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Research Article

Pollution assessment of heavy metals in the surface sediment of Jengka River, Pahang

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Abstract

Heavy metal contamination in river sediments is a serious environmental problem since it has the potential to be persistent, posing long-term ecological hazards, particularly in developing nations like Malaysia. This study was conducted in the Jengka River, Pahang, Malaysia, particularly due to the presence of intensive agronomic activities. The objectives were to investigate the concentration of selected heavy metals, such as iron (Fe), copper (Cu), cadmium (Cd), chromium (Cr), manganese (Mn), nickel (Ni), lead (Pb), and zinc (Zn) in the surface sediments of the Jengka River, to estimate the degree of contamination, and to identify potential heavy metal sources. Heavy metal concentrations were determined using Inductively Coupled Plasma Optical Emission Spectrometry (ICP-OES). The concentration of heavy metals (mg/kg) was found in the following descending concentration order: Fe (0.51-0.60%) > Mn (174.93-712.73) > Pb (10.13-49.47) > Zn (17.00-28.00) > Cu (11.13-39.47) > Cr (14.33-21.80) > Ni (4.33-7.27) > Cd (0.40-0.80). Pollution indices, such as the geo-accumulation index (Igeo), enrichment factor (EF), contamination factor (CF), and pollution load index (PLI), were employed to assess contamination level. All sampling locations exhibited some level of pollution, with Location 5 identified as the most impacted, likely due to nearby domestic and mechanical workshop activities. Principal component analysis (PCA) suggested that heavy metals may originate from both natural and anthropogenic processes. Continuous monitoring and effective pollution control are recommended to protect the Jengka River ecosystem.

Keywords: pollution level, sediment, heavy metals, Jengka River

Introduction

Heavy metal contamination in aquatic ecosystems is a global environmental concern due to its persistence, toxicity, and potential for bioaccumulation in aquatic food webs. In tropical rivers, surface sediments function as both a sink and a secondary source of heavy metals, thereby providing an important record of historical and present contamination [1-2]. Therefore, monitoring heavy metals in sediments is a critical approach for assessing long-term pollution status. In Malaysia, recent studies have reported the presence of metals such as Fe, Mn, Pb, Zn, Cu, Ni, and Cr in rivers, largely attributed to agricultural practices, wastewater discharges, and small-scale industries [3-4]. Research on the sediments has identified multiple heavy metals and evaluated their pollution levels using indices such as the geo-accumulation index (I_{geo}), enrichment factor (EF), contamination factor (CF), and pollution load index (PLI), showing generally low to moderate contamination [1-3]. Similarly, water quality assessments in the Jengka River [4] and Sungai Petani [3] reported that certain metals exceeded guideline values, highlighting the influence of anthropogenic activities on river systems.

Heavy metal contamination in river sediments is commonly assessed using pollution indices such as the enrichment factor (EF), geo-accumulation index (I_{geo}), contamination factor (CF), and pollution load index (PLI). These indices have been widely applied to evaluate sediment contamination around the world [5-8]. They assist in identifying anthropogenic sources of pollution, including urban emissions, agricultural activities, and industrial discharges. For instance, higher concentrations of heavy metals were found in urban and agricultural areas compared to forested regions [5, 8]. The effectiveness of these indices varies, with some researchers favouring one as the most precise indicator of pollution sources, while others choose another index.

Although several studies have examined heavy metal contamination in Malaysian rivers, significant knowledge gaps remain in the Jengka River basin. Previous investigations have largely focused on river water quality, which prevents a holistic understanding of how metals accumulate and are transferred within the system. Furthermore, while conventional pollution indices have been applied to assess contamination levels, more advanced statistical techniques, like principal component analysis (PCA), have not been utilised to provide a robust distinction between natural background inputs and anthropogenic sources. The scope of metals analysed has also been limited, with hazardous elements like cadmium (Cd), which is often linked to agricultural practices and industrial effluents, frequently excluded from assessments. Madzlan et al. [9] reported a multi-index assessment in the Setiu River sediment, Terengganu, but did not apply multivariate statistical analysis. Ruzi et al. [3] focused mainly on wastewater without including sediment analysis. Similarly, studies in other Malaysian rivers, such as the Perak River and the Gebeng coastal area, highlighted the ecological risks of Cd and As, emphasising the importance of source apportionment [10-11]. As a result, no study has yet combined sediment quantification, multi-index pollution evaluation, and PCA-based source identification within an integrated framework. This lack of comprehensive evidence restricts the ability of environmental managers to design effective mitigation measures, especially in the Jengka River.

