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# Heavy Metal Contamination in Taft River Sediments Affected by Bagacay Mine Post-Operation in Hinabangan, Samar, Philippines

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**ABSTRACT**

The purpose of this study was to assess the level of heavy metal contamination in the sediments of the Taft River Basin in Taft Eastern Samar, Philippines. The concentrations and levels of heavy metal contamination in sediments were assessed using the Pollution Load index (PLi), the Contamination Factor (Cfi), and the Geoaccumulation Index (Igeo). Our findings revealed moderate to high levels of potentially toxic elements (PTEs) such as Ti, Cr, Mn, Ni, Cu, Zn, As, Mo, Cd, and Pb. The CF and Igeo values indicated significant pollution, with Igeo values ranging from class 2 to class 6. The CFi indicated moderate to high contamination in river bank sediments following the order of Pb>As>Zn>Mo>Mn>Cu>Ni>Cr>Ti>Cd, and Pb>Cu>Zn>As>Mn>Cr>Ni>Mo>Ti>Cd in river bottom sediments. The PLi values exceeded the critical threshold of 1, confirming severe contamination, especially in the upper reaches of the river near the Bagacay mining site. The contamination showed a consistent presence of heavy metals, with Pb, As, Zn, and Mo being dominant in river bank sediments, and Cu, Pb, Zn, and As in river bottom sediments. Downstream attenuation of PTE levels was observed and is attributed to dilution and sedimentation processes. Overall, the study confirmed the contamination of these heavy metals in the sediments and underscored the need for rehabilitating the Bagacay mine to prevent the buildup of these contaminated sediments in the basin. It is recommended to expand monitoring to include groundwater and biotic components to better assess long-term ecological risks. Regular sediment quality assessments, and multi-stakeholder watershed management are essential for the sustainable health of the Taft River and its surrounding communities.

## 1. INTRODUCTION

Concerns over the effects of mining on the aquatic ecosystem are growing (Gabrielyan et al., 2018). Aquatic ecosystems like rivers are considered sinks of contaminants because they are open systems and are therefore more vulnerable to contamination. The accumulation of contaminants in rivers impacted by mining activities is a prevalent issue in many developing countries (Islam et al., 2014). In the Philippines, inactive and abandoned mines expose and disturb heavy metal-laden soils and sediments, posing significant environmental and health risks (Samaniego et al., 2024).

A notable example is the Bagacay Mines in Samar, which was abandoned after years of operation, leaving behind massive amounts of mining waste containing extremely high concentrations of heavy metals. These pollutants have significantly affected the quality of the Taft River Basin, which receives drainage from the mining site. The conditions of the Taft River before the mining operation supported a relatively intact aquatic environment. However, post-

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mining activities, especially the unrehabilitated waste piles, have contributed to the degradation of the river ecosystem. The riverbed sediments of the primary tributaries stretching from the Bagacay mine site to the Taft River have exhibited levels of heavy metal contamination exceeding critical limits, such as those set by the U.S. Environmental Protection Agency (EPA) and the Canadian Environmental Quality Guidelines (CEQG) for heavy metals in sediments. These excessive levels include arsenic (9.79 mg/kg), lead (50 mg/kg), and cadmium (1.0 mg/kg) (Dayang, 2017).

Heavy metal contamination of sediments has aroused significant concern due to the toxicity, persistence, and bioaccumulation of these pollutants (Yang et al., 2012), as well as the potential risks they pose to human health and aquatic organisms (da Silva et al., 2017). Despite this, most river monitoring practices focus on water quality alone, often overlooking the role of sediments, which continuously interact with the river system (Duncan et al., 2018). In fact, most heavy metals entering the aquatic environment become incorporated into the sediments through flocculation and precipitation (Zhou et al., 2023). Under certain conditions, these heavy metals can also be released from the sediment and reintroduced into the water column, making sediments both sinks and potential secondary sources of contamination.

The presence of toxic heavy metals in sediments threatens the health and balance of the aquatic ecosystem. They can accumulate in microorganisms, aquatic animals, and plants, potentially entering the food chain and posing a serious threat to human health (Feng et al., 2024; Kang et al., 2020). For instance, crustaceans such as mud crabs and shrimp found in the Taft River have shown elevated levels of heavy metals (Cabahug et al., 2023), highlighting the river's contamination from mining pollutants. These organisms, which occupy the lower trophic levels, absorb heavy metals from polluted water and sediments, posing a serious risk to local biodiversity and potentially affecting human populations who rely on them for food. Furthermore, heavy metal-laden sediments may be transported by runoff and precipitation, causing erosion of riverbanks and deposition of pollutants into nearby coastal areas. These sediments act as long-term storage for heavy metals and may affect marine ecosystems and public health (Sabijon et al., 2024). Once bound to sediments, heavy metals become persistent and are considered among the most hazardous pollutants in aquatic environments. Contamination of Cu, Hg, Cd, Fe, and Zn in the sediments of Ambon Bay, located in Maluku Province, Indonesia, was reported by Manullang et al. (2017). Similarly, surface sediments of the Mangonbangon River in Tacloban City have shown the presence of Fe>Mn>Zn>Cu>Cr>Ni>Co (Decena et al., 2018). Belyaeva (2012) likewise reported high concentrations of heavy metals and trace elements such as As, Cu, Mo, Sb, Co, Ni, and Zn in the surface waters and sediments of the Voghji River Basin in Ararat Plain region of Armenia.

Since heavy metal concentrations in sediments are typically much higher than those in surface water, it is critical to evaluate sediment quality as a reliable indicator of pollution (Wang et al., 2014). Unlike water, metal concentrations in sediments remain relatively stable over time (Tupan et al., 2014). However, despite the known environmental risks posed by the Bagacay Mines, limited information is available on the contamination of sediments in the Taft River Basin. Therefore, this study was conducted to assess the extent of heavy metal contamination in the sediments of the Taft River Basin, particularly as affected by post-operational discharges and waste from the Bagacay Mines.

## 2. METHODOLOGY

### 2.1 Study area

The study was done in the Taft River Basin, located between 11°54′N latitude and 125°25′E longitude. The region where the site is located experiences a humid tropical monsoon climate (Cayanan et al., 2018) with annual rainfall ranging from 2,500 mm in Northwest Leyte to over 3,000 mm in Borongan, Eastern Samar, and an average temperature of approximately 28°C. The study area is specifically located in the Taft River in Hinabangan, Samar, Philippines, a region with a documented history of mining and agricultural activities. A significant contributor to environmental degradation in the area was inefficient waste management and the unprogrammed abandonment of Bagacay Mine, which was operational from the mid-20$^{th}$ century until its closure in 1996. The mine was primarily engaged in the extraction of nickel and copper, and its operations led to substantial discharge of mine tailings and heavy metal contaminants into nearby rivers, including the Taft River (MGB, 2005; Dayang, 2017). These contaminants, such as nickel, copper, zinc, and arsenic, remain in the soil and aquatic systems due to their persistent and mobile nature.

The geology of the Bagacay area is predominantly composed of Miocene to Pliocene volcanic and volcaniclastic rocks, including andesitic to basaltic flows, pyroclastics, and tuffaceous sediments, which are part of the Bagacay Formation (MGB, 2005). The area hosts polymetallic sulfide mineralization, consisting mainly of copper, lead, zinc, gold, and silver, associated with hydrothermal alteration zones such as silicification and argillic alteration. Mineralization occurs along vein and fracture systems, indicating that the deposit is structurally controlled, and suggests characteristics of a volcanogenic massive sulfide (VMS) or epithermal-type deposit. The mining activities in the area have exposed mineralized zones and left behind tailings rich in heavy metals, contributing to long-term environmental impacts (MGB, 2005).

A preliminary survey of the Taft River floodplain was conducted to identify representative sampling sites and document ecological conditions. Field observations revealed signs of environmental degradation, including discolored water, sediment plumes, and riverbed alteration, suggesting continued pollution. Soil samples collected across the floodplain showed elevated heavy metal concentration (Sabijon et al., 2024).

The soils in the area which area classified as Eutrudepts derived from limestone (calcite-rich) parent material, have undergone extensive degradation due to decades of cultivation, flooding, and erosion (Asio et al., 2006). Today, agricultural use is limited, and vegetation consists mainly of grasses, shrubs, and isolated crops. In addition to mining, periodic flooding and soil erosion have contributed to the downstream transport and deposition of contaminated sediments, compounding the environmental risks and underscoring the need for ongoing monitoring and rehabilitation efforts.

### 2.2 Sediment sample collection and analysis

Figure 1 and Table 1 show the selected sample collection points in different barangays along the Taft River in Eastern Samar. The barangays are a rural village in Eastern Samar and the smallest administrative unit in the Philippines, functions similarly to a village or neighborhood in other countries. Sediment samples were collected during the rainy season (27 October to 03 November 2020) to capture the potential peak influx of heavy metals associated with surface runoff from the Bagacay Mining site. Rainfall events significantly enhance the mobilization and transport of heavy metals from exposed soils, mine tailings, and disturbed catchments into the Taft river system. Sampling during this period provides a more accurate representation of heavy metal input into sediments. The air-dried sediment samples were pulverized using a wooden mallet to prevent contamination from metallic tools, which can introduce trace metals and affect the accuracy of heavy metal analysis (US EPA, 1996). The pulverized samples were then passed through a 2 mm mesh sieve to remove coarse debris and to isolate the fine fraction, which is more representative of heavy metal accumulation due to its higher surface area and binding capacity (US EPA, 1996). Prepared samples were subjected to laboratory analyses to evaluate their heavy metal concentrations. The analysis for heavy metal concentrations was conducted following the same procedure (Figure 2) of Ultra (2020) and Sabijon et al. (2024) at the Soil Sciensce Laboratory of the Department of Sustainable Natural Resources, School of Earth Sciences and Engineering, Botswana International University of Science and Technology, Palapye, Botswana.

