heavy metals using the 2024 drinking water guideline of the World Health Organization (WHO) for standard value of heavy metals in the water and water quality standard (WQS) of Indonesian Government Regulation number 22 of year 2021 for the standard I and II. The Standard of Class I is referred for guidelines of the drinking water and domestic uses, while the Class II is standard for the water quality criteria for aquaculture, recreation, and agricultural activities (PP Nomor 22 Tahun 2021, 2021). Furthermore, EF, I_{geo}, CF, E_r were also defined for assessing the each of the targeted heavy metal concentration in all the sediment samples, while CD, and potential ecological RI were assessed to define the cause of the pollution in every sites.

Enrichment factor (EF)

The EFs were calculated to assess the trend of heavy metals concentration present in the sediment and its relation to the anthropogenic activities in the surrounding. EF is the ratio of the targeted element concentration in the sample to the background concentration of the same element. The EF is expressed in Equation 1 as follows:

$$EF = \frac{\left(\frac{C_i}{C_{ref}}\right) sampel}{\left(\frac{C_i}{C_{ref}}\right) background} \quad (1)$$

where: the concentration of element "*i*" in the samples is C_i, and the concentration of reference elements in samples is represented by C_{ref}. The EF value is classified in five classed as described in Fadlillah et al., (2023).

Geo-accumulation index (I_{geo})

Background samples were taken into account to illustrate the abundance of the element in the environment. In the EF calculation, the background value is determined though the comparison of the metal concentration, to the background concentration of the samples. Due to the limitation on the detailed information of the background concentration of targeted heavy metals in the Batanghari river, therefore the background samples used in this study for Fe, Cd, Zn, Pb, and Cu were 1501.22 mg/kg, 1.24 mg/kg, 90 mg/kg, 9.01 mg/kg, and 14.01 mg/kg, respectively (Fadlillah et al., 2023; Turekian and Wedepohl, 1961). These values were also used for calculation of pollution index parameters, In the calculation of I_{geo}, the background samples values were used to calculate the pollution index parameter, and the values is similar with the valused used in EF calculation. To evaluate the toxicity level of the heavy metals in the samples, I_{geo} was calculated through the formula as shown in Equation 2, based on the current concentration of heavy metals and the background level.

$$I_{geo} = Log\, 2 \frac{(Ci)}{1.5\,(Bi)} \quad (2)$$

where: Bi is the reference level of each targetted heavy metal originally presents in nature. 1.5 was a factor value that represented background correction in the equation, due to lithogenic variation and anthropogenic impact. There are 7 classes of the geo-accumulation index which are ranged from unpolluted to extremely polluted, as detailed was described in the study of Fadlillah et al. (2023).

Contamination factor (C_f)

C_f is a key parameter of the degree of pollution caused by specific pollutants in the soil or sediment. It measures the ratio between the concentration of the specific pollutant in the sample and its natural background concentration, making it a valuable tool for tracking pollution trends over time. The formula in Equation 3 is calculated for Cf determination (Mavakala et al., 2022).

$$C_f = \frac{C_i}{B_i} \quad (3)$$

The contamination classes based on C_f value, are defined in four classes which are low contamination, moderate contamination, considerable contamination, and very high contamination. The detailed range was mentioned by Hakanson (1980).

Contamination degree (Cd)

The Cd provides an overall assessment of polymetallic contamination at each sampling point. It represents the cumulative contamination level by summing the contamination factors (C_f)

of individual heavy metals or other specified pollutants. The formula for calculating Cd is as follows (Mavakala et al., 2022):

$$Cd = \sum CF_i \tag{4}$$

where: *i* is the count of the heavy metal species. In this study, the value of m is equal to 5. *Cd* is also classified into four classes of contamination level with different classification and detailed range for each class. The classifications of *Cd* are low, moderate, high, and very high contamination. (Hakanson, 1980).

Ecological risk factor (Er)

The Er evaluates the potential harmful effects of the specific contaminant in sediments on the surrounding environment and human health. It represents the toxicity level and ecological sensitivity of a contaminant based on its concentration and background levels. The equation to calculate the Er factor for a single metal is as follows (Mavakala et al., 2022):

$$E_r^i = T_r^i C_f^i \tag{5}$$

where: T_r is toxic factors of single element in period of pre-industrial. Specific T_r for Cd, Fe, and Zn are 30, 6, and 1, respectively. Meanwhile T_r for Cu and Pb are the same which is 5.

The potential ecological risk (RI)

The potential ecological RI was determined to evaluate the overall contamination at each site in this study. RI values were determined by integrating the E_r values. The RI value is derived from the sum of the single ecological risk factors (Er) of each heavy metal in each sampling site and represents the potential risks posed by heavy metal contamination and the sensitivity of biological communities in particular sampling point. The formula for RI calculation was shown through Equations 6:

$$RI = \sum E_{ri} \tag{6}$$

where: *i* is the count of the heavy metal species. In this study, the value of m is equal to 5. *RI* terminology is divided into low ecological risk or ecological pollution level (RI < 150), moderate ecological pollution level or ecological risk for 150 ≤ RI < 300, considerable ecological risk or severe ecological pollution level when *Ri* was in a range of 300 ≤ RI < 600, and very high ecological risk or serious ecological pollution level when the value is higher than 600 (Hakanson, 1980).

Data analysis

Several tools were used for data analysis in this study, for instance, Origin 2022. The uncertainty in source identification was considered when identifying potential sources of heavy metals in the study area of the Batanghari river, to minimize uncertainties during the descriptive analysis of contamination source. Additionally, the mapping of heavy metals (Pb, Fe, Cd, Cu, and Zn) distribution in the river was illustrated by using spatial distribution and inverse distance weighted (IDW) interpolation, which assumes that the values can represent the nearest sampling points and help identify potential contamination sources.

