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Research Article

Heavy metal contamination of Batanghari River, Jambi, Indonesia: determination based on sediment enrichment factor value

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Abstract

Batanghari River is the primary source of water for the people of Jambi. Batanghari River's condition nowadays is worrying because its color is no longer clear. This research focused on determining the content of heavy metals in the Batanghari River's water and sediment. The conducted analysis is an ICP-MS analysis to determine the level of heavy metal (Cu, Cr, Co, Cd, Hg), and an enrichment factor calculation is conducted to determine the source of pollution. The enrichment factor value from the Batanghari River sediment sample declined with the following sequence Cd > Hg > Cu > Cr > Co, in 10 pinpoint locations. These indicate a high degree of anthropogenic activities along the Batanghari River which become the source of heavy metals entering the Batanghari River. The average concentration of heavy metals in the Batanghari River showed that the metal concentrations of Cd, Cu, and Hg are higher than the quality standards that have been set, whereas the metal concentrations of Cr and Co are still by the quality standards that have been set in PP 22 the year 2021.

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Introduction

River sediment quality has been studied deeply because the river has a very important role in human and organism life (Naushad et al., 2014; Sarah et al., 2019). Rapid urbanization and industrial development over the last decade have triggered several serious problems in the environment. Heavy metal contamination in the river is one of the river's primary problems in a developing country (Silambarasan et al., 2012) because the river is the primary transportation route for heavy metal (Mohiuddin et al., 2010). Heavy metals especially enter this water system naturally through weathering and rock erosion as well as anthropogenic sources such as urban activities, industrial activities, mining activities, farming activities, and waste disposal activities (Barakat et al., 2012).

The heavy metal that gets into the waters is rapidly deposited and accumulates into sediment through complex physical and chemical adsorption depending on the sediment's nature and its adsorbed compound nature (Kaushik et al., 2009; Rabee et al., 2011; Zhang et al., 2018). Hence the heavy metal identification and quantification in the river's sediment is an important environmental problem to be studied deeply (Manoj et al., 2012). Every heavy metal probably has different Bioavailability and toxicity; thus, the heavy metal distribution in the water and sediment plays a key role in detecting heavy metal pollution sources in the water ecosystem (Singh et al., 2012). Metals accumulation and distribution in river's water and sediment have increased to a worrying level that causes precipitation and sedimentation in waters would also influence biota, and aquatic organisms, which in certain conditions could enter into a food chain and endanger human health (Mohiuddin et al., 2011; Abdullah, 2013; Zhang et al., 2018).

Heavy metal exposure has been linked with several human diseases such as retardation or developmental disorder, kidney failure, and cancer, affecting one's intellectual and behavior and even fatality in several cases of high heavy metals exposure. The most toxic heavy metals are Cr, Ni, Pb, Cd, and As. Cr (VI), Ni, and Cd are carcinogenic; As and Cd are teratogenic, and Pb's health issue effect includes neurological disorder and the central nervous system. Although several heavy metals such as Fe, Mn, Co, Cu, and Zn are essential micronutrients to flora and fauna nevertheless dangerous at a high level (Saha and Hossain, 2011).

Today, the Batanghari River is still frequently used for public activities and includes many fishery activities. Therefore it is important to conduct the monitoring of water quality control and Batanghari River sediment to find the source of pollution. This research conducted five heavy metals (Cu, Cr, Co, Cd, and Hg) content identification in the water and sediment of Batanghari River, Jambi, Indonesia, and assessed the pollution source.

Materials and Methods

Sampling

Geographically Batanghari River is located at 100°43'3.63"-104°27'22.40" longitude and 0°38'29.02" north latitude and 82°46'11.98" south latitude. The total Batanghari River area is 46.504 km^2 which topographically is classified as lowland, medium land, and highland. This research focused on analyzing the water and sediment Batanghari River in lowland areas, including Jambi city, Muara Jambi District, and Batanghari District. There were ten pinpoint sample location areas conducted in July 2021. The weather when the sample was taken was the dry season. The maps of the ten pinpoint sample location areas are shown in Figure 1.