Therefore, this study makes an important contribution by applying an integrated framework to evaluate heavy metal contamination in the Jengka River sediment. It also expands the range of metals analysed beyond those commonly measured elements, thereby providing a more comprehensive contamination profile. This study aims to address these gaps through the following objectives, which are to determine the concentrations of heavy metals (Cd, Cr, Cu, Fe, Mn, Ni, Pb, and Zn) in the surface sediments of the Jengka River, to assess the degree of contamination using multiple sediment pollution indices (I_{geo}, EF, CF, PI, and PLI), and to identify potential anthropogenic sources of heavy metals using principal component analysis (PCA). By combining sediment-based monitoring, multi-index pollution assessment, and multivariate statistical analysis, the study delivers a more reliable understanding of contamination levels in the Jengka River and the contribution of anthropogenic sources. The findings will generate new evidence to support targeted mitigation strategies, offering a practical scientific basis for sustainable river basin management in the Jengka region.

Materials and Methods

Study area

The Jengka River flows through Jengka's northern forest area and agricultural lands before joining the Pahang River to the south (**Figure 1**). Extensive oil palm and rubber plantations under the FELDA schemes contribute to agrochemical inputs, such as fertilisers and pesticides. In addition, smallholder livestock farming, particularly poultry rearing, produces organic waste that may increase nutrient loading within the river system. Meanwhile, domestic discharges from nearby residential areas are often released directly into drainage channels, further degrading water quality [4]. This land-use transition from forested upstream to agricultural downstream significantly influences the river's sediment and water quality dynamics.

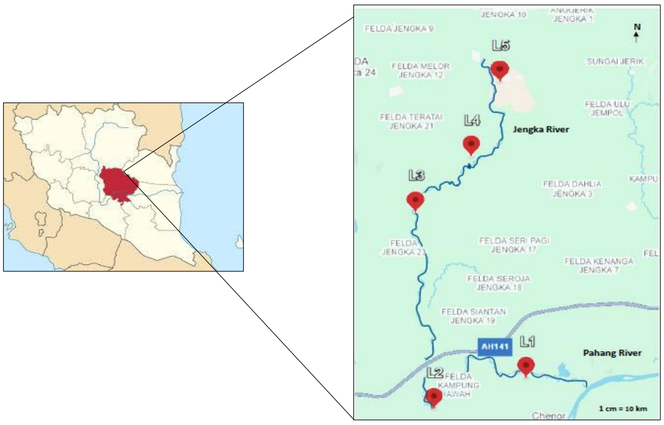


Figure 1. Sampling location along Jengka River in Maran district, Pahang Malaysia

Table 1. Detailed information of all sampling points

Sampling point	GPS coordinates	River flow	Description
L1	3°31′46″ N 102°33′14″E	Downstream	-palm oil plantation -primary school
L2	3°31′17″N 102°30′44″E	Downstream	-near to the main road -palm oil plantation
L3	3°43′12″N 102°32′35″E	Middle Stream	-near to the main road -palm oil plantation
L4	3°44′59″N 102°32′15″E	Middle Stream	-palm oil plantation -near to the main road
L5	3°47′24″ N 102°32′0″E	Upper stream	-near automotive workshops -near to the main road -residential area
Control	3°45'42.5"N 102°34'16.6"E	Control sample	-undisturbed area

Sampling locations

Sediment sampling was conducted in April 2025 during the wet season. The sampling locations and their descriptions are presented in **Table 1** and were classified as downstream (L1-L2), middle stream (L3-L4), and upstream (L5).

