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# Evaluation of heavy metal contamination in sediments of the Linggi River, Malaysia

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## Abstract

This study evaluates the concentrations and contamination levels of selected heavy metals (Mn, As, Cr, Fe, Zn, and Co) in surface sediments from seven locations along the Linggi River, Malaysia. Using Instrumental Neutron Activation Analysis (INAA), elemental concentrations were quantified, and contamination indices were applied to assess ecological risks. Results showed that arsenic (As) exhibited extremely high enrichment, with EF values ranging from 40.02 (S1) to 70.79 (S7), and Igeo values from 4.42 to 5.06, categorizing it as heavily to extremely polluted. Chromium (Cr) showed moderate enrichment (EF: 1.77–2.55; Igeo: –0.34 to 0.26), while zinc (Zn) had minor enrichment (EF: 1.01–1.51; Igeo: –0.92 to –0.57). Manganese (Mn), cobalt (Co), and iron (Fe) exhibited EF and Igeo values below 1 and 0, respectively, indicating minimal anthropogenic influence. The Pollution Load Index (PLI) values ranged from 1.02 (S5) to 1.37 (S7), confirming pollution across all sites, with S7 being the most contaminated. When compared against Canadian and Consensus Freshwater Sediment Quality Guidelines, arsenic and chromium levels exceeded Threshold Effect Levels (TEL) and Threshold Effect Concentrations (TEC), indicating significant ecological risk. These findings highlight the need for urgent environmental monitoring and pollution control in the Linggi River system.

**Keywords:** Aquatic ecosystems, Ecological risks, Environmental pollution, Heavy metal.

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## 1. Introduction

Sediments serve as a reservoir and a possible secondary source of harmful elements in an aquaculture ecosystem [1]. Volcanic eruptions and forest fires are natural sources of these elements. In addition, the natural weathering of rocks and soils release some of these elements, however, under natural conditions, industrial discharge, mining activities, urban runoff, agricultural fertilizers and pesticides, and atmospheric deposition are the primary sources of these elements and take a toll on the ecosystem [2-4]. Heavy metals, harmful elements, are a non-renewable resource. Once they are extracted, they are nearly impossible to replace them, thus it is critical to manage them tightly [5].

Sediment pH, redox conditions, organic matter, microbial activity, and grain size influence heavy metals as they settle, creating a complex system [6]. With some environmental shifts like acidification, resuspension, or anoxia, the heavy metals may be released into the water column, which makes them easier to be taken in biologically [7]. Long after the primary source of contamination is eliminated, this constant flux of metals and sediments threatens aquatic ecosystems, posing an ongoing risk [8].

The buildup of sediments containing heavy metals results in serious ecological problems. No raised amount of sediments containing heavy metals can disrupt the communities of benthic organisms, damage microbe processes necessary for nutrient recycling, and lower the overall biodiversity [9, 10]. Heavy metals are known for their bioaccumulation in aquatic organisms. Moreover, through biomagnification, their concentrations can increase. Fish and other aquatic animals which are exposed to and bioaccumulate heavy metals biomagnify tetrahydrofuran, seriously risking human health, and can expose humans to lifelong neurological damage, kidney dysfunction, developmental abnormalities, and various forms of cancer [11, 12].

Assessing heavy metal concentrations in sediments is essential for the evaluation of environmental assessment programs. It is particularly useful for tracking the trajectory of pollution, identifying pollution hotspots, and informing protective policies regarding human and ecosystem health. Given the heavy metal contamination threat, thorough research and monitoring are needed in order to achieve sustainable development and the best environmental practices in the regions of concern. The Linggi River is of particular concern as it supplies water to the Seremban and Port Dickson area for domestic and industrial uses. The Linggi River, was classified as class III by Department of Environment, Malaysia which has required extensive treatment for water resources. The pollution of the Linggi River was studied by Khan in 1990. However, there hasn't been any recent information published on the sediments collected from the Linggi River regarding heavy metal contamination. Assessment of heavy metals, degree of contamination and evaluation in comparison to the freshwater sediment quality guidelines (FSQGs) for the Linggi River remain sparse.