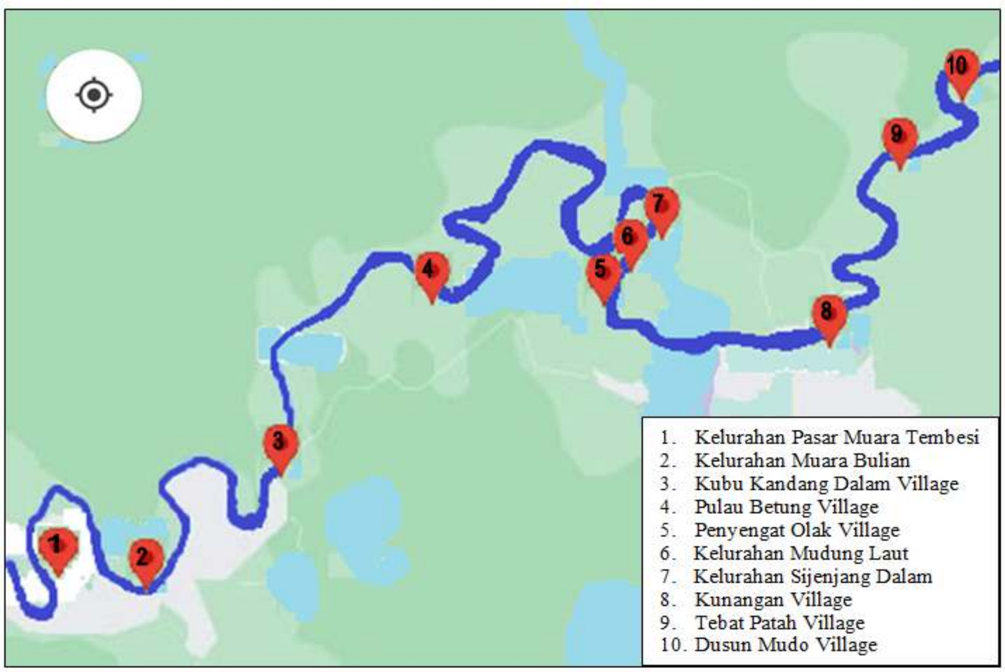

Figure 1. Batanghari River sampling locations.

Heavy metal analysis

The measurement of heavy metals in Batanghari River sediment applied ICP-MS analysis in Universitas Andalas laboratory. Inductively Coupled Plasma (ICP) is the primary tool utilized to conduct element analysis. Non-electricity discharge utilization for atomization, vaporization, and excitation followed by argon ICP cause technique development based on ICP such as atom emission spectroscopy, atom fluorescence spectroscopy, and mass spectroscopy (MS). ICP is a strong characterization technique that could accurately identify and measure all elements in the periodic table and detect up to 20 different element traces simultaneously up to 1-10 ng analyte per liter in a solution. ICP is set as a robust technique that enables all kinds of compound detection through their element characteristic content (Chen et al., 2019). Since commercial ICP-MS was introduced, ICP has developed to be the most multipurpose detection technique to measure individual isotopes from analyte elements and has been used in various fields such as biophysics to study biomolecular structure and dynamics, environmental knowledge to quantify various dangerous elements, forensic science, material science, cosmochemistry, speciation analysis, archaeology, and various industry including, food, chemistry, semiconductor, nuclear, etc. (Nageswaran et al., 2017). The results of ICP analysis results were then processed to calculate the heavy metals (Cu, Cr, Cd, Hg) enrichment factor and combine heavy metal concentration data in water and sediment of the Batanghari River in a graph. The Enrichment Factor (EF) is a valuable indicator to mirror the level of anthropogenic's heavy metal pollution (Sakan et al., 2009; Malvandi, 2017). EF was calculated by equation (1).

$$EF = \frac{\left(\frac{Metal}{Fe}\right)Sample}{\left(\frac{Metal}{Fe}\right)Background} \quad ....(1)$$