Sample collection and sample preparation

Fifteen surface sediment samples (0-5 cm) were collected along the Jengka River using a pre-cleaned stainless-steel scoop. The scoop was washed and rinsed with distilled water after each sample collection. Replicates are also done for each sampling point. Foreign materials, such as small branches and leaves, were first removed from the collected samples before they were sealed in plastic bags. The samples were labelled and stored in a cooler box at a temperature below 4°C. Subsequently, the samples were air-dried at room temperature and then oven-dried at 60°C for 48 hours until a constant weight was achieved. The dried sediments were ground using a pestle and mortar, sieved to obtain a homogeneous particle size, and stored in polyethylene containers until digestion. A control sample was collected from an undisturbed river sediment. The control sample was prepared using the same procedures as the other samples to ensure experimental consistency and was used as a reference sample. The inclusion of the control sample was to represent background conditions, as it was collected from an area with no known anthropogenic contamination. The geological characteristics of the control site were comparable to those of the studied sampling locations, allowing meaningful comparison and facilitating the assessment of contamination attributable to anthropogenic activities [5].

Sample digestion and sample analysis

Sediment samples were oven-dried at 60°C for 24 hours and ground to a fine powder using a sterile mortar and pestle. A 2.5 g portion of each sample was digested with 10 mL of aqua regia ($HCl:HNO_3$, 3:1) on a hot plate at 95°C for 1 hour. After cooling to room temperature, the digests were diluted to 50 mL with deionised water and left to settle overnight [12]. The digested samples were then filtered through Whatman No. 42 filter paper, followed by a 0.45 µm Millipore filter. The concentrations of metals were determined using inductively coupled plasma optical emission spectrometry (ICP-OES, model Agilent 5100), with RF power 1.2 kW, nebuliser flow 0.7 L/min, plasma flow 12 L/min, stabilisation time 15 seconds, and sample uptake time 25 seconds. Recovery tests were performed using certified reference material for soil (ERM CC141), with recovery rates ranging from 80% to 120%.

Pollution assessment indicators

Recent investigations have assessed the degree of pollution in river sediments through the application of various pollution assessments indicators. Among these, the geo-accumulation index (I_{geo}), contamination factor (CF), enrichment factor (EF), and pollution load index (PLI) are most frequently employed to evaluate the extent of heavy metal contamination [13-15].

Geo-accumulation Index (I_{geo})

The geo-accumulation index (I_{geo}), first proposed by Müller [16], is a quantitative approach used to classify sediment contamination into distinct categories, ranging from uncontaminated to extremely contaminated. It is determined using the following equation:

$$I_{geo}=\log 2\ [C_i/\ (1.5\ Bi)] \qquad \text{(Eq. 1)}$$

where C_i represents the measured concentration (mg/kg) of the element in the sample, B_i is the geochemical background concentration (mg/kg) obtained from the control sample, and the constant 1.5 is a correction factor that accounts for natural fluctuations in background levels due to lithogenic effects.

Enrichment factor (EF)

The enrichment factor (EF), introduced by Sinex and Helz [17], is a widely applied quantitative approach for assessing the extent of anthropogenic influence on sediment or soil contamination. It normalises the concentration of a given metal to that of Fe as a reference element and compares this ratio with the corresponding background value (control sample), thereby distinguishing between natural and human-induced contributions. The EF is calculated using the following equation:

$$EF=(C_i/C_{ref})\ \text{sample}/(C_i/C_{ref})\ \text{background} \quad \text{(Eq. 2)}$$

where C_i is the concentration (mg/kg) of the element of interest and C_{ref} is the concentration (mg/kg) of the selected reference element, which is Fe. The C_i/C_{ref} sample corresponds to the sample, and the C_i/C_{ref} background denotes the control sample.

Contamination factor (CF)

The contamination factor (CF), proposed by Hakanson [18], is a commonly used quantitative index for evaluating the degree of metal contamination in sediments or soils. It represents the ratio of the measured concentration of a metal to its corresponding background or pre-industrial level. The CF is expressed as the following equation:

$$CF = C_i/ C_{background} \quad \text{(Eq. 3)}$$

where Ci is the concentration of the element in the sample and $C_{background}$ is the geochemical background concentration (control sample).