**Table 1.** Coordinates and relative proximity of the sampling sites from the Bagacay Mines

| Sampling Sites | Latitude | Longitude | Distance from Bagacay Mines (km) |
|---|---|---|---|
| San Rafael | 11.80861111 | 125.2952778 | 5.332 |
| Binaloan | 11.85194444 | 125.3247222 | 13.172 |
| Malinao | 11.873824 | 125.347566 | 17.482 |
| San Pablo | 11.88027778 | 125.36 | 20.112 |
| Mabuhay | 11.89777778 | 125.3688889 | 22.637 |
| Gayam | 11.88531 | 125.39912 | 26.629 |
| Pob.6 | 11.90916667 | 125.4152778 | 32.049 |
| Pob. 1 | 11.90138889 | 125.4216667 | 33.131 |
| Polangi | 11.88777778 | 125.4219444 | 34.917 |

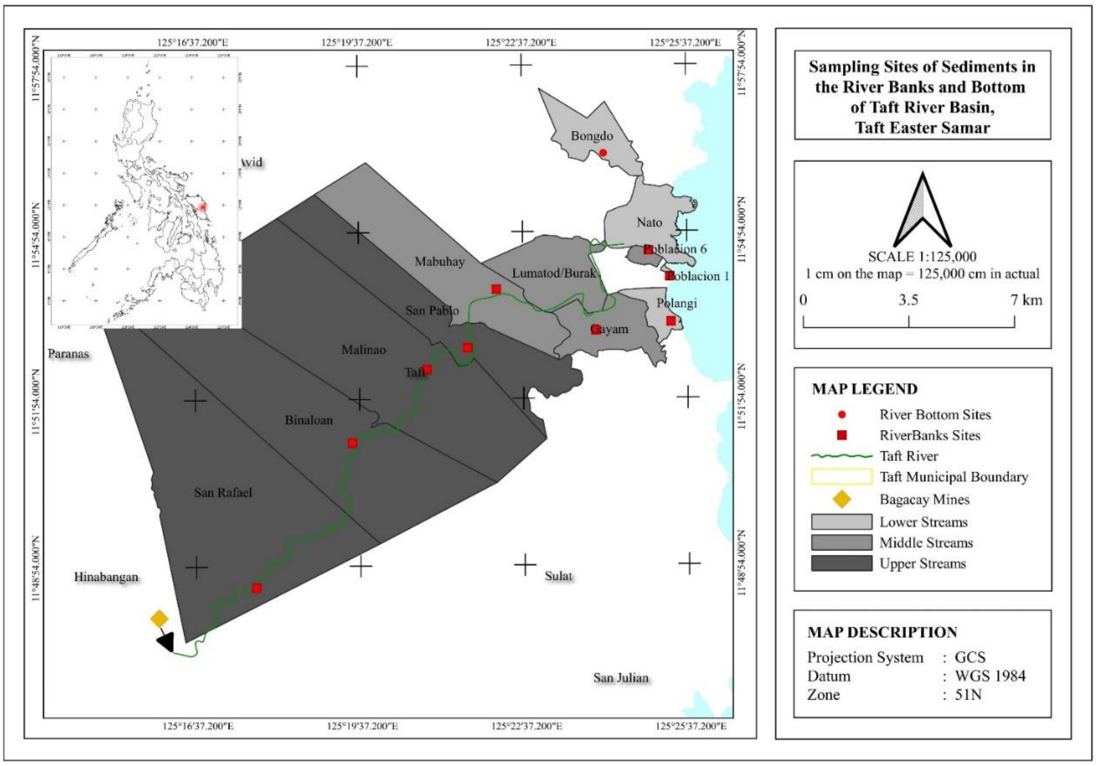



**Figure 1.** Map showing the sampling sites of sediments in Taft River Basin

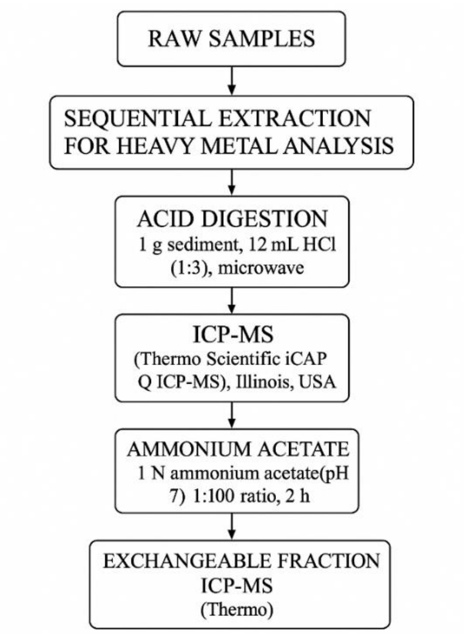



**Figure 2.** Flow chart of the procedural analyses for heavy metals

## 2.3 Sediment contamination indices

*2.3.1 Geoaccumulation index*

The geoaccumulation index was used to determine the degree of contamination in a sample (Müller, 1979) whuch was estimated using the formula:

$$\text{Igeo} = \log_2\left(\frac{\text{Cn}}{1.5\text{Bn}}\right) \qquad (1)$$

Where; Cn is the metal (n) concentration measured in the study area's sediments, Bn is the background value of the corresponding metal (n), and factor 1.5 is the background matrix correction for lithogenic effects (Salomons and Forstner, 1984).

*2.3.2. Contamination factor*

The contamination factor (CFi), a single metric, is regarded as a simple and useful instrument for monitoring heavy metal contamination (Shen et al., 2019). CFi is calculated using this equation:

$$\text{CFi} = \frac{\text{Ci}}{\text{Bi}} \qquad (2)$$

Where; Ci and Bi are the measured concentration and background value of metal i, respectively. CFi is an indicator of heavy metal contamination in sediments. The background concentrations of heavy metals (in mg/kg) were determined from non-contaminated samples collected within the same area. The values were as follows: Ti (3697), Cr (43.2), Mn (242), Ni (38), Cu (15), Zn (55.6), As (8.7), Mo (3.4), Cd (6.6), and Pb (5.5).

*2.3.3 Pollution load index (PLi)*

Tomlinson et al. (1980) employed the PLi to determine the site's total amount of heavy metals. The PLi value for a site in the sediments was computed using the following formula:

$$PLi = (CF1 \times CF2 \times CF3 \times \ldots \times CFn)1/N \quad (3)$$

Where; CFi is the ratio of the observed concentration (Ci) to the number of heavy metals. PLi>1 indicates contaminated, while PLi<1 indicates unpolluted. A PLI level value of 0 denotes excellence, a PLI value of 1 reflects baseline pollution levels, and a PLI value of =>1 indicates progressive degradation of sediment quality.

The Kriging interpolation method was applied in the study using QGIS to create the Pollution Load Index (PLI) map of heavy metals in river sediments, owing to its ability to model spatial autocorrelation and deliver statistically reliable predictions. Kriging is preferred over simpler methods like IDW because it not only interpolates values but also quantifies uncertainty, making it well-suited for environmental assessments. Its effectiveness in mapping heavy metal contamination in soils and sediments has been widely supported in the literature (Zhang et al., 2011; Eze et al., 2018).

## 3. RESULTS

### 3.1 Total concentrations of heavy metals in river sediments

In Figures 3(a-j) and 4(a-j), the Ti concentrations in most of the collected river sediments were higher than the permissible concentration (WHO, 1982). The concentration ranged from 2,869-6,012 mg/kg in the river bank sediments and 2,914-6,224 mg/kg in the river bottom sediments. The highest concentration in river bank sediments was observed in Barangay ("Brgy") Poblacion 6 (lower stream), and in Brgy. Malinao (upper stream) for bottom sediments.

According to Kabata-Pendias and Pendias (2001), the overall concentrations of Cr in sediments were higher than the critical threshold of 75-100 mg/kg, except for the river bank sediments of Brgy. Polangi (lower stream) and river bottom sediments of Brgy. Binaloan (upper stream). Cr concentrations in most river bank sediments and river bottom sediments ranged from 112.24-624.20 mg/kg and 140-1,768 mg/kg, respectively. These values are 1.4-17.7 times and 1.1-6.2 times higher than the critical limit. The highest Cr concentration in river bank sediments was found in Brgy. Burak, and in Brgy. Bungdo (both middle stream) for river bottom sediments.

Also, Mn concentrations of river sediments in all sites were found to be lower compared to the critical level of 600 mg/kg (Vodyanitskii, 2016), except for Brgy. San Pablo (upper stream) which recorded 720 mg/kg. Generally, all river sediments were found to have have safe concentrations of Mn.

Additionally, the total Ni concentration in the river bank sediments of Barangays San Rafael, Binaloan (upper stream), Gayam (middle stream), Poblacion 6, Poblacion 1, and Polangi (lower stream) exceeded the 100 mg/kg threshold level (Kabata-Pendias and Pendias, 2001). The river bank sediments around Brgy. Polangi recorded the highest concentration, which was 98 times greater than the threshold amount (98,194 mg/kg). For bottom sediments, only samples from Brgys. Malinao (upper stream), Gayam and Bungdo (middle stream), and Polangi (lower stream) had Ni concentrations above the critical level. The highest Ni concentration was observed in Brgy. Bungdo (middle stream) at 435 mg/kg, which is four times higher than the critical limit. Relatively higher total Cu concentrations above the critical level of 60-125 mg/kg were observed in most of the river bank sediments, except for samples from Brgy. Poblacion 1 and Brgy. Polangi (lower stream), and in all bottom sediments except for Brgy. Bungdo (middle stream). River bank and bottom sediment Cu concentrations ranged from 144-1,244 mg/kg and 144-3,116 mg/kg, respectively.