In this research, iron (Fe) was used as a reference element to normalize geochemistry. The interpretation given by (Sakan et al., 2009; Malvandi, 2017) from EF value was used for testing, where: EF<1 shows that there is no enrichment; <3 minor enrichment; 3-5 moderate enrichment; 5-10 moderately severe enrichment; 10-25 severe enrichment; 25-50 very severe enrichment; and >50 extremely severe enrichment (Sakan et al., 2009; Malvandi, 2017; Siddique et al., 2021). The background value used as the base calculation is the sum average of the world's metals in the earth's crust (Turekian and Wedepohl, 1961).

Results and Discussion

Heavy metals concentration of Cu, Cr, Cd, and Hg in water and sediment of Batanghari River is shown in Figures 2-6. Overall, heavy metals concentration is higher 2 to 17 times in the sediment samples compared to the water samples.

Copper

Copper concentration in the Batanghari River fluctuates between 0.0241 mg/L to 0.075 mg/L. That value is above the threshold value according to PP 22 Year 2021, which is 0.02 mg/L. Copper's concentration of sediment in the Batanghari River fluctuates between 0.187 mg/kg to 0.514 mg/kg (Figure 2).

The highest copper concentration in the Batanghari River is located in location number 8 locations which is Kunangan Village. Only population settlement exists in location number 8; hence the cause of pollution could not be identified. This is similar to what happened to Kaushik's research (Kaushik et al., 2009), where the amount of a heavy metal reached its highest value in one area without a specific source of pollution in that area, so it concluded that an unidentified source was the cause of copper entering the Batanghari River water. The highest sediment concentration is located in location number 5, which is Olak Kemang Village. The region around location number 5 is a settlement area with sand mining. The high accumulation of Cu around the location was probably caused by sand mining activities. The factor Enrichment value for Cu metal is shown in Table 1. According to Table 1, it is known that Cu's enrichment factor value in Batanghari River sediment varies between 133.96 to 208.68.

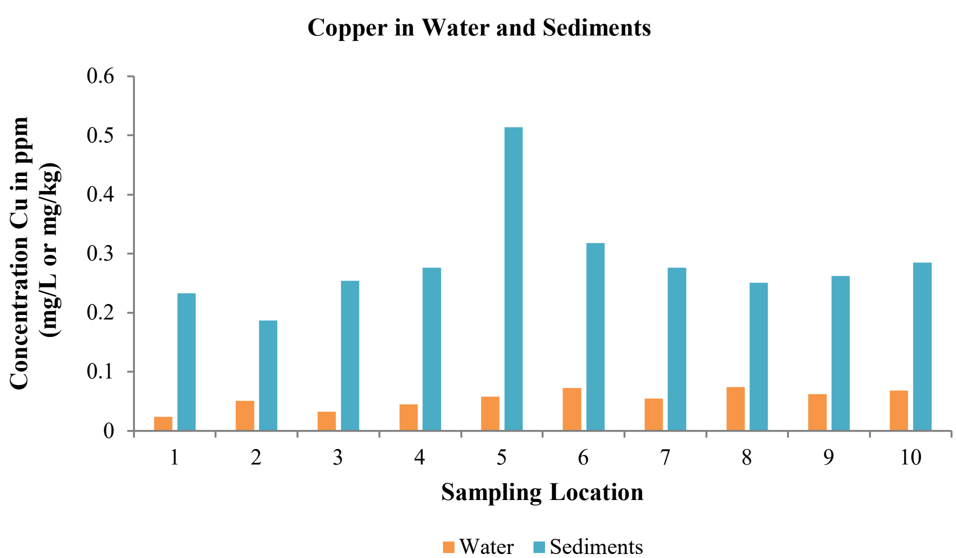

Figure 2. Copper in water and sediment of Batanghari River.

Table 1. Enrichment factor value from Cu, Cr, Co, Cd, and Hg at Batanghari River.