Pollution load index (PLI)

The Pollution Load Index (PLI), introduced by Tomlinson et al. [19], is a composite index used to assess the overall level of heavy metal pollution in sediments or soils by integrating the contamination factors (CF) of multiple metals. It provides a simple comparative measure for evaluating the degree of contamination at a particular site. The PLI is calculated as:

$$PLI=(CF1\times CF2\times CF3\times\cdots\times CFn)1/n \quad \text{(Eq. 4)}$$

where CF1, CF2..., CFn represent the contamination factors of the n metals analysed.

Statistical analysis

The IBM Statistical Package for Social Sciences (SPSS Version 21) was used for statistical analysis. As the data were normally distributed, Pearson's correlation coefficient was employed to assess the relationship between the metals. Hierarchical cluster analysis (HCA) and principal component analysis (PCA) were utilised to classify the heavy metal based on analogous possible pollution sources.

Results and Discussion

Distribution of heavy metals

Table 2 shows that the average concentrations of Cd, Cr, Cu, Fe, Mn, Ni, Pb, and Zn in the surface sediments of the Jengka River. These elevated levels are likely due to anthropogenic inputs, particularly from agricultural activities. Intensive fertiliser and pesticide use associated with oil palm plantations and smallholder farms may introduce Mn and Pb into the river system through surface runoff [4, 9].

L5, located in the upstream section near the main road of Felda Jengka 11, recorded the highest concentrations for all metals except Mn and Zn. The proximity of small-scale automotive workshops may contribute Pb and Zn through particulate deposition, lubricant leakage, and improper waste disposal [21]. Poultry farming activities in the area may also contribute Cr, Pb, and Cd via runoff containing manure enriched with trace metals from feed additives and metabolic waste [22-23]. In contrast, L1, located downstream, exhibited the lowest concentrations, likely due to hydrodynamic dilution and sediment dispersion effects [24-25].

All samples exceeded the control sample and the estimated average concentrations in shales and crustal materials of the Earth [26]. Based on the Interim Sediment Quality Guidelines (ISQG) established by the Canadian Council of Ministers of the Environment [27], most metal concentrations were below the guideline values, with an exception for Cu and Pb at L5.

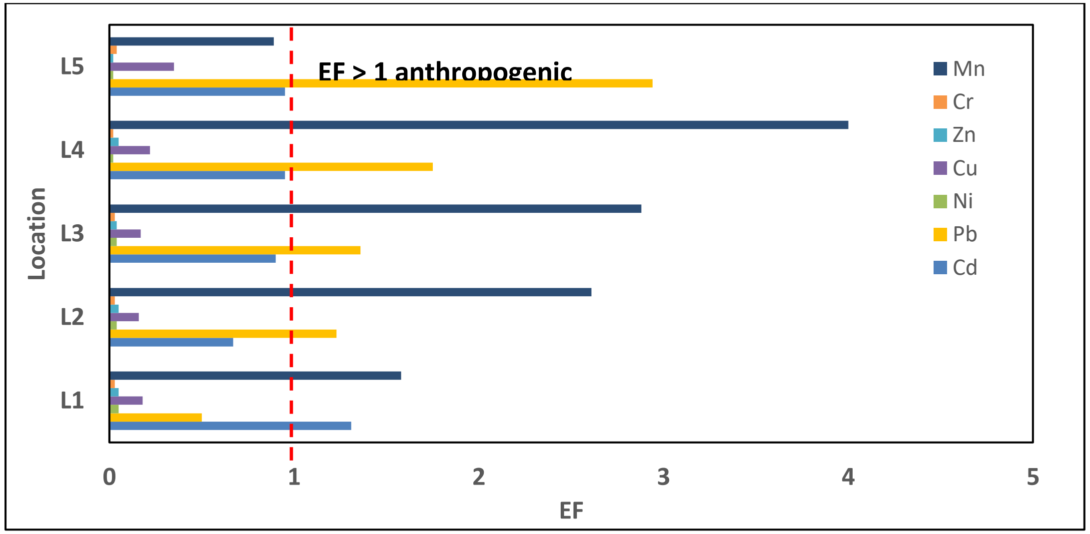
Enrichment Factor (EF)