The highest concentration in river bank sediments was recorded in Brgy. San Rafael (upper stream) at 1,244 mg/kg, which is ten times higher than the highest critical threshold. In bottom sediments, the highest Cu concentration was detected in samples from Brgy. San Pablo (upper stream) at 3,116 mg/kg. A higher concentration trend of Cu was observed in samples from the upper stream, likely due to proximity to a mining site.

The majority of the river bank and bottom sediments contained high quantities of Zn. Zn concentrations were above the minimum critical value of 70 mg/kg (Kabata-Pendias and Pendias, 2001), ranging from 196-2,276 mg/kg in river bank sediments and 167-5,064 mg/kg in river bottom sediments. Brgy. Poblacion 6 (lower stream) had the greatest Zn concentrations in both river bank (2,276 mg/kg) and river bottom sediments (5,064 mg/kg), which are 33 and 72 times higher than the minimum critical level, respectively. The same trend was observed for arsenic (As), which was higher in all river sediments. Values for both river bank and bottom sediments were above the critical level of 1-40 mg/kg (ATSDR, 2007), ranging from 123-6,252 mg/kg. The highest As concentrations were found in both river bank and bottom sediments of Brgy. Poblacion 6 (lower stream).

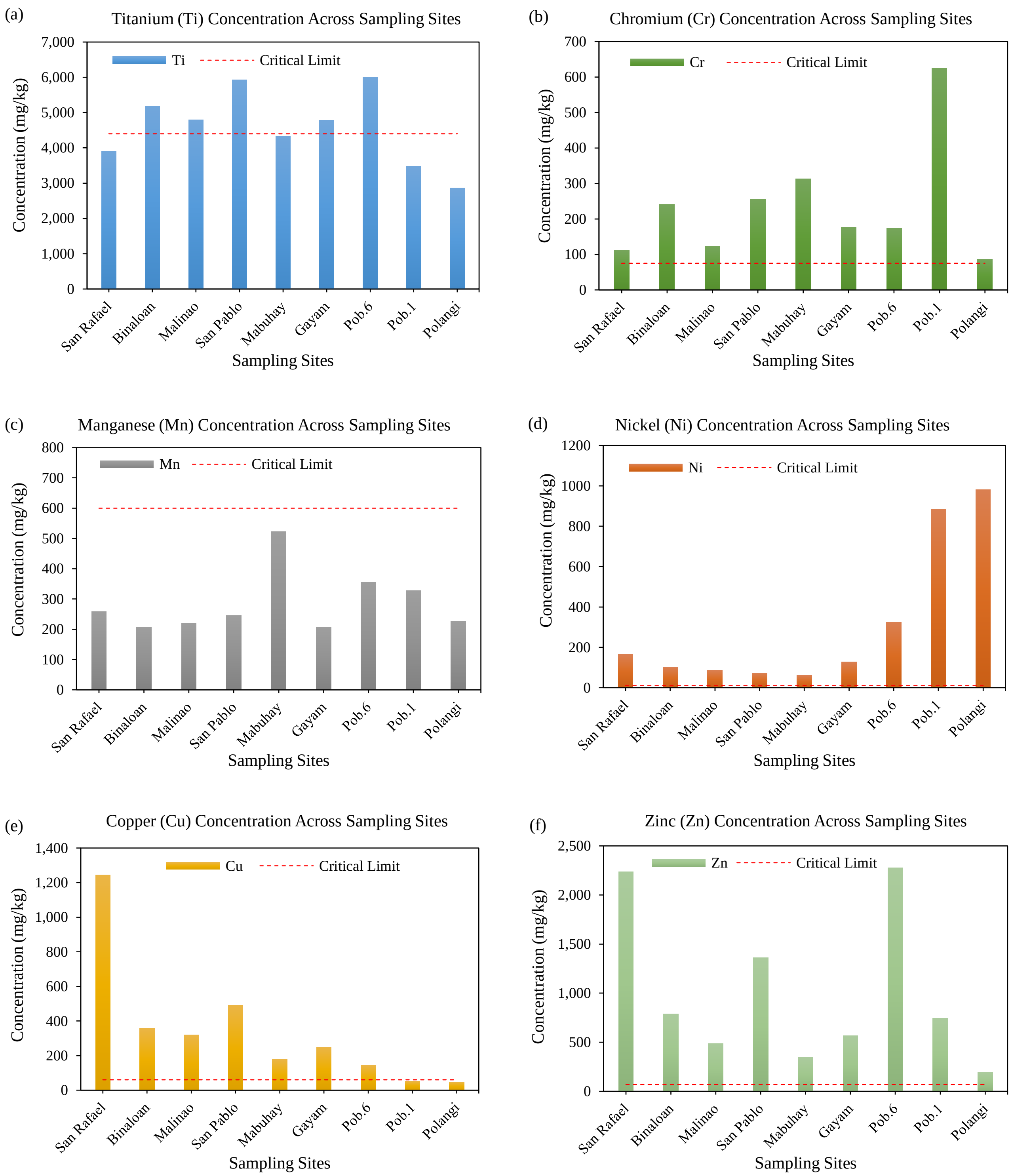



**Figure 3.** Total concentrations of (a) Ti, (b) Cr, (c) Mn, (d) Ni, (e) Cu, (f) Zn, (g) As, (h) Mo, (i) Cd, (j) Pb, in river bank sediments

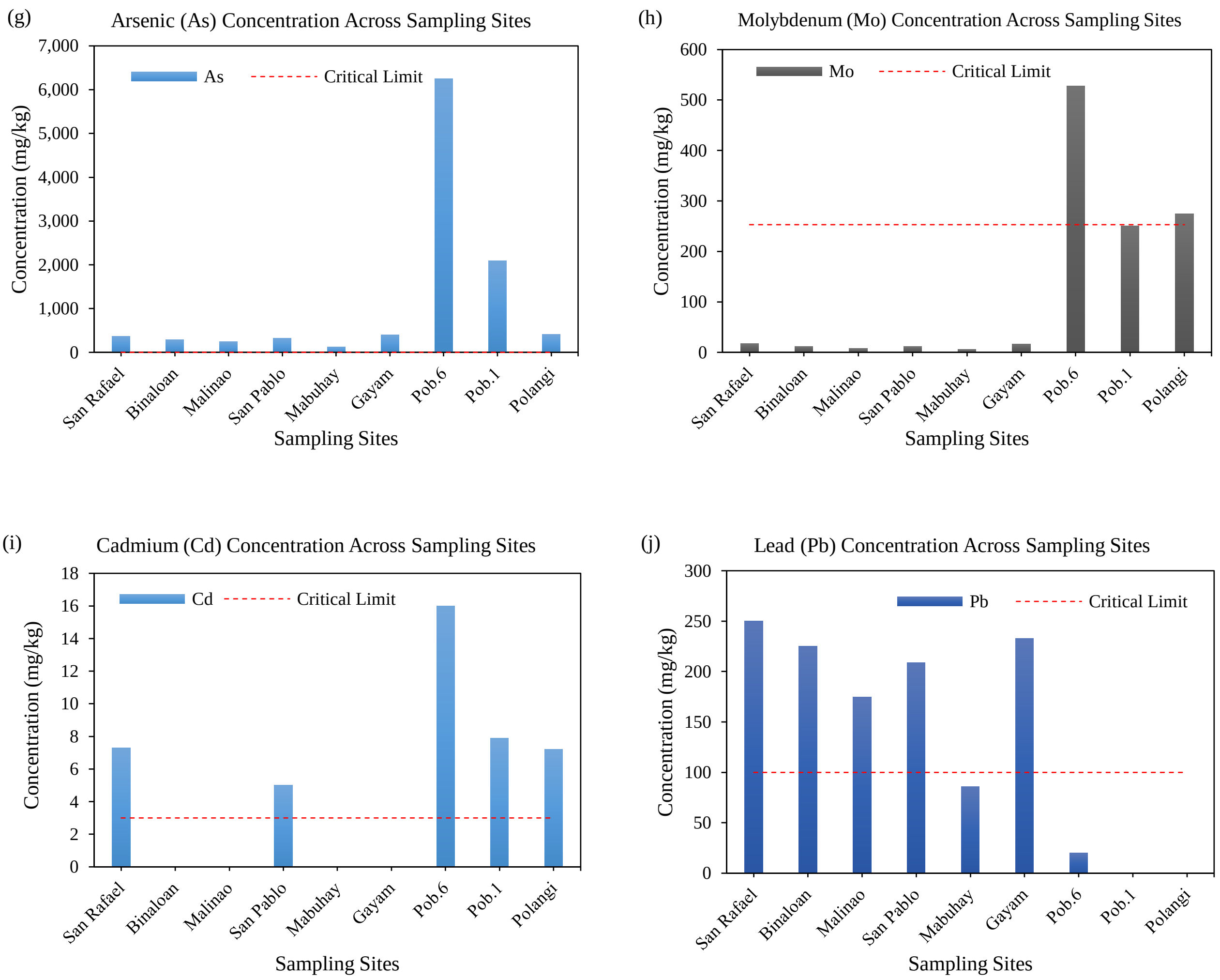



**Figure 3.** Total concentrations of (a) Ti, (b) Cr, (c) Mn, (d) Ni, (e) Cu, (f) Zn, (g) As, (h) Mo, (i) Cd, (j) Pb, in river bank sediments (cont.)