RESULTS AND DISCUSSION

Heavy metal presence in the river water

Table 1 summarized the concentration of specific heavy metals in water samples across fifteen sites. The presented number was the average concentration from three depths at each site. From the presented results in the Table, the concentrations of Fe was in a range of 0.93–1.16 mg/L, while the concentration of Cd was 0.003–0.007 mg/L, and for Zn was 0.00–0.177 mg/L. Notably, the present of Pb and Cu were not detected in any surface water samples.

Based on the Indonesian Government Regulation No. 82 of 2001, revised by Regulation No. 22 of 2021 (PP Nomor 22 Tahun 2021, 2021), concerning environmental management, the Batanghari river water in the focused study area complied only with the water quality standard (WQS) for Class IV, which permits its use for irrigation. However, the water quality did not meet the requirements for Class I, which is designated for drinking water purposes. Specifically, the concentrations of Fe and Zn in the surface water significantly exceed the Class I thresholds of 0.03 mg/L and 0.05 mg/L, respectively.

Meanwhile, the evaluation based on the WHO guidelines (WHO, 2024) for drinking water, the concentrations of Fe and Zn were below the permit limits, with 2 mg/L and 3 mg/L, respectively. Therefore, the surface water in the study area could be considered suitable for drinking purposes under WHO standards. Overall, the evaluation on the river water based on the WHO 2024 guidelines suggest that the concentrations of heavy metals in the Batanghari River at Dharmasraya exceeded the Indonesian WQS thresholds for Classes I, II, and III, which are applicable for drinking water, tourism, and aquaculture, respectively. Further research is required to evaluate the water's suitability for agricultural irrigation.

In comparison to the Batanghari river in Jambi, (Badariah et al., 2023), in the current study were lower. Similarly, when compared to other rivers in Indonesia, including Damsari river, Jabawi river, and Komba river in Jayapura, as reported in the study by Tanjung et al. (2022). The levels of Cd, Pb, and Cu in the Batanghari river were found to be lower, while for Fe and Zn were higher. Furthermore, relative to the Halda river in Bangladesh (Dey et al., 2021), the Pb and Cu concentrations were lower, whereas the concentrations of Fe, Zn, and Cd were higher. The order of the average concentration in this study in ascending form, were Pb < Cu < Cd < Zn < Fe.

Figure 2 illustrated the spatial distribution of heavy metal concentrations in surface water samples collected from fifteen study sites along the Batanghari river in Dharmasraya region, relative

Table 1. The concentration (in mg/L) of Fe, Cd, Zn, Pb and Cu in water samples of Batanghari river, Dhamasraya region

Sites	Coordinate	Land use	Pollution sources	Fe	Cd	Zn	Pb	Cu
S1	101,717869; -1,133367	Plantation area, suburban	Agriculture, road, domestic	1.148	0.005	1.513	ND	ND
S2	101,724841; -1,131339	Plantation area	Agriculture, road, domestic	1.082	0.005	0.012	ND	ND
S3	101,728073; -1,125445	Plantation area	Agriculture, domestic waste disposal	1.048	0.004	ND	ND	ND
S4	101,730798; -1,124177	Plantation area, suburban	Agriculture, road, domestic	0.997	0.005	0.014	ND	ND
S5	101,733191; -1,126918	Plantation area, suburban	Local mining, domestic, agriculture	1.063	0.004	ND	ND	ND
S6	101,733905; -1,127585	Plantation area	Local mining, domestic, agriculture	1.155	0.007	0.018	ND	ND
S7	101,735082; -1,128465	Plantation area	Local mining, domestic, agriculture	1.102	0.004	1.301	ND	ND
S8	101,738687: -1,128215	Plantation area	Local mining, domestic, agriculture	1.035	0.005	0.006	ND	ND
S9	101,740460: -1,129215	Plantation area, suburban town	Local mining, domestic, agriculture	0.956	0.005	1.001	ND	ND
S10	101,746611: -1,130595	Plantation	Local mining, domestic, agriculture	0.983	0.003	1.770	ND	ND
S11	101,757140; -1,127085	Plantation area	Local mining, domestic, agriculture	1.004	0.005	0.003	ND	ND
S12	101,749803: -1,125383	Plantation area	Local mining, domestic, agriculture	0.982	0.005	ND	ND	ND
S13	101,757996; -1,144122	Plantation area, suburban town	Local mining, domestic, agriculture	0.993	0.006	ND	ND	ND
S14	101,751715; -1,142980	Plantation area	Local mining, agriculture	0.924	0.004	0.042	ND	ND
S15	101,746632; -1,146178	Plantation area	Agriculture, vehicle	1.032	0.007	0.025	ND	ND
Mean				1.030	0.005	0.380	ND	ND
WHO Guideline value for drinking water 2024				2	0.003	3	0.01	0.05
Indonesian WQS Class I				0.3	0.01	0.05	0.03	0.02
Indonesian WQS Class II				-	0.01	0.05	0.03	0.02
Indonesian WQS Class III				-	0.01	0.05	0.03	0.02
Indonesian WQS Class IV				-	0.01	2	0.5	0.2