In this study, enrichment factor (EF) values for Cd, Cr, Cu, Mn, Ni, Pb, and Zn across the five sampling points (L1–L5) in the Jengka River ranged from 0.02 to 4.00 (**Figure 2**). For most metals, EF values were below 1, indicating concentrations consistent with natural background levels and minimal anthropogenic influence. Cd values ranged from 0.67 to 1.31, also reflecting minimal enrichment. Cu (0.16–0.35), Zn (0.02–0.05), and Cr (0.019–0.039) remained within natural background ranges. However, the EF values for Pb indicated minor enrichment at L2-L5, with the highest value recorded at L5 (2.94). Mn showed consistently elevated enrichment at all locations except L5, peaking at L4 with an EF of 4.00, indicative of moderate enrichment potentially

Table 2. Average concentration of heavy metals in surface sediments ± standard deviation (mg/kg)

Locations	Cd	Cr	Cu	Fe (%)	Mn	Ni	Pb	Zn
L1	0.80 ± 0.72	12.80 ± 0.60	11.80 ±0.53	0.52 ± 0.007	271.53 ± 3.69	4.33 ± 0.46	10.13 ± 1.47	17.00 ± 0.92
L2	0.40 ± 0.00	12.67 ± 0.31	11.13 ± 0.50	0.51 ± 0.009	439.53 ± 27.78	4.67 ± 0.12	12.40 ± 5.19	16.87 ± 1.01
L3	0.60 ± 0.00	17.93 ±1.40	18.47 ± 1.17	0.57 ± 0.008	539.20 ± 26.88	7.07 ± 2.19	20.60 ± 7.02	22.20 ± 1.78
L4	0.60 ± 0.00	14.33 ± 0.81	18.87 ± 0.31	0.54 ± 0.002	712.73 ± 52.82	5.60 ± 0.20	26.47 ± 1.62	**28.00 ± 0.87**
L5	**0.67 ± 0.12**	**21.80 ± 0.72**	**39.47 ± 2.19**	0.60 ± 0.005	174.93 ± 9.73	**7.27 ± 0.42**	**49.47 ± 15.89**	20.40 ± 1.56
Range	0.40-0.80	14.33-21.80	11.13-39.47	0.51-0.60	174.93-712.73	4.33-7.27	10.13-49.47	17.00-28.00
Control	0.27 ± 0.12	6.27 ± 0.46	3.53 ± 0.12	0.23 ± 0.006	76.80 ± 6.43	2.00 ± 0.20	5.80 ± 1.51	7.00 ± 0.20
ISQG [27]	0.7	31.3	35.7	NA	NA	16	35	123

ISQG Interim Sediment Quality Guidelines, NA not available. Bold value indicates the highest concentration



EF < 1 No enrichment, 1 < EF < 3 Minor enrichment, 3 < EF < 5 Moderate enrichment

Figure 2. Enrichment factor (EF) value of heavy metals in surface sediments of the Jengka River

associated with local anthropogenic inputs. Overall, the findings highlight Pb and Mn as the metals most affected by localised anthropogenic sources in the study area.

Geo-accumulation index (I_{geo})

The geo-accumulation index (I_{geo}) classified the sediments of the Jengka River as predominantly in the unpolluted category ($I_{geo} \leq 0$) for most metals and sites [16]. Cd, Ni, Zn, and Cr recorded I_{geo} values below zero across all locations, confirming their concentrations are within natural background levels and are largely of geogenic origin (**Table 3**). Pb and Cu displayed slightly higher I_{geo} values at L5 (Pb = 1.71; Cu = 2.24), placing them in the moderately contaminated (Class 2). Mn at L4 also fell into the moderately contaminated (Class 2). However, Cu at L5 shows an I_{geo} value in Class 3, indicating a moderately to heavily contaminated condition. Overall, the Igeo classification indicates that the river sediments are mostly unpolluted, with only localised, low-level enrichment observed for Pb, Cu, and Mn.