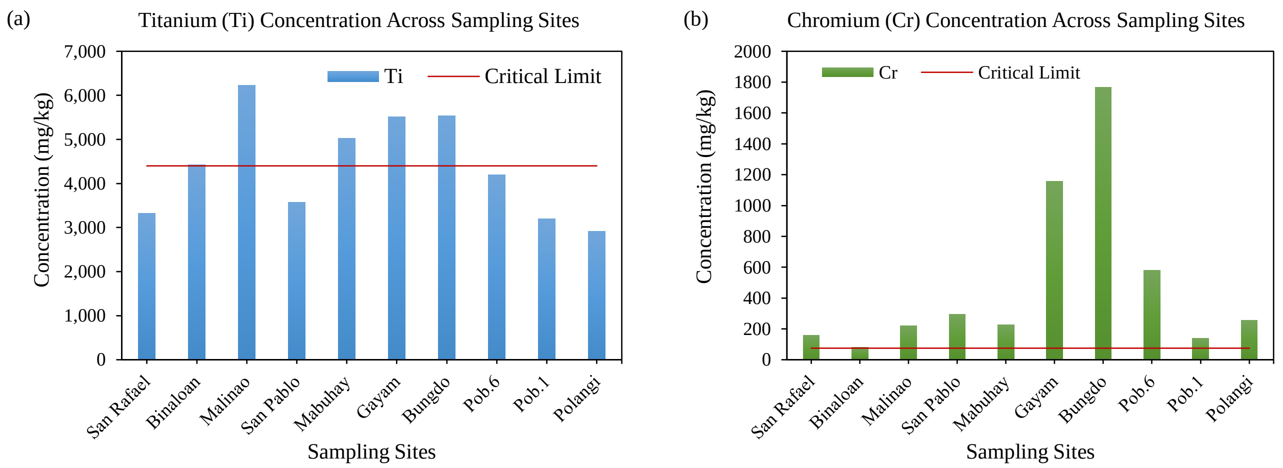



**Figure 4.** Total concentrations of (a) Ti, (b) Cr, (c) Mn, (d) Ni, (e) Cu, (f) Zn, (g) As, (h) Mo, (i) Cd, (j) Pb, in river bottom sediments

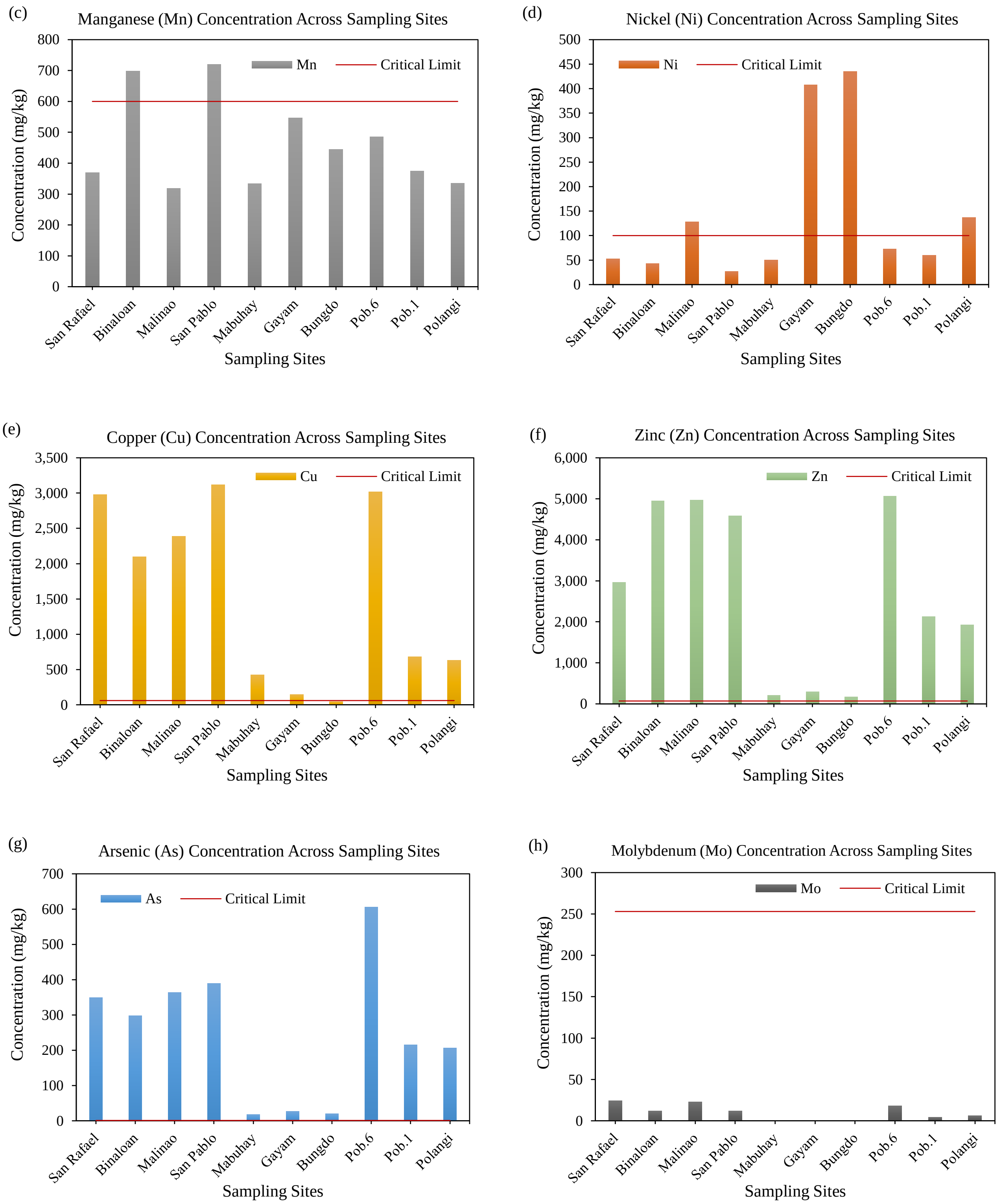
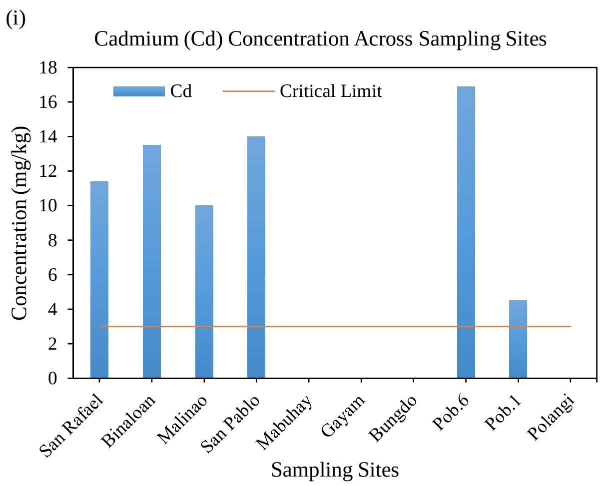



**Figure 4.** Total concentrations of (a) Ti, (b) Cr, (c) Mn, (d) Ni, (e) Cu, (f) Zn, (g) As, (h) Mo, (i) Cd, (j) Pb, in river bottom sediments (cont.)



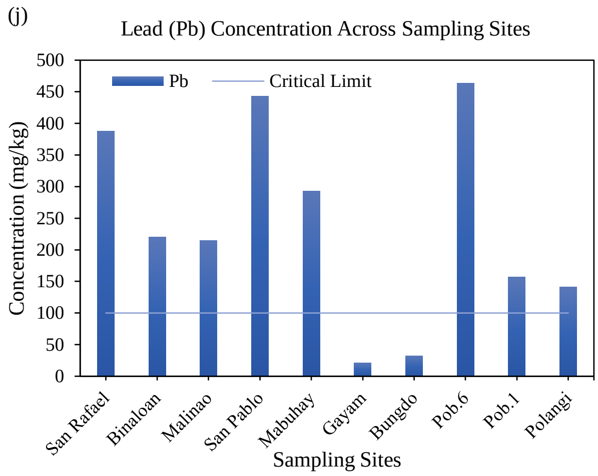




**Figure 4.** Total concentrations of (a) Ti, (b) Cr, (c) Mn, (d) Ni, (e) Cu, (f) Zn, (g) As, (h) Mo, (i) Cd, (j) Pb, in river bottom sediments (cont.)

In the case of molybdenum (Mo), concentrations in river sediments were below the critical level of 253 mg/kg. Similarly, most samples had Cd concentrations below the critical limit of 3-8 mg/kg. Only river bank sediment samples from Brgy. San Rafael, Brgy. San Pablo (upper stream), Brgy. Poblacion 6, Brgy. Poblacion 1, and Brgy. Polangi (lower stream) were within or above the critical level, especially in the middle stream. The highest Cd concentration (16 mg/kg) was found in samples from Brgy. Poblacion 6 (lower stream).

River bottom sediment samples from Brgy. San Rafael, Binaloan, Malinao, San Pablo (upper stream), and Poblacion 6, Poblacion 1 (lower stream) also showed Cd concentrations above the critical level. All other samples from different barangays, particularly in the middle stream, had Cd concentrations below the critical level. Furthermore, total Pb concentrations in river bank and bottom sediments were higher than the critical level of 100-400 mg/kg. Pb concentrations were highest in the river bank sediments of Brgy. San Rafael (upper stream) at 250 mg/kg, and in the bottom sediments of Brgy. Poblacion 6 (lower stream) at 464.00 mg/kg.

### 3.2 Contamination and pollution of sediments

The results indicated that the total heavy metal concentrations in riverbank sediments followed a decreasing order of Ti > Ni > Zn > As > Cu > Cr > Mn > Mo > Cd > Pb, while in river bottom sediments, the distribution followed Ti > Zn > Cu > Cr > Mn > Ni > As > Pb > Mo > Cd. The critical and permissible levels used as comparison thresholds for each metal were based on values reported in relevant scientific literature. "Critical levels" refer to the concentrations above which adverse environmental or biological effects may occur (Kabata-Pendias and Pendias, 2001; ATSDR, 2007), while "permissible limits" are typically regulatory standards such as those from WHO (1982).