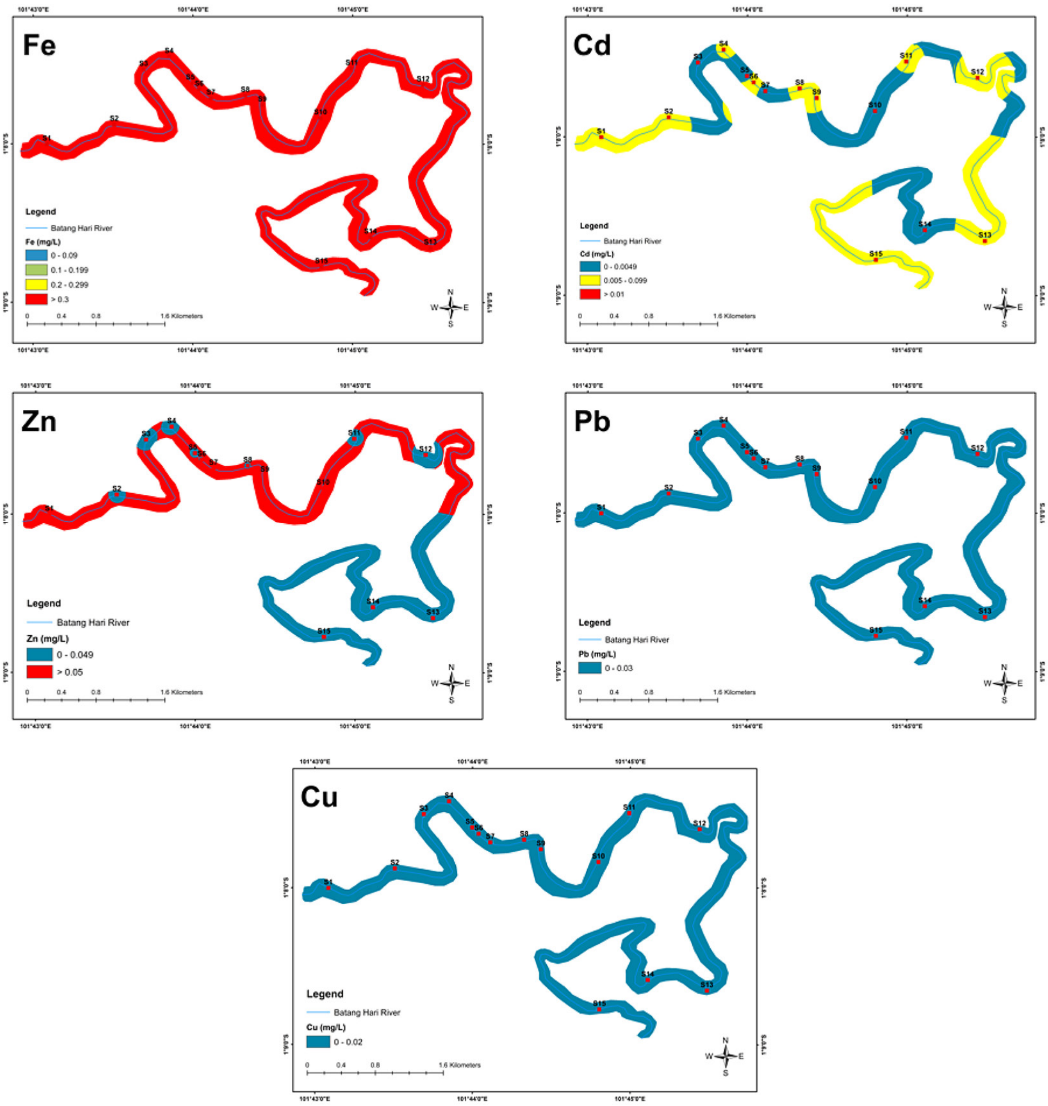

Figure 2. The mapping of heavy metal concentration distribution in the water of Batanghari river, Dharmasraya region

to the Class I of the Indonesian WQS. The figure reveals that only Fe and Zn concentrations exceeded the permissible limits. Specifically, Fe levels surpassed the drinking water standard at all study sites, while Zn was absent at four sites (S3, S5, S12, S13) but exceeded the limit at four other locations (S1, S7, S9, S10). The elevated Fe concentration is likely associated with the yellowish coloration of the surface water (Rusydi et al., 2021) observed at the study sites (Figure 2). Cd concentrations were close to the permissible limit at certain locations (S6, S13, S15). Among the study sites, the total concentration of heavy metals exceeded 2 mg/L at S1, S7, and S10, primarily due to the concentration of Fe and Zn was in high level. Site S1 is located in a densely populated area where Fe and Zn contamination could originate from anthropogenic activities, vehicular emissions, and agricultural effluents from nearby plantations. In contrast, at S7 and S10, where traffic is minimal, local mining activities are likely significant contributors to Fe and Zn concentrations. Although Fe and Zn levels remained below the limits specified by WHO guidelines, their presence in tap water should ideally not exceed 0.5 mg/L for Fe and 0.05 mg/L for Zn, as heavy metals are essential trace elements that occur naturally in food and potable water in the form of salts or organic complexes (WHO, 2024).

The presence of Cd in surface water is likely linked to local mining activities, fertilizers from plantations, and air pollution caused by vehicular emissions (Kubier et al., 2019; WHO, 2024). While Cd concentrations were below the safe limit of the Indonesian WQS Class I, they exceeded the WHO guideline at all study sites. Cd can naturally originate from atmospheric deposition and the Earth's crust, but anthropogenic activities can significantly elevate its concentration in the environment (Kubier et al., 2019; Sirajuddin et al., 2022). The highest Cd level was observed at site S6, where local mining is prevalent, and the surrounding land is primarily used for plantations. Cd is known to be one of the most bioavailable heavy metals, easily flowed in environmental media, such as from soil to water (Kubier et al., 2019).

Heavy metal presence in river sediment

The concentrations of heavy metals in the sediment from fifteen study sites along the Batanghari river were summarized in Table 2. Overall, the concentrations of heavy metals in the sediment showed significant spatial variation across the sampling sites. The observed concentration ranges were as follows: Fe (6.510–26.250 mg/kg), Cd (0–1.267 mg/kg), Zn (0–139 mg/kg), Pb (7.7–30.09 mg/kg), and Cu (15.43–42.32 mg/kg).