Sampling Location	Cu	Cr	Co	Cd	Hg
1	142.81	26.97	0.92	898.92	465.81
2	134.58	46.58	1.57	1247.47	626.14
3	140.29	28.52	0.81	910.02	452.91
4	135.15	29.38	0.94	624.94	514.18
5	208.68	36.02	0.70	599.31	515.60
6	105.63	53.39	0.93	623.21	880.24
7	107.46	36.10	0.86	526.54	689.14
8	133.96	43.08	1.02	640.45	603.09
9	129.64	38.86	0.90	617.31	766.93
10	134.03	47.37	1.03	573.31	921.78

The value of over 50 shows that Cu enrichment in the Batanghari River is in an extremely severe state (Sakan et al., 2009; Malvandi, 2017; Siddique et al., 2021), that indicates Cu pollution in the Batanghari River originated from human activities.

Chromium

Cr concentration in Batanghari River varies between 0.0105 mg/L to 0.0336 mg/L. This value indicates that the Cr concentration is below the 0.05 mg/L threshold value determined by the government according to PP No 22 year 2021 which means the water in Batanghari River is in good condition. Cr concentration of sediment in the Batanghari River is about 0.121 mg/kg to 0.442 mg/kg (Figure 3). The maximum value of Cr in Batanghari River is located in location number 6, which is Kelurahan Mundung Laut. Around those location, there are settlements, Batik Industry, and market activities that allow Cr source pollution of sediment in river. This is in line with research by Kaushik et al. (2009) which stated that the textile dyeing industry was the main source of chromium entering the river.

Enrichment factor calculation was conducted and varied result values are obtained between 26.97 to 53.39 (Table 1). The lowest value is included between 25-50 which indicates very severe enrichment. The highest value, above 50 indicates that the enrichment factor in that location is in a extremely severe condition (Sakan et al., 2009; Malvandi, 2017; Siddique et al., 2021). Human activities become the primary Cr pollution to sediment in that area.

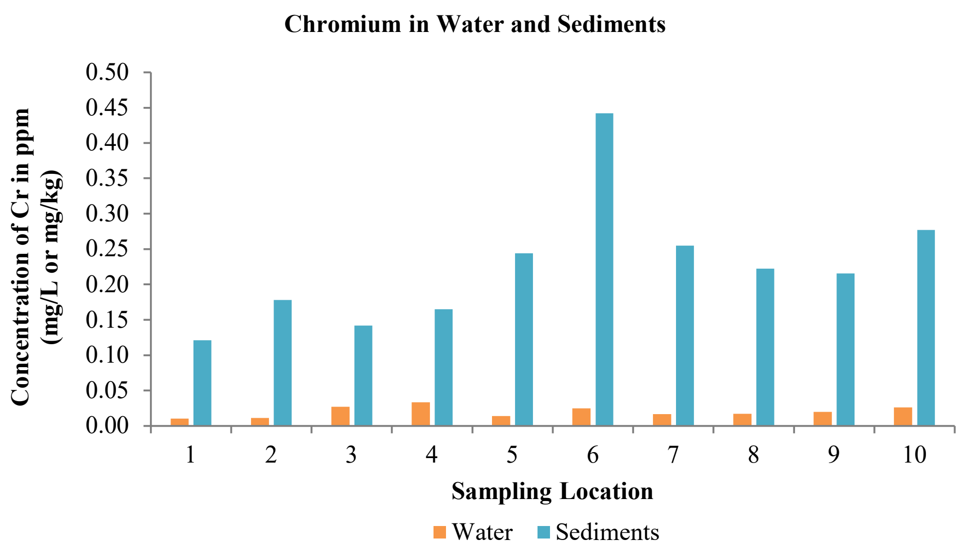

Figure 3. Chromium in water and sediment of Batanghari River.

Cobalt

Cobalt concentration in Batanghari River water varies between 0.0102 mg/L to 0.0215 mg/L (Figure 4). In several location points, which are sampling point number 1,2, and 3, cobalt elements in river water are not detected. These values comply with the basic standard quality set by the government 0.2 mg/L according to PP No 22 Year 2021. The cobalt concentration of sediment in the Batanghari River varies between 0.055 mg/kg to 0.082 mg/kg as shown in Table 1.