In Figures 5(a-j) to 6(a-j), the majority of the quantifiable heavy metals corresponded to Class 2 to 6 based on the geo-accumulation index (Igeo) proposed by Müller (1979), indicating that most of the river sediments in the Taft River Basin were moderately to extremely polluted. In riverbank sediments, all sites were classified as very highly contaminated (Igeo>5, Class 6) with titanium (Ti), nickel (Ni), zinc (Zn), arsenic (As), copper (Cu), chromium (Cr), and manganese (Mn). Molybdenum (Mo) contamination ranged from moderately to very highly contaminated (Igeo 2->5, Class 2-6), while cadmium (Cd) ranged from uncontaminated to highly contaminated (Igeo 0-5, Class 1-5). Lead (Pb) contamination was absent (Igeo=0, Class 0) in Brgy. Binaloan and Brgy. Malinao (both Upper Stream), and Brgy. Mabuhay and Brgy. Gayam (Middle Stream), but all other barangays, particularly those in the Lower Stream areas such as Brgy. Poblacion 6 and Brgy. Polangi, showed moderate to high Pb contamination.

In the river bottom sediments, all sites were classified as very highly contaminated (Igeo>5, Class 6) with Ti, Zn, Cu, Cr, Mn, Ni, and As. No Pb, Mo, or Cd contamination (Igeo=0, Class 0) was observed in Brgy. Mabuhay, Brgy. Gayam, and Brgy. Bungdo (Middle Stream). Additionally, no Mo contamination was recorded in Brgy. Poblacion 1 (Lower Stream), and no Cd contamination was found in both Brgy.

Poblacion 1 and Brgy. Polangi (Lower Stream). In contrast, all other bottom sediment samples showed moderate to high contamination levels (Igeo 2-4, Class 2-4) for Pb, Mo, and Cd.

When grouped according to stream location, the Lower Stream barangays (Brgy. Poblacion 6, Brgy. Poblacion 1, and Brgy. Polangi) were observed to be the most highly contaminated, showing extreme Igeo values especially for Zn, Cu, Pb, and As. The Middle Stream barangays (Brgy. Mabuhay, Brgy. Gayam, Brgy. Bungdo, and Brgy. Burak) exhibited moderate contamination, with minimal Pb, Mo, and Cd contamination in some areas.

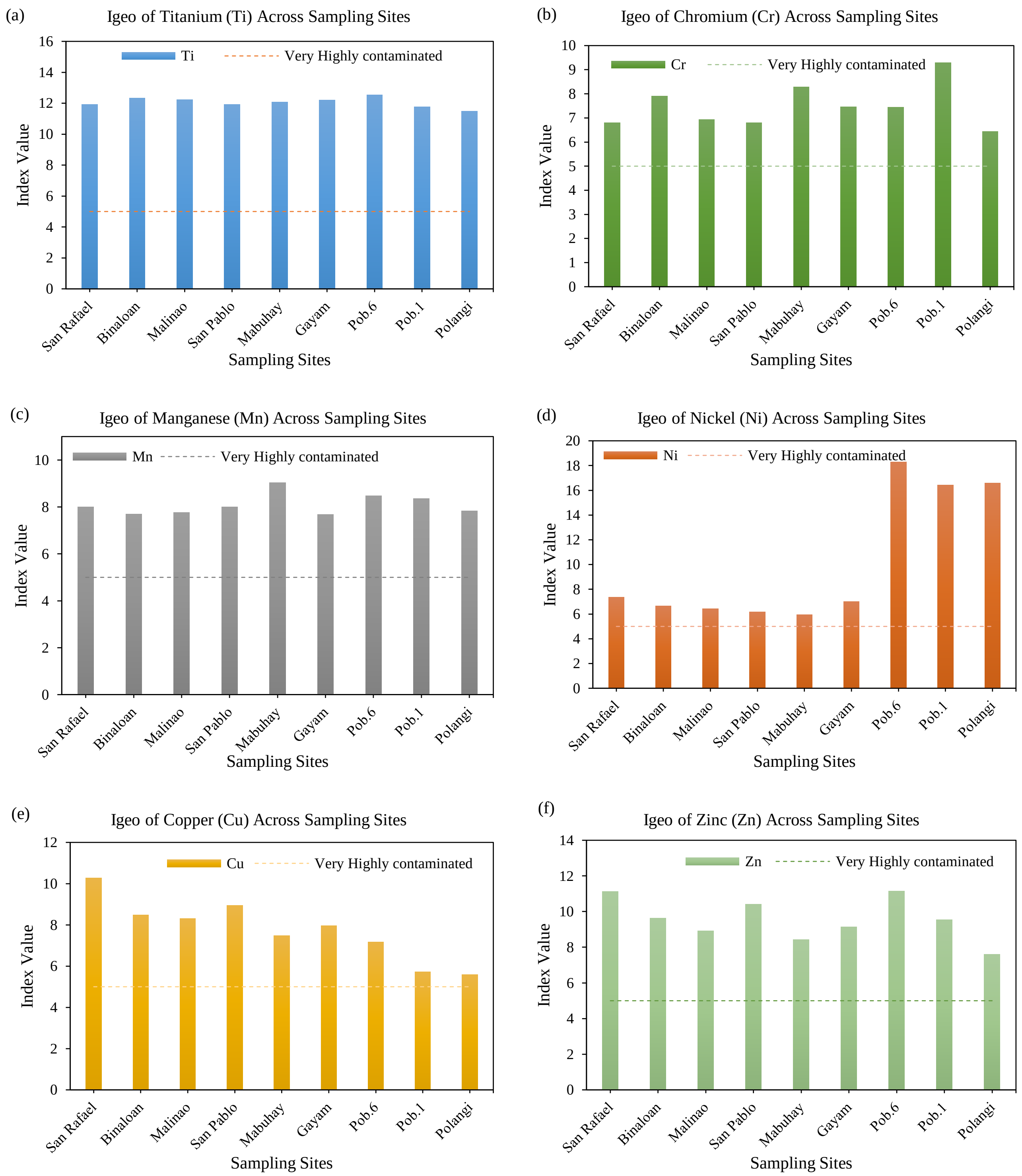



**Figure 5.** Geo-accumulation of (a) Ti, (b) Cr, (c) Mn, (d) Ni, (e) Cu, (f) Zn, (g) As, (h) Mo, (i) Cd, (j) Pb, in river bank sediments

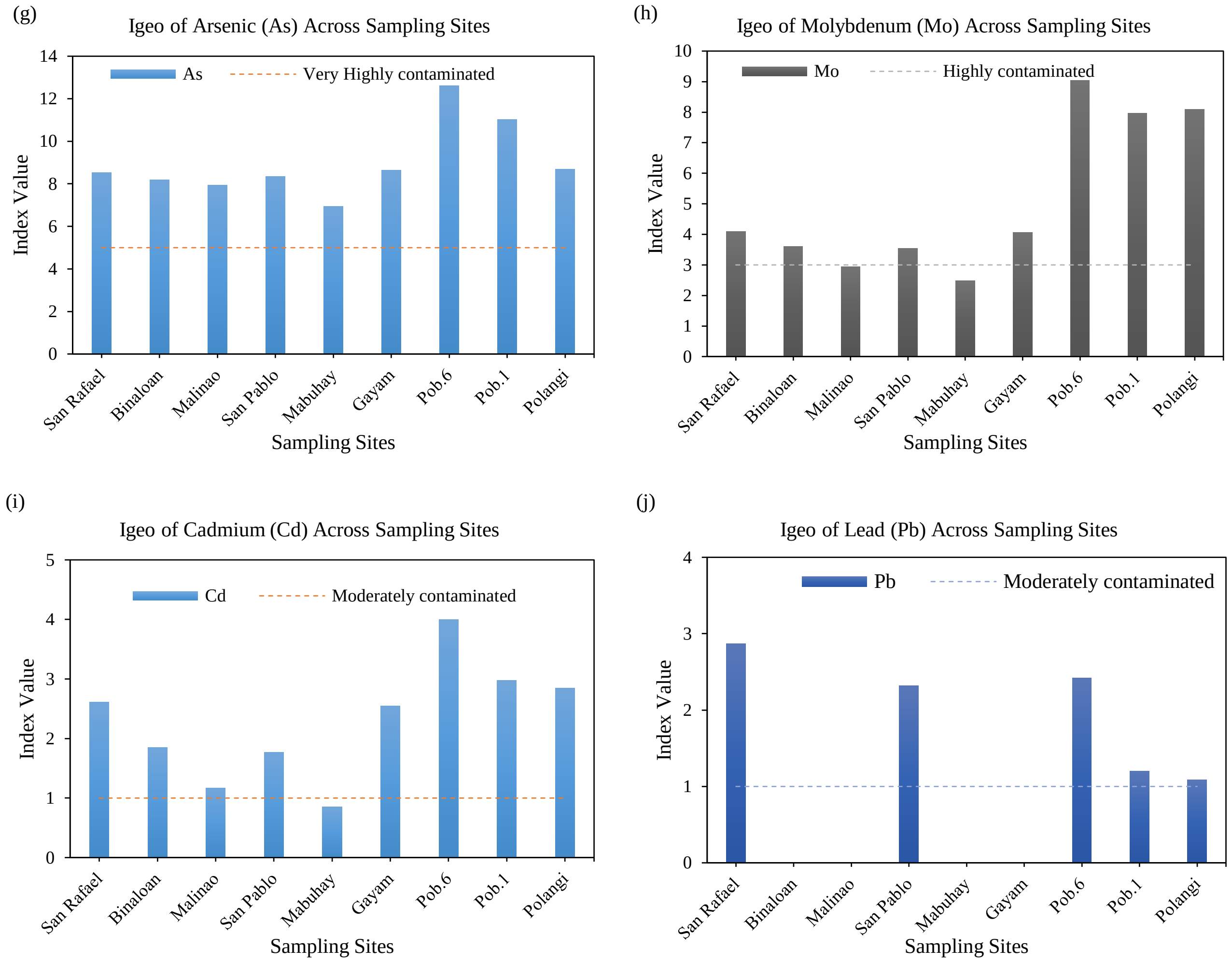



**Figure 5.** Geo-accumulation of (a) Ti, (b) Cr, (c) Mn, (d) Ni, (e) Cu, (f) Zn, (g) As, (h) Mo, (i) Cd, (j) Pb, in river bank sediments (cont.)