Similar to the surface water, Fe concentrations in the sediment were notably high, far exceeding the background concentration of 1,501.22 mg/kg. Based on the mean concentrations, the order of heavy metal content in the sediment was Fe > Zn > Cu > Pb > Cd., with Fe was 14,422.37 mg/kg and Zn was 53.05 mg/kg. The elevated Fe concentration in the Batanghari river sediment can be attributed to its status as a major element, which possibly naturally introduced through weathering processes of lithological materials in the surrounding area (Adamo et al., 2005). This natural input is likely further exacerbated by runoff from anthropogenic activities, including local mining operations and the use of agricultural pesticides (Badariah et al., 2023; Fadlillah et al., 2023; Mavakala et al., 2022).

Table 2. The concentration (in mg/kg dry weight) of Fe, Cd, Zn, Pb and Cu in sediment of Batanghari river, Dhamasraya region

Sites	Coordinate	Land use	Pollution sources	Fe	Cd	Zn	Pb	Cu
S1	101,717869; -1,133367	Plantation area, suburban town	Agriculture, road, domestic	11316.25	0.08	134.53	30.09	42.32
S2	101,724841; -1,131339	Plantation	Agriculture, road, domestic	11698.13	ND	91.00	21.98	26.90
S3	101,728073; -1,125445	Plantation	Agriculture, domestic waste disposal	15970.67	ND	17.65	14.82	19.87
S4	101,730798; -1,124177	Plantation area, suburban town	Agriculture, road, domestic	9557.50	ND	ND	16.04	22.07
S5	101,733191; -1,126918	Plantation area, suburban town	Local mining, domestic, agriculture	13380.00	1.27	88.61	29.19	29.67
S6	101,733905; -1,127585	Plantation	Local mining, domestic, agriculture	13383.33	0.05	3.23	17.77	18.43
S7	101,735082; -1,128465	Plantation	Local mining, domestic, agriculture	9275.56	0.16	24.63	19.63	19.97
S8	101,738687: -1,128215	Plantation	Local mining, domestic, agriculture	11010.00	0.05	40.88	25.57	22.15
S9	101,740460: -1,129215	Plantation area, suburban town	Local mining, domestic, agriculture	13094.17	ND	22.98	13.06	22.69
S10	101,746611: -1,130595	Plantation	Local mining, domestic, agriculture	24033.33	ND	139.00	9.08	17.83
S11	101,757140; -1,127085	Plantation	Local mining, domestic, agriculture	20130.00	0.18	ND	18.02	18.67
S12	101,749803: -1,125383	Plantation	Local mining, domestic, agriculture	15878.33	ND	35.52	7.70	18.68
S13	101,757996; -1,144122	Plantation area, suburban town	Local mining, domestic, agriculture	6510.00	0.15	132.45	10.90	15.43
S14	101,751715; -1,142980	Plantation	Local mining, agriculture	14848.33	ND	38.07	22.70	18.07
S15	101,746632; -1,146178	Plantation	Agriculture, vehicle	26250.00	ND	27.17	13.50	22.87
Mean				14422.37	0.13	53.05	18.00	22.37
SD								
USEPA (Department of Ecology State of Washington, 2013)				9500	6	90	40	25

Cu was the third most abundant heavy metal out of five heavy metals investigated in the sediment samples, with a mean concentration of 22.37 mg/kg, followed by Pb with 18 mg/kg and Cd with 0.13 mg/kg. The levels of Cu and Cd in this study were higher, compared to the concentrations in the sediments along the Batanghari river in Jambi city (Badariah et al., 2023). Similarly, the concentrations of Fe, Pb, Cu, and Cd in the sediments analyzed in this study were also significantly higher than those reported for the Winongo river in Yogyakarta (Fadlillah et al., 2023).

Notably, the findings from this study indicated that the level of the heavy metals present in the sediment samples were substantially higher than those in the surface water. A comparison of the concentrations between the two matrices was presented in Figure 3. While Pb and Cu were below detection limits in the surface water of the Batanghari river, these metals were consistently detected in sediment samples across all study sites. The linear correlation analysis of metal concentrations in water and sediment across the study sites revealed positive correlations for each metal: Fe (0.19), Cd (0.028), Zn (0.012), Pb (0.267), and Cu (0.381). These results suggest the possibility of a leaching process from sediments to surface water, potentially due to the high bioavailability of heavy metals in the sediment matrix (Ali et al., 2019). Unlike surface water quality, sediment quality in the study sites along the Batanghari river in Dharmasraya region was assessed based on the USEPA guidelines (Department of Ecology State of Washington, 2013), to identify polluted areas. The mapping of average concentrations of each heavy metal at the fifteen study sites was spatially distributed and presented in Figure 4. The figure shows that only Cd and Pb concentrations were below the pollution limits set by the USEPA.

Similar to the water samples, Fe concentrations exceeded the guideline values at almost all sites, except at S13. Although the land use at S13 includes plantations, local mining, and suburban activities, the relatively lower scale of these activities might have contributed to the reduced Fe levels compared to other sites.

For Zn and Cu, only a few sites exceeded the guideline values. Zn concentrations were above the limit at S1, S10, and S13, while Cu exceeded the threshold at S1, S2, and S5. From the distribution map, it is evident that S1 exceeded the limits for Fe, Zn, and Cu and recorded the highest Pb concentration among all study sites. Despite the absence of local mining activities at S1, the area is densely populated with domestic activities and features high-traffic roads. Additionally, the land at this site is utilized for plantation activities. The elevated concentrations of Fe and Zn in the sediment could be attributed not only to their roles as essential micronutrients in soil but also to domestic activities,