## 2. Materials and Methods

### *2.1. Sampling Locations*

Seven sampling locations were selected along the Linggi River, west coast of Peninsular Malaysia as shown in Figure 1. The surface sediment samples were collected by using a Ponar grab sampler. Sediment samples were kept in polyethylene bottle and transported to the laboratory. Sediments were dried in an oven at 60°C until constant weight, ground to a powder form with an agate mortar and then sieved through 63 µm mesh sieve and kept in polyethylene containers.

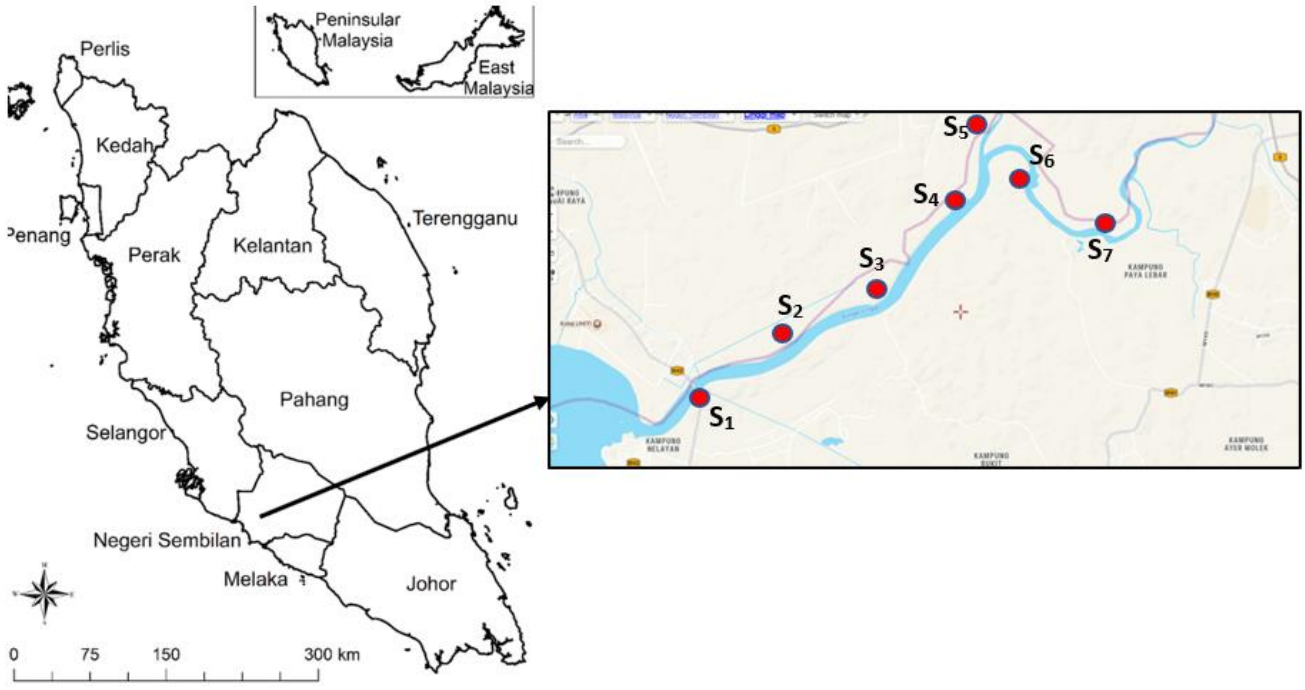


**Figure 1**.
Map of Sampling Locations.

*2.2. Sample Preparation for Instrumental Neutron Activation Analysis*

Powdered samples from each location were prepared in four replicates, with approximately 0.150 g and 0.200 g of each placed into separate heat-sealed polyethylene vials for short and long irradiation, respectively. Elemental concentrations were determined using the comparative method of Instrumental Neutron Activation Analysis (INAA). For calibration and quality control, blank samples and standard reference materials (SRMs) IAEA-Soil-7 and SL-1 (Lake Sediment) were irradiated using a pneumatic transport system at the MINT TRIGA Mark II research reactor, operating at 750 kW with a thermal neutron flux of $4.0 \times 10^{12}$ $cm^{-2}$ $s^{-1}$. The irradiation and counting times for the samples are summarized in Table 1.