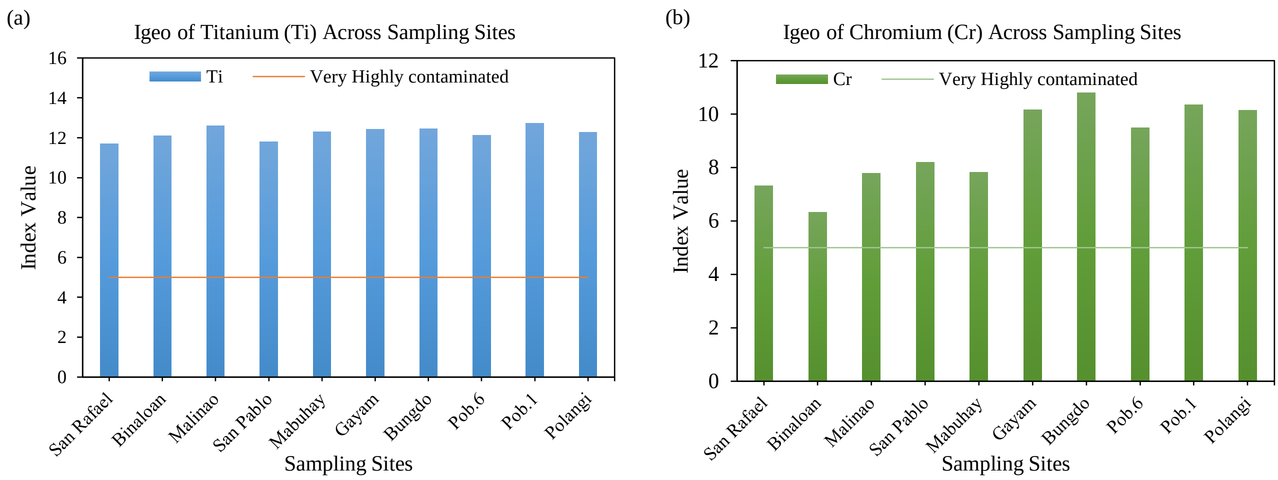



**Figure 6.** Geo-accumulation of (a) Ti, (b) Cr, (c) Mn, (d) Ni, (e) Cu, (f) Zn, (g) As, (h) Mo, (i) Cd, (j) Pb, in river bottom sediments

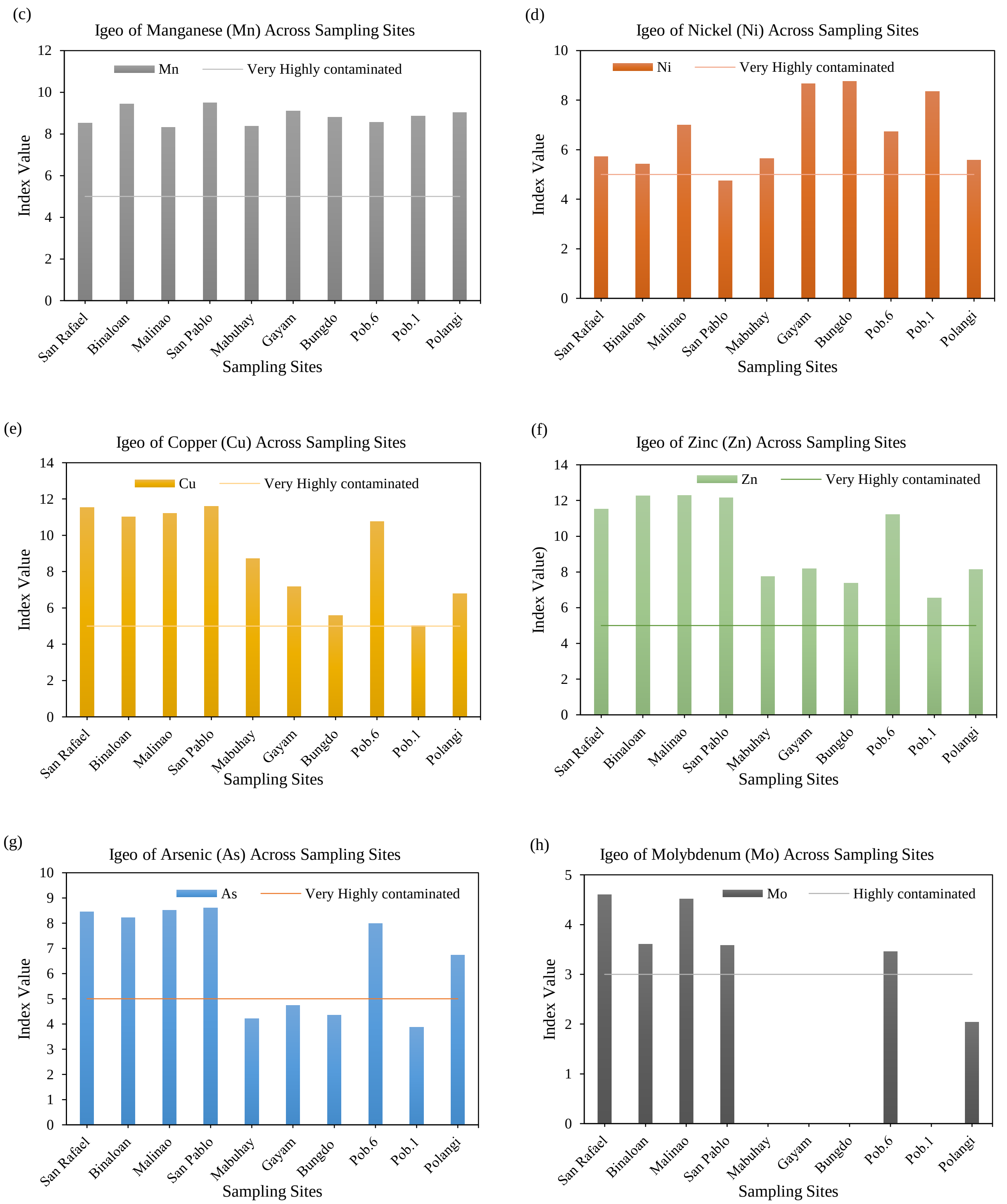



**Figure 6.** Geo-accumulation of (a) Ti, (b) Cr, (c) Mn, (d) Ni, (e) Cu, (f) Zn, (g) As, (h) Mo, (i) Cd, (j) Pb, in river bottom sediments (cont.)

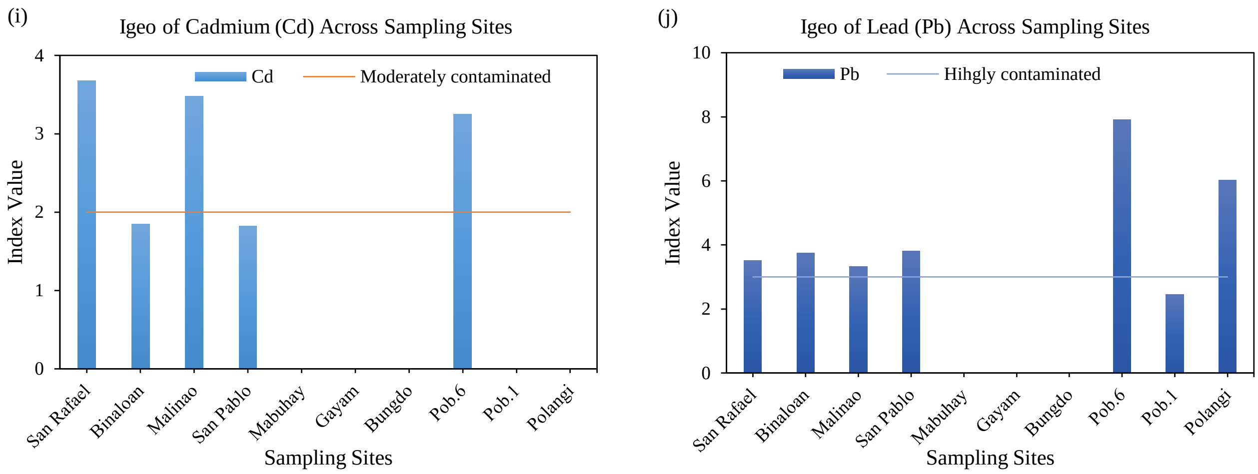



**Figure 6.** Geo-accumulation of (a) Ti, (b) Cr, (c) Mn, (d) Ni, (e) Cu, (f) Zn, (g) As, (h) Mo, (i) Cd, (j) Pb, in river bottom sediments (cont.)

The Pollution Load Index (PLI), used to assess the degree of heavy metal contamination in sediments, varied across all the riverbank and river bottom sediments studied in the Taft River Basin (Figures 7(a) and 7(b); Figures 8(a) and 8(b)). According to standard classification, PLI values below 1 (PLI<1) indicate no pollution; values between 1-1.5 suggest high contamination with potential for rehabilitation and safe reuse; and values greater than 1.5 (PLI>1.5) indicate that the sediment is unsuitable for crop production due to heavy contamination. In this study, all sediment samples recorded PLI values greater than 1, with riverbank sediments ranging from 1.43 to 1.65, and river bottom sediments from 1.50 to 1.71. These values reflect a general trend of gradual degradation of sediment quality and confirm that the Taft River Basin is heavily contaminated with heavy metals.