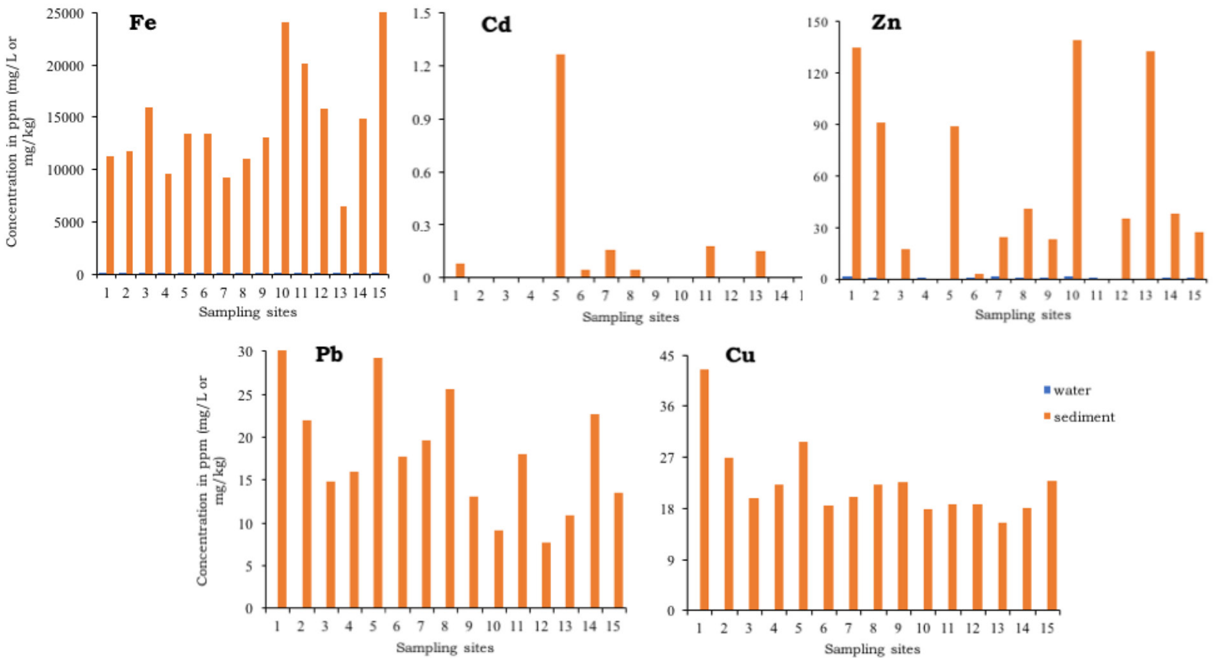

Figure 3. The comparison of heavy metal concentrations (in ppm) in between surface water (mg/L) and sediments (mg/kg) in all study sites of Batanghari river

such as corrosion from pipes. Meanwhile, the high Pb concentrations in the sediment may result from the accumulation of vehicle-related pollution and the use of pesticides in plantation activities (Gu et al., 2022; Sirajuddin et al., 2022).

Pollution assessments in river sediment

The pollution levels of sediment along the Batanghari river based on the specific heavy metals present at all sampling sites were assessed using the EF, Igeo, C_f, and Er, while the assessments based on CD and potential RI were conducted to define the relation of specific land use and each of the study site and the pollution degree. The results of EF and Igeo are presented in Table 3, while the C_f, CD, Er, and RI results were summarized in Table 4 and Figure 5.The EF analysis was utilized to evaluate anthropogenic influences and activities contributing to the concentrations of the specific heavy metals in the sediment (Adamo et al., 2005). EF calculations depend on both the comparison of current concentrations to pre-industrial levels (background concentrations) of the heavy metals and the choice of reference element. Fe was selected as the reference element for geochemical normalization (Badariah et al., 2023). As the data for specific background concentration data for the Batanghari river were not accessible, the following background values (in mg/kg, data from (Fadlillah et al., 2023) and (Joseph et al., 2016)) were used: Fe (1501.22), Cd (1.24), Zn (90), Pb (9.01), and Cu (14.01). As Fe served as the reference element, its EF was not calculated.