**Table 1.**
Duration time of sample radiation and counting period.

| | Duration time | Cooling time | Counting time |
|---|---|---|---|
| Short radiation | 1 minute | 20 minutes | 5 minutes |
| | | 24 hours | 20 minutes |
| Long radiation | 6 hours | 3 - 4 days | 1 hour |
| | | 21-28 days | 1 hour |

A High-Purity Germanium (HPGe) detector, with an energy resolution of 1.8 keV at 1,332 keV for $^{60}Co$, was used for radioactivity counting. The detector was coupled with a multichannel analyzer (MCA) and gamma spectrometry system. Element identification was based on the specific energies of delayed gamma rays, while elemental concentrations were calculated using the intensity of the corresponding gamma peaks. The distance between the sample and the detector was adjusted according to the activity level of the irradiated samples maintained at 12–14 cm for short irradiation and 1–2 cm for long irradiation. Throughout all measurements, the system's dead time was kept at approximately 10% [13-17].

## 3. Results and Discussion

The SRM (IAEA Soil-7) was used as quality control and quality assurance in the analytical method analysis. The SRM measurement followed the same procedure as a sample analysis. The recovery percentage of the analysed SRM ranged from 86.5 to 112.2%.

The concentration of heavy metals is tabulated in Table 2. Mn concentrations ranged from $154 \pm 15$ mg/kg (S3) to $359 \pm 8$ mg/kg (S7). All values were below the average crustal value of 600 mg/kg, suggesting natural background levels. The highest Mn level in S7, while elevated compared to other sites, is still considered geogenically normal. As concentrations were significantly higher than the UCC value of 1.5 mg/kg, ranging from $48.3 \pm 1.0$ to $74.8 \pm 0.6$ mg/kg. The elevated levels, particularly in S2, S6, and S7, strongly suggest anthropogenic inputs, possibly from the use of arsenic-based agrochemicals or industrial effluents. Cr concentrations ranged from $41.5 \pm 0.7$ mg/kg (S5) to $62.8 \pm 0.4$ mg/kg (S7), all below the UCC reference of 92 mg/kg. This indicates that Cr in these samples likely originates from natural lithogenic sources. Fe concentrations were substantial, ranging from $18{,}335 \pm 422$ mg/kg (S5) to $30{,}541 \pm 1{,}093$ mg/kg (S3), but still below the UCC value of 35,000 mg/kg. The lower Fe levels in S5 suggest potential depletion, while relatively higher levels in S2 and S3 could be attributed to local iron-rich lithology. Zn concentrations varied from $75.1 \pm 1.0$ mg/kg (S5) to $96.3 \pm 0.8$ mg/kg (S7). All samples showed Zn enrichment relative to the crustal average (70 mg/kg). This could be indicative of anthropogenic contribution, possibly from urban runoff or waste discharge. Co levels were relatively low, ranging from $3.26 \pm 0.13$ to $4.42 \pm 0.23$ mg/kg, and substantially lower than the crustal average of 25 mg/kg. These results suggest a lack of contamination and a dominantly natural source.

**Table 2.**
Concentration of heavy metals in mg/kg.

| | S1 | S2 | S3 | S4 | S5 | S6 | S7 |
|---|---|---|---|---|---|---|---|
| Mn | 276 ± 59 | 198±42 | 154±15 | 326±25 | 304±9 | 348±29 | 359±8 |
| As | 48.3±1.0 | 65±3 | 60.4±0.3 | 57.0±2.6 | 52.4±1.1 | 69.5±1.0 | 74.8±0.6 |
| Cr | 55.8±1.3 | 59.0±0.45 | 54.0±0.4 | 55.0±1.9 | 41.5±0.7 | 57.4±0.5 | 62.8±0.4 |
| Fe | 28164±1752 | 30488±1998 | 30541±1093 | 24644±3147 | 18335±422 | 23897±332 | 24656±589 |
| Zn | 85.8±3.3 | 86.4±3.0 | 83.5±2.6 | 85.5±1.1 | 75.1±1.0 | 92.2±0.5 | 96.3±0.8 |
| Co | 4.20±0.33 | 4.42±0.23 | 4.24±0.06 | 4.07±0.08 | 3.26±0.13 | 4.26±0.27 | 4.36±0.06 |