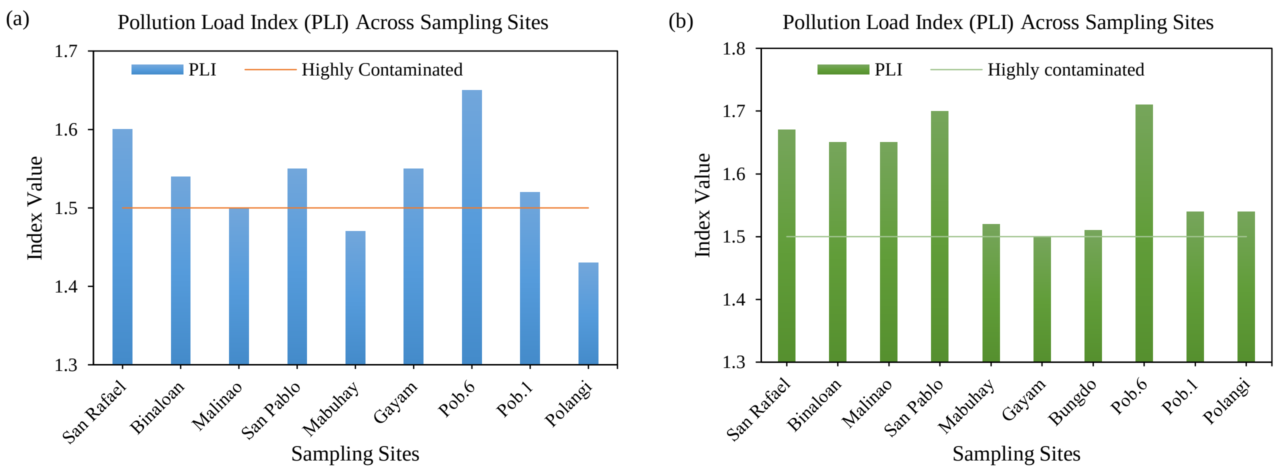


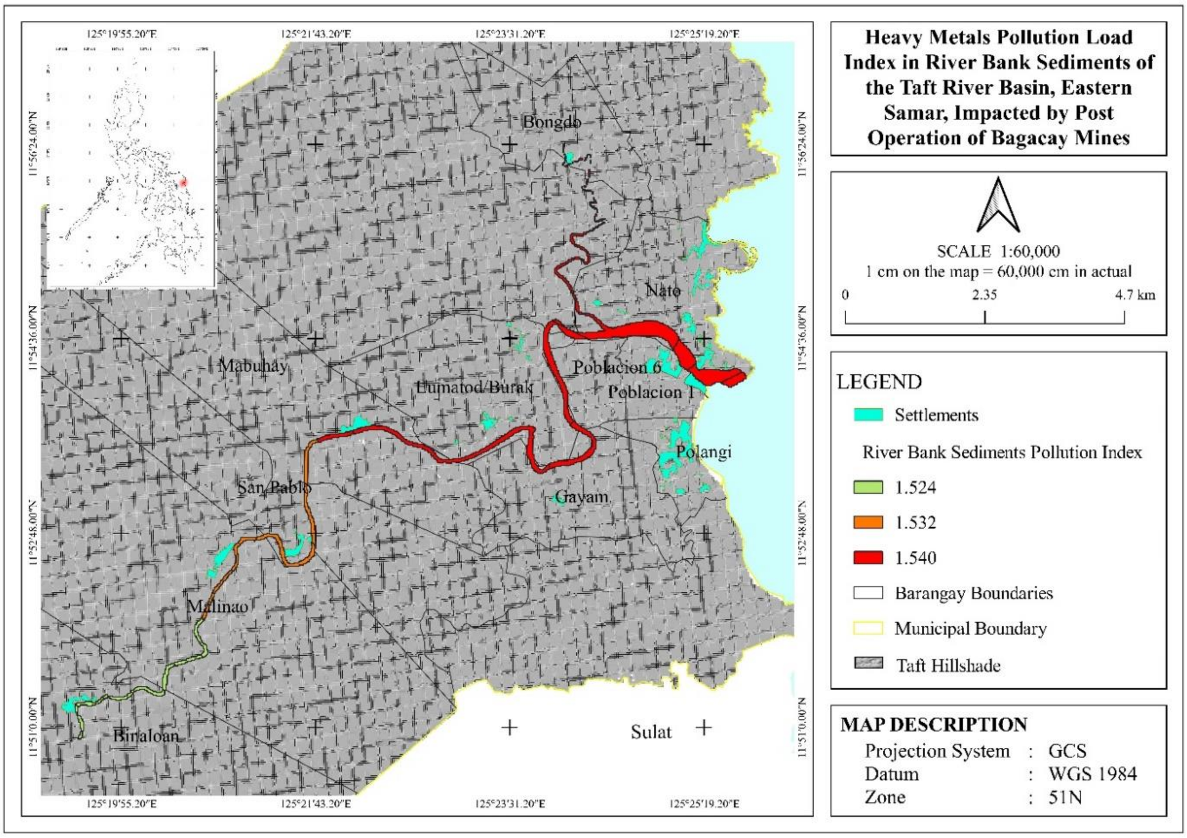

**Figure 7.** Contamination and Pollution of heavy metals in river bank sediments (a) and river bottom sediments (b)

## 4. DISCUSSION

### 4.1 Heavy metal concentrations in river sediments

Heavy metals are present in the sediments of river systems due to their capacity to act as carriers, sources, and sinks of pollutants (Zhu et al., 2018). Because river sediments serve as effective environmental indicators for monitoring pollution levels in aquatic ecosystems (Sun et al., 2018), this study assessed the concentrations of Ti, Cr, Cu, Zn, Mn, Ni, As, Mo, Cd, and Pb in the Taft River Basin, particularly in areas influenced by the post-operational impacts of the Bagacay mining site. The results showed that most heavy metal concentrations in both riverbank and river bottom sediments exceeded their respective critical or permissible limits, with the exception of Mn, Mo, and Cd (Figures 3 and 4). These concentrations were found to vary across different locations, reflecting the evident spatial distribution of heavy metals at the surface of the sediments.

(a)




(b)

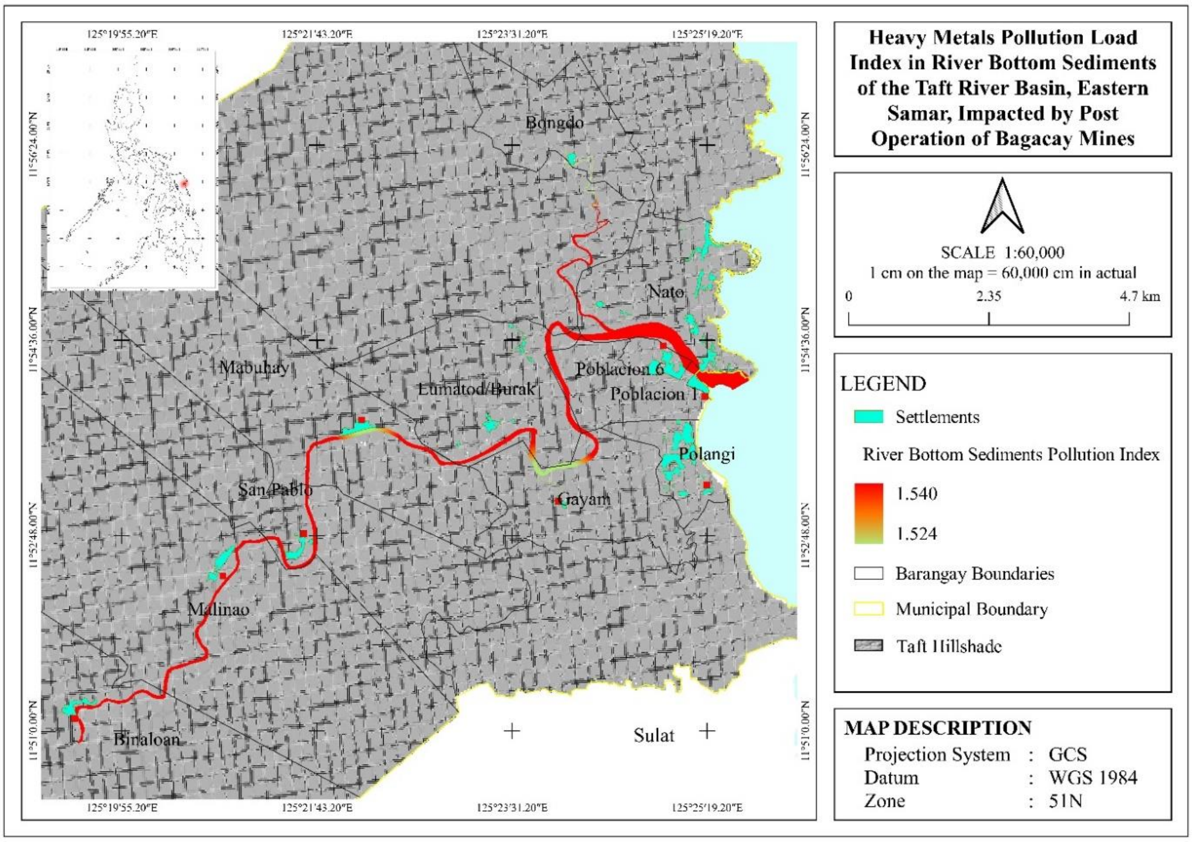



**Figure 8.** Pollution index map of river bank (a) and bottom sediments (b)

The varying concentrations of heavy metals in sediments are likely influenced by several dynamic processes within the river system. This is consistent with the findings of Weber and Opp (2020), who highlighted that the distribution of heavy metals in rivers and floodplains is affected by numerous environmental and anthropogenic factors. One of these processes is flooding, which contributes significantly to the transfer and redistribution of waste materials from upper to lower stream sections, thereby increasing the concentration of contaminants downstream (Sabijon et al., 2024). In this study, elevated levels of Ti, Cr, Cu, Zn, Ni, As, and Pb were observed across all sampled sediments within the Taft River Basin.