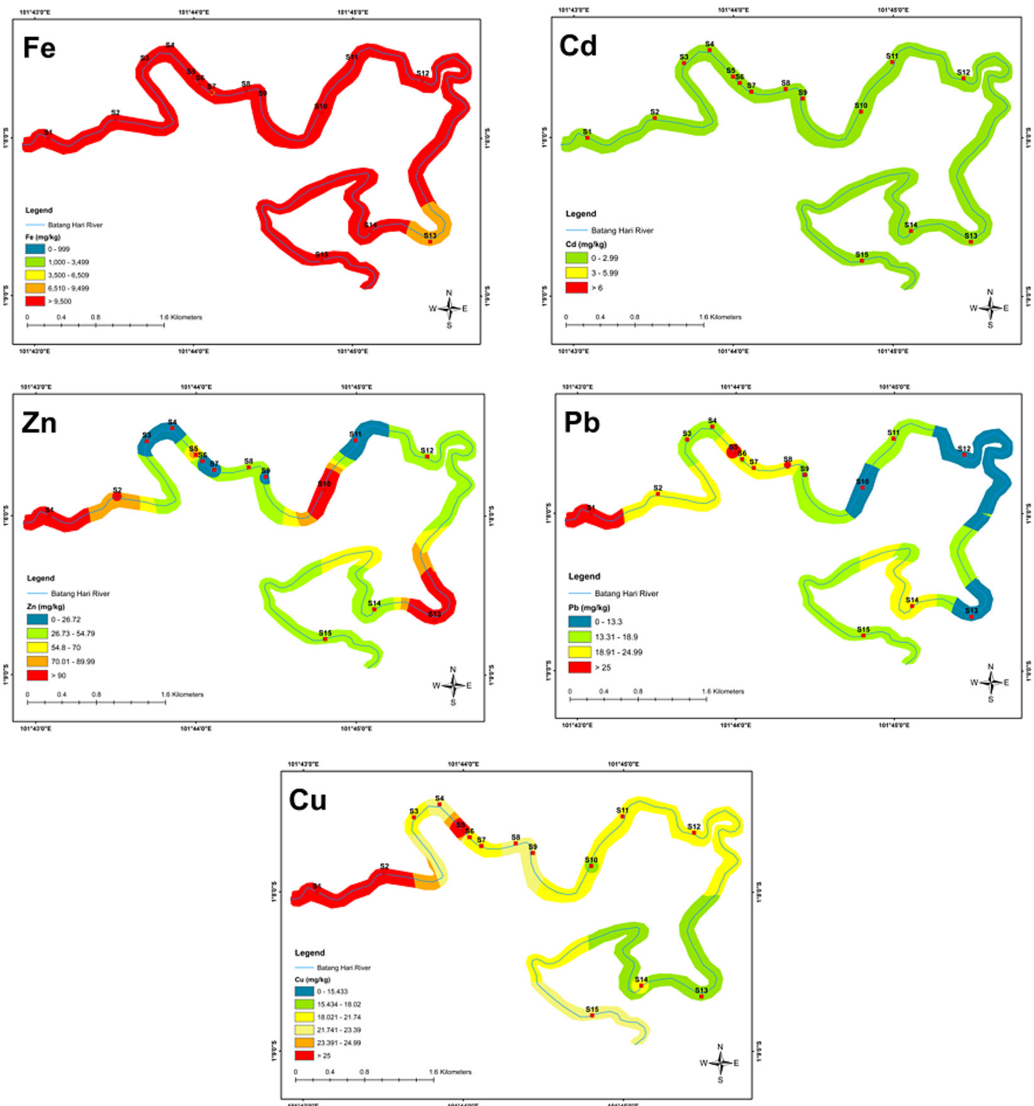

Figure 4. The mapping of the heavy metals concentration distribution in the river sediment of Batanghari river

Table 3. Enrichment factor (EF) and geoaccumulation index (Igeo) assessments in Batanghari river

Sites	Enrichmen factor (EF)					Igeo				
	Fe	Cd	Zn	Pb	Cu	Fe	Cd	Zn	Pb	Cu
S1	-	0.01	0.2	0.44	0.40	2.33	-4.48	-0.01	1.15	1.01
S2	-	-	0.13	0.31	0.25	2.38	-	-0.57	0.70	0.36
S3	-	-	0.02	0.15	0.13	2.83	-	-2.94	0.13	-0.08
S4	-	-	-	0.28	0.25	2.09	-	-	0.25	0.07
S5	-	0.12	0.11	0.36	0.24	2.57	-0.55	-0.61	1.11	0.50
S6	-	0.02	-	0.22	0.15	2.57	-5.22	-5.38	0.39	-0.19
S7	-	0.02	0.04	0.35	0.23	2.04	-3.58	-2.45	0.54	-0.07
S8	-	0.01	0.06	0.39	0.22	2.29	-5.22	-1.72	0.92	0.08
S9	-	-	0.03	0.17	0.19	2.54	-	-2.55	-0.05	0.11
S10	-	-	0.10	0.06	0.08	3.42	-	0.04	-0.57	-0.24
S11	-	0.01	-	0.15	0.10	3.16	-3.34	-	0.41	-0.17
S12	-	-	0.04	0.08	0.13	2.82	-	-1.93	-0.81	-0.17
S13	-	0.03	0.34	0.28	0.25	1.53	-3.63	-0.03	-0.31	-0.45
S14	-	-	0.04	0.25	0.13	2.72	-	-1.83	0.75	-0.22
S15	-	-	0.02	0.09	0.09	3.54	-	-2.31	0.00	0.12

Table 4. The assessment values of contamination factor (Cf), contamination degree (CD), ecological risk (Er) and potential ecological risk index (RI)

Sites	C_f					CD	Er					RI
	Fe	Cd	Zn	Pb	Cu		Fe	Cd	Zn	Pb	Cu	
S1	7.54	0.07	1.49	3.34	3.02	15.46	45.23	2.02	1.49	20.04	15.10	83.88
S2	7.79	-	1.01	2.44	1.92	13.16	46.75	-	1.01	14.64	9.60	72.01
S3	10.64	-	0.20	1.64	1.42	13.90	63.83	-	0.20	9.87	7.09	80.98
S4	6.37	-	-	1.78	1.58	9.72	38.20	-	-	10.68	7.88	56.76
S5	8.91	1.02	0.98	3.24	2.12	16.28	53.48	30.65	0.98	19.44	10.59	115.13
S6	8.91	0.04	0.04	1.97	1.32	12.28	53.49	1.21	0.04	11.83	6.58	73.15
S7	6.18	0.13	0.27	2.18	1.43	10.18	37.07	3.76	0.27	13.07	7.13	61.31
S8	7.33	0.04	0.45	2.84	1.58	12.25	44.00	1.21	0.45	17.03	7.91	70.60
S9	8.72	-	0.26	1.45	1.62	12.05	52.33	-	0.26	8.70	8.10	69.38
S10	16.01	-	1.54	1.01	1.27	19.83	96.06	-	1.54	6.05	6.36	110.01
S11	13.41	0.15	-	2.00	1.33	16.89	80.45	4.44	-	12.00	6.66	103.55
S12	10.58	-	0.39	0.85	1.33	13.16	63.46	-	0.39	5.13	6.67	75.65
S13	4.34	0.12	1.47	1.21	1.10	8.24	26.02	3.63	1.47	7.26	5.51	43.89
S14	9.89	-	0.42	2.52	1.29	14.12	59.35	-	0.42	15.12	6.45	81.33
S15	17.49	-	0.30	1.50	1.63	20.92	104.91	-	0.30	8.99	8.16	122.37

The results in Table 3 show that EF values for all heavy metals across the sampling sites were below 1, indicating minimal enrichment despite their concentrations being significantly higher than the background levels (Table 2). The low EF values were attributed to the high Fe concentration in the sediments, which exceeded the concentrations of other metals by more than fiftyfold. Using an alternative reference element, such as scandium (Sc) (Mavakala et al., 2022), may provide a more representative EF that better reflects actual heavy metal concentrations in sediments where Fe is abundant.