Table 3 presents the measured concentrations of Mn, As, Cr, Fe, Zn, and Co in seven environmental samples (S1–S7), along with corresponding average upper continental crust (UCC) values for comparison. The elemental concentrations observed in the sediment samples show significant variations when compared to their respective upper continental crust (UCC) values. Manganese (Mn), with a crustal value of 600 µg/g, recorded a maximum concentration of 359 ± 8 µg/g in sample S7, indicating moderate enrichment. Arsenic (As) exhibited the most notable anomaly, with a maximum value of 74.8 ± 0.6 µg/g in S7, far exceeding its crustal reference of 1.5 µg/g—suggesting substantial anthropogenic input or natural enrichment. Chromium (Cr) in S7 also surpassed half of its crustal benchmark (92 µg/g), reaching 62.8 ± 0.4 µg/g. For iron (Fe), although its maximum concentration of 30,541 ± 1,093 µg/g in S3 remains below the UCC value of 35,000 µg/g, it is still relatively high, indicating possible lithogenic influence. Zinc (Zn) exceeded its crustal value of 70 µg/g, peaking at 96.3 ± 0.8 µg/g in S7, suggesting mild contamination. Cobalt (Co), however, remained well below its UCC threshold of 25

µg/g across all samples, with the highest concentration of 4.42 ± 0.23 µg/g observed in S2. Overall, sample S7 exhibited the highest concentrations for most trace elements, pointing toward it being a potential hotspot for elemental accumulation.

**Table 3.**
Concentration of metals from this study compared with crustal value in mg/kg.

| Element | Crustal Value (UCC)* | Min. | Max. | Sample with Max. |
|---|---|---|---|---|
| Mn | 600 | 154 ± 15 | 359 ± 8 | S7 |
| As | 1.5 | 48.3 ± 1.0 | 74.8 ± 0.6 | S7 |
| Cr | 92 | 41.5 ± 0.7 | 62.8 ± 0.4 | S7 |
| Fe | 35,000 | 18,335 ± 422 | 30,541 ± 1,093 | S3 |
| Zn | 70 | 75.1 ± 1.0 | 96.3 ± 0.8 | S7 |
| Co | 25 | 3.26 ± 0.13 | 4.42 ± 0.23 | S2 |

**Note:** *UCC values from Wedepohl [18] and Taylor and McLennan [19].

*3.1. Enrichment Factor (EF)*

The Enrichment Factor (EF) helps to identify whether the elements are from natural sources or due to anthropogenic activities. Iron (Fe) is used as the reference element. EF values greater than 2 suggest moderate to significant enrichment, indicating human-induced pollution. EF of heavy metals was determined based on the equation below [20]:

$$EF_{metal} = \frac{\left(\frac{M_{exp}}{Fe_{exp}}\right)_{sample}}{\left(\frac{M_{ref}}{Fe_{ref}}\right)_{shale}}$$

The terms $M_{exp}$ or $Fe_{exp}$ refer to the concentration of an element in the experimental sample, while $M_{ref}$ or $Fe_{ref}$ represent the concentration of a commonly abundant reference element in average shale, as reported by Turekian and Wedepohl [21]. The enrichment factor (EF) is interpreted as follows:

- EF < 1 indicates no enrichment,
- EF between 1 and 3 suggests minor enrichment,
- EF between 3 and 5 indicates moderate enrichment,
- EF between 5 and 10 shows moderately severe enrichment,
- EF between 10 and 25 reflects severe enrichment,
- EF between 25 and 50 suggests very severe enrichment, and
- EF greater than 50 indicates extremely severe enrichment.