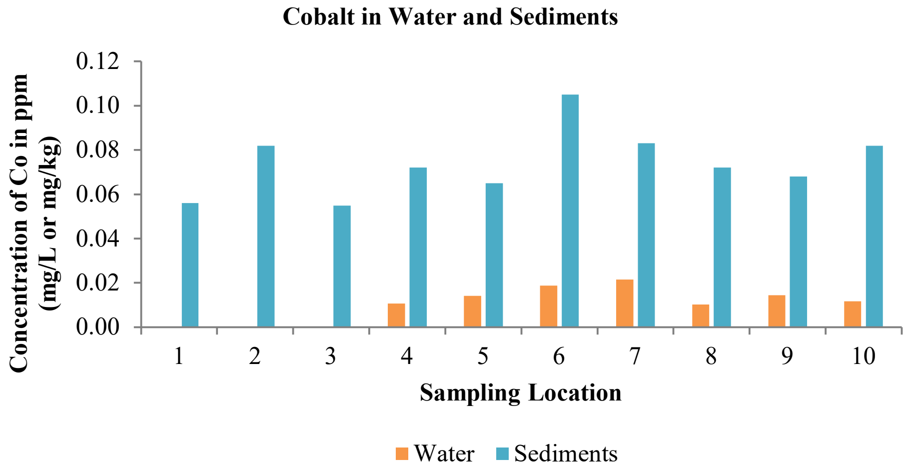

Figure 4. Cobalt in water and sediment of Batanghari River.

Enrichment factor calculation shows that cobalt value varies between 0.70 to 1.57. EF value that is less than 1 indicates that there is no metal Co enrichment in that location (Sakan et al., 2009; Malvandi, 2017; Siddique et al., 2021). An enrichment value that is smaller than 3 shows that there is a small amount of enrichment (Sakan et al., 2009; Malvandi, 2017; Siddique et al., 2021). This indicates that anthropogenic activities around the Batanghari River were not the primary cause of Co's metal entry into the sediment of the Batanghari River.

Cadmium

Cd concentration in Batanghari River water varies between 0.0211 mg/L to 0.0782 mg/L (Figure 5). According to PP no 22 Year 2021, Cd's threshold in river water is 0.01 mg/L; thus, the sampling location is indicated polluted by Cd because the Cd value is above the threshold value. This concentration increased because in 2020, Yanova et al. (2020) conducted research that states that Cd content in Batanghari River-water complies with the set threshold value.

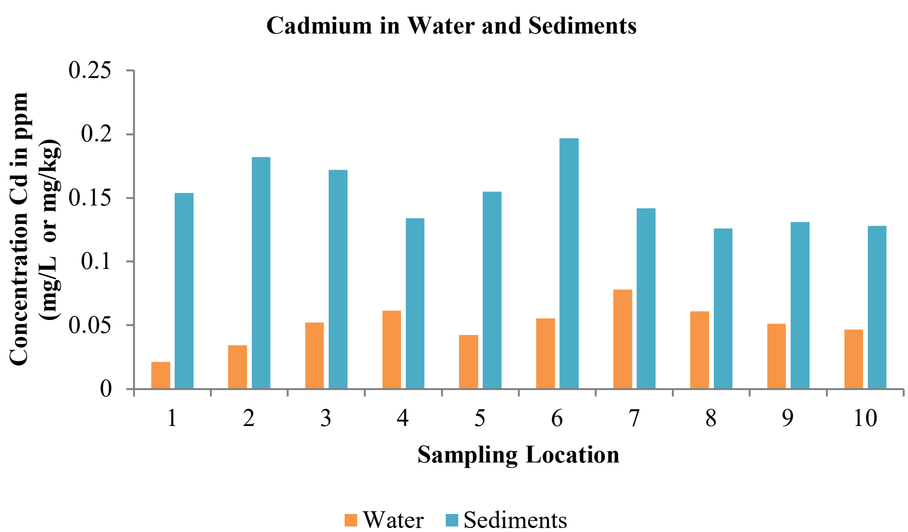

Figure 5. Cadmium in water and sediment of Batanghari River.