In addition to EF, I_{geo} was employed to provide a quantitative criterion for characterizing sediment contamination by heavy metals (Adamo et al., 2005). The I_{geo} assessment reflected the trends in heavy metal concentrations in the sediment.

Based on I_{geo} calculations, the toxicity ranking of heavy metals at the study sites was as follows: Fe > Pb > Cu > Zn > Cd. Fe concentrations exceeded the unpolluted threshold at all sites, with classifications ranging from moderately polluted (S13) to heavily polluted (S10, S11, S15), and from moderately to heavily polluted across the remaining sites.

Pb contamination was classified as moderately polluted at S1 and S5, while Cu contamination was limited to S1. In contrast, all sites were classified as unpolluted for Cd and Zn. Although Zn concentrations were higher than those of Pb and Cu, its background concentration is ten times higher than that of Pb and 30 times higher than that of Cu. As Zn is considered an essential micronutrient in soil, its detected concentrations were classified within the unpolluted range according to the I_{geo} assessment.

The Cf values presented in Table 4 indicated that most heavy metals moderately contaminate the sediment across all sampling sites, with the exception of Fe. As shown in the table, the Cf values for Fe exceeded 6 at all sites except S13, where the C_f value was 4.34, indicating a condition of considerable contamination. Cd and Zn generally exhibited Cf values below 1, except at S1, S10, and S13 for Zn, where the values exceeded 1, classifying these sites as moderately contaminated. For Pb, Cf values greater than 3, indicating considerable contamination, were observed at S1 and S3. Similarly, Cu showed Cf

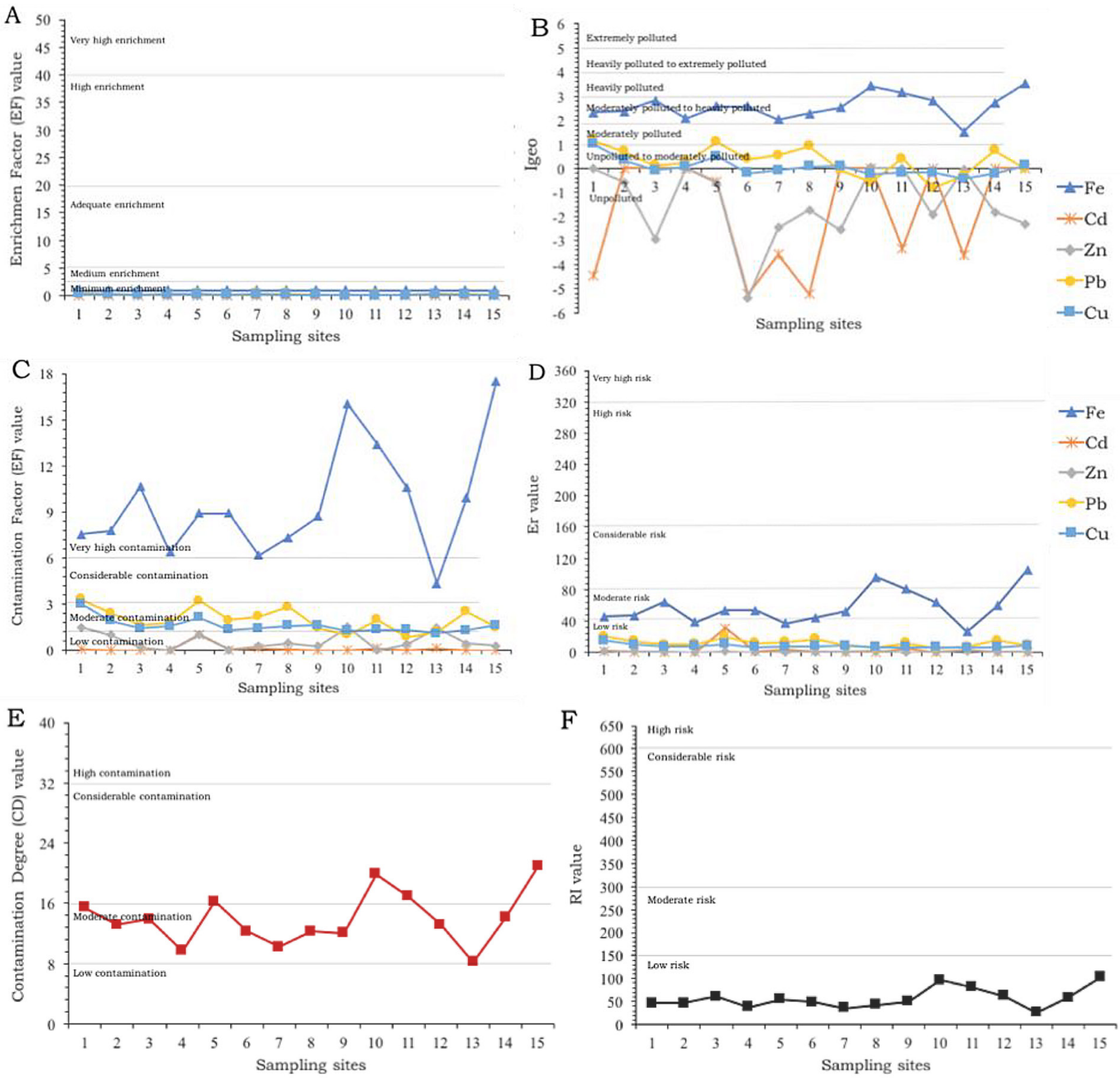

Figure 5. The values of (A) EF, (B) I_{geo}, (C) Cf, (D) Er of heavy metals at all sites, and (E) CD and (F) RI at all sites in Batanghari river with a range of classification

values higher than 3 only at S1. Additionally, the CD values in Table 4 reveal that several sites had CD values exceeding 16, categorizing them as highly contaminated areas. The findings suggest that contamination at the study sites was predominantly driven by Fe, Pb, and Cu. Among the study sites, S15 emerged as the most heavily contaminated, followed by S5. The elevated contamination levels at these sites were primarily attributed to the high Fe concentrations, which played a significant role in the overall pollution levels observed in this study.