Table 4 presents the enrichment factor (EF) values for the analyzed elements across the sediment samples reveal distinct patterns of contamination and potential anthropogenic influence. Arsenic (As) displays the highest EF values among all elements, ranging from 40.02 in S1 to a peak of 70.79 in S7, indicating extremely high enrichment and likely contamination beyond natural background levels. Chromium (Cr) shows moderate enrichment with EF values between 1.77 (S3) and 2.55 (S7), suggesting possible anthropogenic input. Zinc (Zn) exhibits minor enrichment, with EF values consistently above 1.0, reaching up to 1.51 in S5, which may be indicative of low-level contamination. Manganese (Mn) shows minimal enrichment, with values below 1.0 in most samples, implying a predominantly natural origin. Cobalt (Co) maintains low EF values ranging from 0.19 to 0.25, suggesting no significant anthropogenic contribution. Notably, iron (Fe) was used as the reference element and thus maintains a constant EF value of 1.00 across all samples. Overall, As stands out as the most enriched element, particularly in sample S7, pointing to potential localized contamination sources.

**Table 4.**
Enrichment Factor (EF) of heavy metals in mangrove sediments from Linggi River.

| Element | S1 | S2 | S3 | S4 | S5 | S6 | S7 |
|---|---|---|---|---|---|---|---|
| Mn | 0.57 | 0.38 | 0.29 | 0.77 | 0.97 | 0.85 | 0.85 |
| As | 40.02 | 49.75 | 46.15 | 53.97 | 66.68 | 67.86 | 70.79 |
| Cr | 1.98 | 1.94 | 1.77 | 2.23 | 2.26 | 2.40 | 2.55 |
| Fe | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 |
| Zn | 1.12 | 1.04 | 1.01 | 1.28 | 1.51 | 1.42 | 1.44 |
| Co | 0.21 | 0.20 | 0.19 | 0.23 | 0.25 | 0.25 | 0.25 |

*3.2. Geoaccumulation Index (Igeo)*

The Geoaccumulation Index (Igeo), introduced by Müller [22] is widely used to evaluate whether the concentration of a metal exceeds natural background levels. It helps assess the intensity of pollution by comparing current concentrations with baseline values. An Igeo value greater than 0 indicates contamination, while values above 4 reflect heavy to extreme

pollution. Based on Müller [22] classification, the degree of metal pollution is divided into seven classes. The Igeo is calculated using the following formula:

$$I_{geo} = log_2\left[\frac{c_n}{1.5 \times B_n}\right]$$

In the Igeo calculation, *Cn* represents the concentration of the element in the sample, while *Bn* refers to the background or baseline concentration. A constant factor of 1.5 is included to account for natural variations in background values that may arise due to lithological differences in the sediments. The Igeo values are classified into seven categories, ranging from unpolluted to extremely polluted conditions. Specifically:

- Igeo < 0: Class 0 – unpolluted
- 0 ≤ Igeo < 1: Class 1 – unpolluted to moderately polluted
- 1 ≤ Igeo < 2: Class 2 – moderately polluted
- 2 ≤ Igeo < 3: Class 3 – moderately to heavily polluted
- 3 ≤ Igeo < 4: Class 4 – heavily polluted
- 4 ≤ Igeo < 5: Class 5 – heavily to extremely polluted
- Igeo ≥ 5: Class 6 – extremely polluted

Table 5 shows the geo-accumulation index (Igeo) values across the sediment samples indicate varying levels of elemental pollution. Arsenic (As) stands out with significantly high Igeo values, ranging from 4.42 in S1 to 5.06 in S7, categorizing it as *strongly to extremely polluted* and suggesting severe anthropogenic contamination. Chromium (Cr) shows values fluctuating between -0.34 and 0.26, placing it in the *unpolluted to moderately polluted* category, with the highest level detected in S7. Zinc (Zn) and Manganese (Mn) both exhibit negative Igeo values, indicating an *unpolluted* status, though Mn values show a slight upward trend toward S7. Iron (Fe) also shows consistently negative values from -0.78 to -1.52, suggesting no contamination and reflecting its natural lithogenic origin. Cobalt (Co) demonstrates the lowest Igeo values, from -3.08 to -3.52, indicating a very clean and unpolluted environment. Overall, arsenic is the only element that exceeds safe background levels significantly, especially in sample S7, highlighting it as the primary pollutant of concern in the study area.