Contamination factor (CF) pollution load index (PLI)

The contamination factor (CF) values for all metals in the Jengka River sediments exceeded 1, indicating moderate contamination across all sites. Cd (1.48–2.96), Ni (2.17–3.63), Zn (2.41–4.00), and Cr (2.02–3.48) consistently fell within the moderate contamination range (**Table 4**). Pb exhibited moderate contamination at L1–L3 (1.75–3.55), increasing to considerable levels at L4 (4.56) and reaching very high contamination at L5 (8.53). Cu ranged from considerable contamination at L1–L4 (3.15–5.34) to very high contamination at L5 (11.18). Mn showed moderate contamination at L1 (3.57) and L2 (5.78), with considerable to very high levels at L3 (7.09) and L4 (9.38). The pollution load index (PLI) also showed a similar pattern. The increasing PLI pattern downstream suggests cumulative contamination, with Pb, Cu, and Mn emerging as the dominant contributors to overall sediment pollution, consistent with findings by Çelen and Oruç [28].

Table 3. The I_{geo} value of the surface sediments in the Jengka River (bold values indicate the highest I_{geo} value)

Sampling points	Fe	Cd	Pb	Ni	Cu	Zn	Cr	Mn
L1	0.45	0.59	0.35	0.43	0.67	0.49	0.41	0.72
L2	0.44	0.30	0.43	0.47	0.63	0.48	0.41	1.16
L3	0.49	0.45	0.71	0.71	1.05	0.64	0.57	1.42
L4	0.47	0.45	0.92	0.56	1.07	0.80	0.46	**1.88**
L5	0.52	0.50	**1.71**	0.73	**2.24**	0.58	0.70	0.46
Average	0.48	0.46	0.82	0.58	1.13	0.60	0.51	1.13
Igeo Class*	1	1	2	1	3	1	1	2

* Class 0 = Igeo<0 uncontaminated; Class 1 = 0<Igeo<1 Uncontaminated to moderately contaminated; Class 2 = 1<Igeo<2 Moderately contaminated; Class 3 = 2<Igeo<3 Moderately to heavily contaminated.

Table 4. Contamination factor (CF) and pollution load index (PLI) of heavy metals in surface sediments of the Jengka River

Locations	Contamination Factor (CF)								PLI
	Cd	Cr	Cu	Fe	Mn	Ni	Pb	Zn	
L1	2.96	2.04	3.34	2.26	3.57	2.17	1.75	2.43	2.50
L2	1.48	2.02	3.15	2.21	5.78	2.33	2.14	2.41	2.48
L3	2.22	2.86	5.23	2.46	7.09	3.53	3.55	3.17	3.51
L4	2.22	2.29	5.34	2.34	9.38	2.80	4.56	4.00	3.64
L5	2.47	3.48	11.18	2.60	2.30	3.63	8.53	2.91	3.88

PI > 1 indicates pollution/contamination from anthropogenic sources, PLI > 1 indicates progressive or significant pollution

Potential sources of metal

Table 5 presents the correlation between metal concentrations in the Jengka River sediments at a confidence level of $p < 0.01$. Cr showed a strong relationship with Cu ($r = 0.920$), Fe ($r = 0.971$), Ni ($r = 0.844$), and Pb ($r = 0.817$). Cu also exhibited strong correlations with Fe ($r = 0.921$) and Pb ($r = 0.914$), as well as a moderate relationship with Ni ($r = 0.676$). Fe demonstrated strong correlations with Ni ($r = 0.808$) and Pb ($r = 0.790$). Zn and Mn were also strongly correlated ($r = 0.718$). However, Cd showed no correlation with the other metal elements.

Figure 3 shows the hierarchical cluster analysis for Cd, Cr, Cu, Fe, Mn, Ni, Pb, and Zn concentrations in the Jengka River sediments, forming two different groups. Clearly, Fe is considered a stand-alone cluster, with other metals (Cd, Cr, Cu, Mn, Ni, Pb, and Zn) in another cluster. This finding indicates that Fe is perhaps originally from natural sources, as Fe is a well-known abundant element in the Earth's surface [29]. In contrast, the other metal elements may be influenced by anthropogenic origins. Significant agricultural activities along the Jengka River could be a potential source of Cd, Cr, Cu, Mn, Ni, Pb, and Zn. Previous works by Razali et al. [30], Ghannam [31], and Abdullah et al. [32] have reported similar findings.