Batanghari River sediments have been analyzed, and it is known that Cd concentration varies between 0.126 mg/kg to 0.197 mg/kg. EF values have been calculated and tabulated in Table 1 and it is known that Cd's EF value in the Batanghari River sediment varies between 526.54 to 1247.47. Averagely, the EF value is higher than 50, which indicates that Cd enrichment is extremely severe (Sakan et al., 2009; Malvandi, 2017; Siddique et al., 2021). This confirms that human activities are the primary source of that Cd entering the

Batanghari River sediments. The highest EF value is located in location number 6, Kelurahan Mundung Laut. There are Batik industries and markets around that location that enable those activities to be the source of Cd pollution in the Batanghari River sediment. This is in line with research by Kaushik et al. (2009), which stated that the textile dyeing industry was the main source of Cadmium entering the river.

Mercury

Mercury is a very poisonous metal; reflecting on the Minamata tragedy, mercury is very dangerous for human life (Kudo and Miyahara, 2018). In 2020, Yanova et al. (2020) have conducted research regarding mercury content in Batanghari River water with the result that shows mercury contents are higher than the threshold value of about 0.017 mg/L to 0.032 mg/L (Figure 6).

Mercury threshold value according to PP No 22 Year 2021 is 0.001 mg/L. One year later, when this research is conducted, there is an increase in mercury concentration in Batanghari River water that varied between 0.011 mg/L to 0.1005 mg/L. This value far exceeds the determined threshold value up to 100x times. The highest mercury content in every location is located in location number 6, Kecamatan Mundung Laut. Around that location, there are settlements, Batik industry, and markets that are highly likely to be the source of the pollution. According to the resident in that location, fish are often found dead where the sample of this research is taken; this is typical in an area with a high level of mercury, where accumulated methyl-mercury in the sediment will influence organisms in that area (Kudo et al., 1998). Hg concentration in the Batanghari River sediment is about 0.076 mg/kg to 0.265 mg/kg.

Enrichment Factor calculations have been conducted and presented in Table 1. Based on Table 1 it is known that the EF Hg value in Batanghari River sediments fluctuates from 452.91 to 921.78. The highest EF value is located in location number 10, Dusun Mudo Village. That area only consists of settlements and fish cage activities hence the source of pollution could be detected yet. Location number 10 is also the most downstream location from the sample-taking process; those accumulated Hg may be carried away from anthropogenic activities from the river's upstream activities. Based on previous research on the source of mercury entering rivers, it explained that mining is the common source of mercury pollutants entering the river (Mao et al., 2023). Based on field observations, along the Batanghari River there are many illegal gold mining. This is one of the causes of mercury contamination in the Batanghari River. The very high EF value, which indicated extremely severe (Sakan et al., 2009; Malvandi, 2017), far exceeds 50, that is proof that the source of Hg pollution in the Batanghari River sediment is human activities.