**Table 5.**
Geoaccumulation index ($I_{geo}$) of heavy metals in mangrove sediments from Sungai Besar River.

| Element | S1 | S2 | S3 | S4 | S5 | S6 | S7 |
|---|---|---|---|---|---|---|---|
| Mn | -1.71 | -2.18 | -2.55 | -1.47 | -1.57 | -1.37 | -1.33 |
| As | 4.42 | 4.85 | 4.75 | 4.66 | 4.54 | 4.95 | 5.06 |
| Cr | 0.09 | 0.17 | 0.04 | 0.07 | -0.34 | 0.13 | 0.26 |
| Fe | -0.90 | -0.78 | -0.78 | -1.09 | -1.52 | -1.14 | -1.09 |
| Zn | -0.73 | -0.72 | -0.77 | -0.74 | -0.92 | -0.63 | -0.57 |
| Co | -3.16 | -3.08 | -3.14 | -3.20 | -3.52 | -3.14 | -3.10 |

*3.3. Pollution Load Index (PLI)*

The Pollution Load Index (PLI) provides a comprehensive assessment of the overall degree of heavy metal contamination at each sampling site. It is calculated using the formula:

$$PLI = (CF_1 \times CF_2 \times CF_3 \times ... \times CF_n)^{1/n}$$

where CF represents the contamination factor of each metal and n is the number of metals considered. A PLI value greater than 1 indicates anthropogenic influence and progressive pollution, while a value equal to or below 1 suggests low contamination or natural background levels. This index serves as a valuable tool for comparing pollution levels across different sites, facilitating the identification of locations with potential environmental concerns [23].

Table 6 shows the PLI values across the sediment samples. The PLI values for the sediment samples provide a cumulative indication of the overall pollution status at each site. PLI All samples recorded PLI values greater than 1.0, suggesting the presence of pollution across the study area. Sample S7 exhibited the highest PLI value of 1.37, indicating the most contaminated site, likely due to elevated levels of multiple trace elements. This is followed closely by S6 (1.31) and S2 and S4 (both at 1.22), reflecting moderate pollution levels. Samples S1 and S3 showed slightly lower PLI values of 1.19 and 1.13, respectively, while S5 recorded the lowest PLI value of 1.02, suggesting relatively minimal contamination. Overall, the PLI data confirm that all sampling locations are affected by pollution to varying degrees, with S7 being the most impacted.

**Table 6.**
Polution level index (PLI) of heavy metals in mangrove sediments from Linggi River.

| Sample | PLI Value |
|---|---|
| S1 | 1.19 |
| S2 | 1.22 |
| S3 | 1.13 |
| S4 | 1.22 |
| S5 | 1.02 |
| S6 | 1.31 |
| S7 | 1.37 |