The factor loadings with varimax rotation suggested two factors, accounting for 79.12% of the cumulative variance (**Table 6**). Factor 1 was considered as the significant factor with the high variability (56.25%) of the dataset. This factor showed strong positive loading for Cr, Cu, Fe, Ni, and Pb, indicating these metals were sharing the same origins. Moreover, the dendrogram in Figure 3 supports that these metals were generated from similar sources, except for Fe, which is most likely from agricultural activities with extensive use of fertilisers and pesticides. Factor 2 demonstrated strong loadings for Mn and Zn, with a lower total variance of 22.94%. This factor may suggest additional potential sources of metal pollutants. As all sampling locations were located nearby main roads, it is believed that road runoff could contribute to Mn and Zn levels in the river sediment. The residual components of vehicles, such as tires and brakes, may potentially contribute to the road runoff and flow into rivers and settle as river sediment components [33].

Table 5. Pearson correlation between metal concentrations in the Jengka River sediments (bold values show strong correlation)

	Cd	Cr	Cu	Fe	Mn	Ni	Pb	Zn
Cd	1	0.067	0.082	0.054	-0.179	0.043	0.069	-0.031
Cr		1	**0.920****	**0.971****	-0.362	**0.844****	**0.817****	0.205
Cu			1	**0.921****	-0.424	0.676**	**0.914****	0.239
Fe				1	-0.305	**0.808****	**0.790****	0.311
Mn					1	-0.020	-0.258	**0.718****
Ni						1	0.589*	0.040
Pb							1	0.351
Zn								1

** Correlation is significant at the 0.01 level (2-tailed), * Correlation is significant at the 0.05 level (2-tailed).

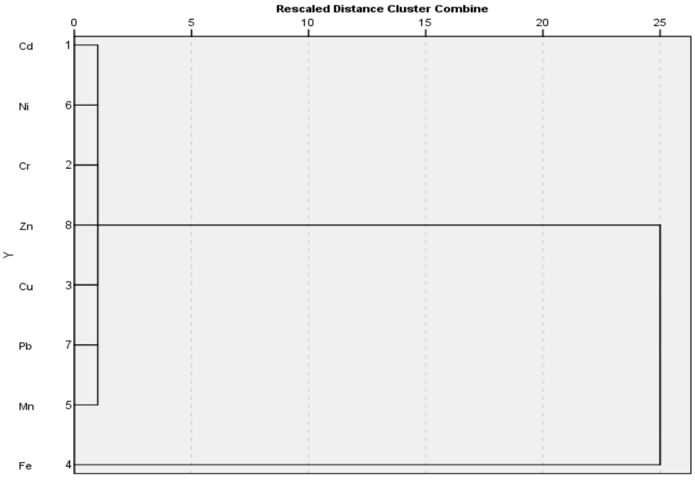


Figure 3. Dendrogram of the cluster analysis for metals in the Jengka River sediments

Table 7. Factor loading of metal in the Jengka River sediments after varimax rotation using principal component analysis (the factor in bold shows a strong factor loading)

	Factor 1	**Factor 2**
Cd	0.07	-0.25
Cr	**0.96**	-0.16
Cu	**0.94**	-0.20
Fe	**0.96**	-0.08
Mn	-0.22	**0.95**
Ni	**0.84**	0.16
Pb	**0.89**	-0.05
Zn	0.40	**0.86**
Eigenvalues	4.50	1.83
Variability (%)	56.25	22.94
Cumulative (%)	56.25	79.12

Conclusion

This study showed that heavy metals in the Jengka River sediments followed the order Fe > Mn > Pb > Zn > Cu > Cr > Ni > Cd. Pollution indices identified Location 5 (L5) as the most contaminated site, largely influenced by domestic discharges and nearby workshop activities. Principal component analysis (PCA) indicated that the metals originated from both natural and anthropogenic sources. Overall, the findings highlight the need for continuous monitoring and effective pollution control measures to preserve the ecological integrity of the Jengka River and minimise potential risks to aquatic life and human health.

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