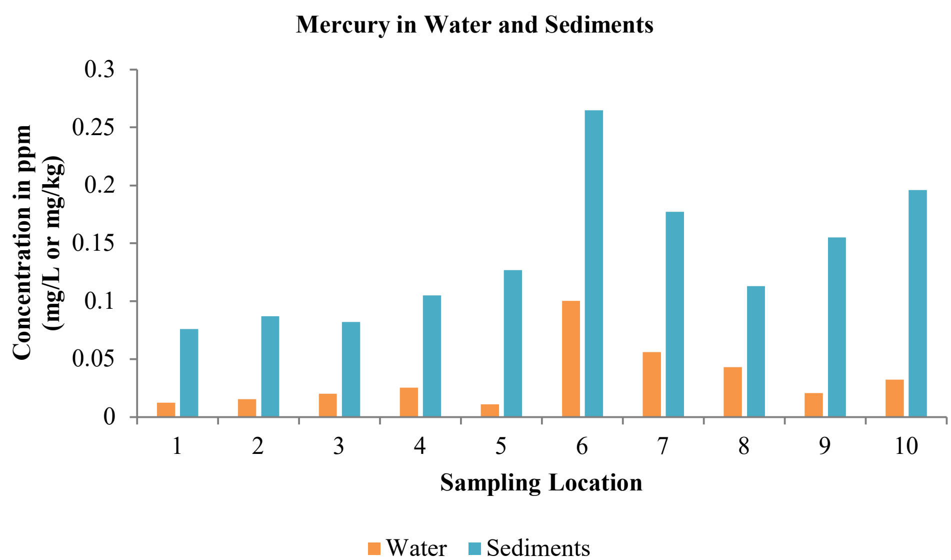

Figure 6. Mercury in water and sediment of Batanghari River.

Batanghari River water is indicated polluted by Cu, Cd, and Hg while Co and Cr still comply lower than the threshold value. In the case of sediment, there are anthropogenic activities from human activities marked by the value of EF that varies from 0.70 to 1,247.47 that shows metals enrichment level varies from no enrichment to extremely severe enrichment. The linkages relationship between heavy metal variables to water and sediment is studied through correlation analysis and indicates a significant relationship statistically, which is shown in Table 2. The positive correlation value indicates that the variables have a positive relationship; on the contrary, negative value indicate an inverse relationship (Kaushik et al., 2009).

Based on Table 2, Cr, and Co sediment values show a strong positive relationship which means that both enter through the same source and support each other sediment adsorption. The significant negative correlation showed by Cd's sediment and Cd water shows that Cd removal from water is highly related to Cd entering sediment. From the correlation data shown in Table 2, only two matrixs show a negative correlation. Nearly all matrices show a positive correlation which means that metal Cu, Cd, Cr, Co, and Hg pollution in the Batanghari River originated from the same source.

Table 2. Significance correlation from various variables.

Matrix		**Correlation**	**P-Value**
X axis	**Y axis**		
Cu Sediments	Cu Water	0.246	0.494
Cr Sediments	Cr Water	0.197	0.586
Co Sediments	Co Water	0.587	0.074
Cd Sediments	Cd Water	-0.282	0.430
Hg Sediments	Hg Water	0.830	0.003
Cu Sediments	Cr Sediments	0.345	0.329
Cu Sediments	Co Sediments	-0.013	0.971
Cu Sediments	Cd Sediments	0.007	0.986
Cu Sediments	Hg Sediments	0.254	0.479
Cr Sediments	Co Sediments	0.863	0.001
Cr Sediments	Cd Sediments	0.314	0.376
Cr Sediments	Hg Sediments	0.950	0.000
Co Sediments	Cd Sediments	0.342	0.333
Co Sediments	Hg Sediments	0.825	0.003
Cd Sediments	Hg Sediments	0.151	0.678
Cr Water	Cu Water	0.120	0.741
Co Water	Cu Water	0.676	0.032
Cd Water	Cu Water	0.441	0.202
Hg Water	Cu Water	0.553	0.097
Co Water	Cr Water	0.201	0.578
Cd Water	Cr Water	0.471	0.170
Hg Water	Cr Water	0.277	0.438
Cd Water	Co Water	0.698	0.025
Hg Water	Co Water	0.631	0.051
Hg Water	Cd Water	0.526	0.119

Conclusion

This research could conclude that currently, the water of the Batanghari River has been contaminated with Hg, Cd, and Cu. Co, Cr, Cd, and Cu enrichment value is more or less identical along the Batanghari River. Mercury enrichment values in several locations are very high; thus, it needs special attention to identify and rectification from the source of the pollution. Overall, Cu, Cd, Cr, Co, and Hg metal contamination in the Batanghari River is caused by anthropogenic activity and have the same source.

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