Comparison of toxic element concentrations in sediments of Malaysian rivers with freshwater sediment quality guidelines showed in Table 7. The average concentrations of heavy metals in the current study were 281.1 ± 81.7 mg/kg for Mn, 61.0 ± 8.9 mg/kg for As, 55.1 ± 6.6 mg/kg for Cr, 25,831 ± 4,532 mg/kg for Fe, 86.9 ± 6.7 mg/kg for Zn, and 4.16 ± 0.41 mg/kg for Co. These values fall within or exceed the ranges reported in previous studies conducted in various Malaysian locations. Elias, et al. [24] recorded a wide range of As (3.6–65.9 mg/kg) and Cr (1.8–105 mg/kg) values, with Zn concentrations ranging from 12.4 to 430 mg/kg. These values are comparable to or slightly lower than those reported by Nadia [25] reported comparable values for As (63.04 ± 0.90 mg/kg) and Cr (52.62 ± 1.03 mg/kg), while Mn and Fe concentrations were slightly higher at 334.42 ± 29.02 mg/kg and 29,261.68 ± 367.88 mg/kg, respectively. Krishnan, et al. [16] in a study at Pasir Gudang, recorded lower As levels (21.72 ± 0.46 mg/kg) and slightly lower Fe (22,856 ± 830 mg/kg). Metal concentrations reported from Sepang showed considerably lower levels for As and Cr, ranging from 3.316–9.827 mg/kg and 5.340–15.815 mg/kg, respectively [15] while Sepang 2 recorded moderate Mn (137.68 mg/kg), As (16.95 mg/kg), and Fe (23,659 mg/kg) concentrations [15]. When compared to international sediment quality guidelines, such as the Canadian-FSQGs and Consensus-FSQGs, the concentrations of As and Cr in the current study notably exceed the Threshold Effect Levels (TEL) and the Threshold Effect Concentrations (TEC), indicating potential ecological risks. Specifically, As (61.0 mg/kg) surpasses the TEL (5.9 mg/kg), PEL (17.0 mg/kg), and TEC (9.79 mg/kg), while Cr (55.1 mg/kg) is above TEL (37.3 mg/kg) and TEC (43.4 mg/kg), but remains below the Probable Effect Level (PEL) and Probable Effect Concentration (PEC) values [26]. These findings suggest elevated contamination levels for certain metals, particularly As, and underscore the need for further monitoring and management of sediment quality in the study area.

**Table 7.**
Comparison of toxic element concentrations in sediments of Malaysian rivers with freshwater sediment quality guidelines.

| | Mn. | As | Cr | Fe | Zn | Co | References |
|---|---|---|---|---|---|---|---|
| Current study | 281.1 ±81.7 | 61.0±8.9 | 55.1±6.6 | 25831±4532 | 86.9±6.7 | 4.16±0.41 | |
| Linggi river 2018 | NA | 3.6 – 65.9 | 1.8 – 105 | NA | 12.4 –430 | NA | Elias, et al. [24] |
| Linggi river 2025 | 334.42±29.02 | 63.04±0.90 | 52.62±1.03 | 29,261.68±367.88 | 151.86±5.32 | 5.25±0.36 | Nadia [25] |
| pasir Gudang 2022 | NA | 21.72± 0.46 | NA | 22856 ±830 | 69.94 ±7.07 | | Krishnan, et al. [16] |
| Sepang river 1(2022) | NA | 3.316 - 9.827 | 5.340- 15.815 | NA | NA | 1.434 - 3.122 | Krishnan, et al. [17] |
| Sepang 2 (2022) | 137.68 | 16.95 | | 23659 | 91.78 | | Kumar, et al. [15] |
| | | | | | | | |
| Canadian-FSQGs – TEL | NA | 5.9 | 37.3 | NA | 123 | NA | Canadian Council of Ministers of the Environment (CCME) [27] |
| Canadian-FSQGs – PEL | NA | 17.0 | 90.0 | NA | 315 | NA | Canadian Council of Ministers of the Environment (CCME) [27] |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Consensus-FSQGs – TEC value | NA | 9.79 | 43.4 | NA | 121 | NA | MacDonald, et al. [26] |
| Consensus-FSQGs – PEC value | NA | 33.0 | 111 | NA | 459 | NA | MacDonald, et al. [26] |

**Note:** NA- Not available.

## 4. Conclusion

The present investigation provides critical insight into the spatial distribution and ecological implications of heavy metal contamination in the sediments of the Linggi River. The application of geochemical indices such as EF, Igeo, and PLI revealed that arsenic is the dominant contaminant, with levels far exceeding natural background values and international sediment quality guidelines. Other elements, including Cr and Zn, also showed signs of mild to moderate enrichment, whereas Mn, Fe, and Co were largely attributed to natural sources. Notably, all sediment samples demonstrated PLI values greater than 1, indicating pollution across all sites, with sample S7 being the most heavily impacted. The elevated As and Cr concentrations underscore the potential ecological and human health risks, likely originating from agricultural runoff, industrial effluents, and other anthropogenic sources. This study emphasizes the urgent need for regular environmental monitoring and proactive management strategies to address sediment pollution and ensure the long-term sustainability of the Linggi River ecosystem.

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