The Cf values were also used to assess the Er of heavy metals at the study sites. Based on the Er values presented in Table 4, the heavy metals in the sediment were generally categorized as posing low to moderate ecological risk. However, Fe in S10, S11, and S15 showed higher Er values of 90.06, 80.45, and 104.91, respectively. These values exceed the threshold of 80, indicating a considerable ecological risk of heavy metals in the sediment at these sites.

Additionally, the potential ecological RI was calculated using the Er values for all heavy metals across the study sites. The RI values, shown in Table 4, were all below 150, suggested that the heavy metal concentrations in the sediment of the Batanghari river exhibited a low potential ecological risk which indicated small environmental risk across all study sites. The highest RI was recorded in S15 (122.37), while the lowest was in S13 (43.89). The higher RI in S15 can be attributed to the high Fe concentration at this site, which, according to Table 2, was the highest among all sites. In contrast, the low RI at S13 corresponds to the lowest Fe concentration recorded at this site, reinforcing the relationship between sediment Fe levels and ecological risk. Furthermore, these findings suggest that downstream areas like S15 have a greater tendency for accumulation of heavy metals, due to their mobilization with flowing river water. A similar trend of higher downstream accumulation compared to upstream was also observed in the study of Fadlillah et al. (2023). The variation in the concentrations across the study sites suggest that their distribution in river water and sediment are strongly influenced by the surrounding land use. Hence, the finding of this study cannot be generalized to other rivers in Indonesia with different land use patterns and anthropogenic activities in their surroundings.

Overall, the findings indicate that Fe shows significant enrichment in the sediment, whereas the other heavy metals (Zn, Pb, Cu, and Cd) generally present a low ecological risk. However, it is necessary for continuous monitoring of the water and sediment of the Batanghari river, regarding the present of the specific heavy metals, as the river is a vital resource for domestic use and agricultural activities. This study highlights that anthropogenic activities and land use changes contribute to the persistence of heavy metals in the environment, which may increase their load in river water and sediment over time. To mitigate pollution from agricultural practices, reducing the use of artificial fertilizers is recommended. Additionally, pollution control strategies such as bioremediation can minimize heavy metal leaching into river water; for example, applying biochar to the soil can be an effective solution (Hasegawa et al., 2015). Furthermore, the installation of wastewater treatment plants (WWTPs) is strongly advised, particularly for domestic industries like palm oil processing, to reduce the overall pollution load in the Batanghari river.

CONCLUSIONS

This study quantified pollution degree in surface water and sediment of Batanghari river, Dharmasraya region, based on the concentrations of Fe, Zn, Pb, Cu and Cd. The analysis was conducted by the mapping of heavy metal distribution in the water and sediment, along with the determination of the values of EF, Igeo, Cf, CD, Er, and RI. Based on the results of samples analysis, the water of Batang hari rivere xceeded thresholds values of Indonesian water quality standard class II and WHO water quality guidelines. The mean concentration of heavy metals load in the river water from the measurement were 1.030 mg/L for Fe, 0.380 mg/L for Zn, 0.005 mg/L for Cd, while the present of Cu and Pb were not detected. The mapping of heavy metals distribution indicated that the loads of heavy metals were mainly linked to anthropogenic activities, for instance agricultural activity, local mining activity, road, vehicle, and domestic purposes. However, the EF assessment implies that the contamination level of Zn, Cd, Pb and Cu in the river water from anthropogenic activities was low. The mean values of the heavy metals in sediment were 14422.37 mg/kg for Fe, 53.05 mg/kg for Zn, 22.37 mg/kg for Cu, 18.00 mg/kg for Pb, and 0.13 mg/kg for Cd. The Igeo assessment unraveled that Fe load in the sediment exceeded the unpolluted threshold at all sites, with classifications ranging from moderately polluted to heavily polluted. In contrast, the presence of Cd and Zn were remained in unpolluted classification in all sampling sites, while Pb and Cu were in moderately polluted in only the particular sites. The Similarly, Cf and Er for Fe indicated a condition of considerable contamination which posing low to moderate ecological risk, except in several sites (S10, S111 and S15), with the Er values of Fe exceeded the threshold of 80, indicating a considerable ecological risk. Referring to CD values, S15 was emerged as the most heavily contaminated, which the elevation contamination level was primarily attributed to the high Fe concentrations. The site also had the highest RI value, yet the value still posed a low potential ecological risk. The potential ecological risk from this study sites as follows: S15 > S5 > S10 > S11 > S1 > S14 > S3 > S12 > S6 > S2 > S8 > S9 > S7 > S4 > S13. Overall, the spatial distribution showed that the highest heavy metal pollution in Batanghari river, was in the downstream area, due to the mobilization of heavy metals through river water flow. To address pollution caused by agricultural activities, it is recommended to decrease the reliance on artificial fertilizers. Implementing pollution control measures, such as bioremediation, can also help reduce heavy metal leaching into river water; for instance, the application of biochar to soil can serve as an effective mitigation strategy. Moreover, installing wastewater treatment plants (WWTPs), especially for domestic industries like palm oil processing, is strongly encouraged to lower the overall pollution burden in the Batanghari River.

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