Supporting these observations, Dayang (2017) also reported excessive levels of heavy metal contamination including As, Cu, Pb, Hg, Zn, and Fe in both water and sediment samples from the Bagacay mine downstream to the Taft River. Similarly, Sabijon et al. (2024) documented that heavy metal concentrations in the surface soils of the Taft River floodplain followed a decreasing trend of Ti > Cr > Mn > Zn > Cu > Ni > As > Pb > Mo > Cd, which further confirms the sediment data presented in this study. Other regional and international studies provide similar evidence: Manullang et al. (2017) identified Fe, Cu, Zn, Pb, Cd, and Hg contamination in the surface sediments of Ambon Bay; Decena et al. (2018) observed Fe, Mn, Zn, Cu, Cr, and Ni in the Mangonbangon River; and Gabrielyan et al. (2018) reported high concentrations of As, Cu, Mo, Sb, Co, Ni, and Zn in the Voghji River Basin. Likewise, the Fenhe River sediments have shown variable heavy metal concentrations, including cadmium (0.040-0.296 mg/kg), lead (20.30-39.60 mg/kg), chromium (50.00-177.70 mg/kg), nickel (20.70-49.60 mg/kg), mercury (0.053-0.101 mg/kg), arsenic (5.76-10.10 mg/kg), copper (16.90-56.80 mg/kg), and zinc (72.30-233.60 mg/kg), further substantiating the widespread occurrence and environmental relevance of heavy metal pollution in riverine sediments (Chen et al., 2020).

### 4.2 Contamination and pollution of heavy metals in river sediments

The contamination of river sediments by heavy metals has garnered increasing attention in the context of water quality and ecological research (Edokpayi et al., 2022). In this study, moderate to high contamination of Ti, Cr, Mn, Ni, Cu, Zn, As, Mo, Cd, and Pb in the sediments of the Taft River basin was observed (Salomons and Forstner, 1984). These levels significantly exceeded the critical limits for heavy metals (Figures 3 and 4) across all sampling sites. River bank sediments exhibited high contamination levels for Pb, As, Zn, Mo, Mn, and Cu, while moderate contamination was found for Ni, Cr, Ti, and Cd (Figures 5-8). In river bottom sediments, the contamination followed a similar trend, with high contamination of Cu, Pb, Zn, As, Mn, Cr, and Ni, while Mo, Ti, and Cd showed moderate contamination (Figures 5-8). The contamination sequence for river bank and bottom sediments was as follows: Pb > As > Zn > Mo > Mn > Cu > Ni > Cr > Ti > Cd, and Cu > Pb > Zn > As > Mn > Cr > Ni > Mo > Ti > Cd, respectively.

The calculated pollution load index (PLI) values (Figures 7(a) and 7(b); Figures 8(a) and 8(b)) suggested a progressive deterioration of river sediments, with PLI>1 indicating moderate to severe contamination (Shen et al., 2019). These results confirmed that all the sediments in the riverbanks and bottoms of the Taft River Basin are polluted with heavy metals. Notably, higher pollution levels were observed in the upper (1.55, 1.67) and lower (1.53, 1.60) stream sites, with the highest pollution observed in the river bottom sediments at Poblacion 6 (lower stream), reaching a PLI of 1.71. The highest pollution values were predominantly observed in the upper stream, which is geographically closer to the Bagacay mining site, corroborating findings by Sabijon et al. (2024). The greater contamination observed in the upper stream may be attributed to the proximity of the Bagacay Mines, with contaminants being carried downstream by hydrological processes. The observed reduction in heavy metal levels downstream could be explained by the dilution effect of unpolluted water inflow as contaminants spread over greater distances (Luo et al., 2020).

Heavy metals are known to be poorly soluble in water (Zahra et al., 2014), with a significant portion being adsorbed onto particulates that eventually accumulate as bottom sediments (Zheng et al., 2008). This explains why heavy metal contamination is especially evident in the bottom sediments, as these sediments have a remarkable ability to accumulate low levels of contaminants over time (Islam et al., 2018). Additionally, disturbed sediments are more likely to be transported along hydrological gradients, spreading contamination to a wider area (Zhang et al., 2019).

Another important consideration for the potential influence to the increase in heavy metal contamination is the study areas natural geology. The

Taft River Basin is known to have certain mineral-rich geological formations, such as titanium-bearing rocks, which could naturally result in higher concentrations of elements like Ti, even without anthropogenic contamination. Heavy metals such as Ti, a common component of rocks and sediments, are naturally occurring and may not necessarily indicate pollution (Zhu et al., 2018).

Beyond the Bagacay Mines, potential sources of contamination could include agricultural runoff, industrial discharges, or other local anthropogenic activities in the region. Such sources may have contributed to the elevated levels of heavy metals in the river sediments, particularly in areas where industrial and agricultural practices are prevalent. Several other studies have also highlighted the contamination of sediments in river systems, confirming similar findings. For example, Sabijon et al. (2024) observed moderate to high contamination in Cu, Cr, Pb, As, Zn, Ni, Ti, Mo, and Cd in the sediments of the Taft River Basin. Similarly, Basir et al. (2022) reported heavy metal contamination (Hg < Zn < Pb < As) in the Mahakam river sediments of Indonesia, and Arifin et al. (2015) found that artisanal and small-scale gold mining (ASGM) activities in Indonesia's Bone River and Wubudu River contaminated these rivers with mercury, arsenic, and lead. Furthermore, research from China's Daniangkou Reservoir indicated high ecological risks due to surface sediment contamination with Cd and Cr (Lei et al., 2013). Other studies from large Chinese reservoirs, such as the Three Gorges Reservoir and the Liujiaxia and Xiaolangdi Reservoirs on the Yellow River, have reported heavy metal buildup and contamination in sediment profiles, including metals like Pb, Cd, Zn, and Cr (Zhao et al., 2015).

The evidence from this study revealed that the Taft River Basin is affected by heavy metal contamination, though a more comprehensive understanding of natural geological conditions and additional local pollution sources is necessary for a thorough assessment of the river's overall ecological health.

The comparative analysis in Table 2 underscores the global prevalence of heavy metal contamination in riverine sediments, positioning the Taft River within a broader environmental context of pollution linked to anthropogenic activities. Notably, the Taft River's contamination profile marked by the presence of ten potentially toxic elements (PTEs) reflects a complex and multifaceted pollution scenario. This mirrors patterns observed in similarly impacted rivers such as the Voghji River in Armenia and the Fenhe River in China, where intensive mining and industrial operations have been identified as primary contributors to elevated heavy metal concentrations.

**Table 2.** Comparison of potentially toxic elements in sediments from Taft River and other rivers

| River/Location | Country | PTEs detected | Contamination level | Source/Notes |
|---|---|---|---|---|
| Taft River (Present Study) | Philippines | Ti, Cr, Mn, Ni, Cu, Zn, As, Mo, Cd, Pb | Moderate to High (PLI > 1) | Highest in upper and lower stream; linked to Bagacay Mines |
| Taft River (Sabijon et al., 2024) | Philippines | Cu, Cr, Pb, As, Zn, Ni, Ti, Mo, Cd | Moderate to High | Confirms multi-metal contamination in the same basin |
| Mangonbangon River (Decena et al., 2018) | Philippines | Pb, Cd, Cr, Zn | Moderate to High | Possible sources include domestic and urban runoff |
| Bone and Wubudu Rivers (Arifin et al., 2015) | Indonesia | Hg, As, Pb | High | Contamination from ASGM activities |
| Mahakam River (Basir et al., 2022) | Indonesia | Hg, Zn, Pb, As | Moderate to High | Prioritization sequence: Hg < Zn < Pb < As |
| Daniangkou Reservoir (Lei et al., 2013) | China | Cd, Cr | High | High ecological risk due to sediment contamination |
| Three Gorges Reservoir (Zhao et al., 2015) | China | Pb, Cd, Zn, Cr | Moderate to High | Heavy metal buildup observed in sediment profiles |
| Liujiaxia and Xiaolangdi Reservoirs (Zhao et al., 2015) | China | Pb, Cd, Zn, Cr | Moderate to High | Found along Yellow River; evidence of sediment pollution |
| Fenhe River (Chen et al., 2020) | China | Cu, Pb, Zn, Cd, Cr | High | Related to industrial wastewater and coal mining |
| Voghji River Basin (Gabrielyan et al., 2018) | Armenia | As, Cd, Cr, Cu, Ni, Pb, Zn | High | Contamination linked to mining in the Zangezur Copper Mine |

Among Philippine rivers, the Taft River demonstrates broader contamination than the Mangonbangon River, which shows fewer PTEs but still registers high levels of Pb, Cd, Cr, and Zn. This could be attributed to the stronger industrial influence and proximity to the Bagacay mining site in the Taft River area. On the other hand, urban runoff appears to be the primary contamination source in the Mangonbangon River, indicative of different anthropogenic pressures.

Compared to international sites, the Taft River's PLI (Figures 7(a) to 8(b)) values suggest similar or slightly lower contamination severity than those of the Bone and Wubudu Rivers in Indonesia and the Voghji River in Armenia. These rivers are heavily affected by mining operations (ASGM and large-scale copper mining, respectively), which are known for introducing persistent and toxic metals into aquatic ecosystems.

Chinese rivers and reservoirs, such as the Three Gorges, Daniangkou, and Fenhe Rivers, also exhibit similar heavy metal profiles, although the Fenhe River shows extreme contamination due to both industrial effluents and coal mining. These comparisons underscore the critical role that mining and industrial activities play in shaping sediment contamination profiles and offer insight into how Philippine rivers like the Taft could follow similar contamination trajectories without appropriate environmental controls.

Overall, this comparison underscores the urgent need for national strategies in river monitoring, mining waste management, and pollution remediation. The Taft River's contamination profile, while alarming, is not unique but rather it is part of a global trend that demands integrated and science-based responses.

## 5. CONCLUSION

This study reveals that sediments in the Taft River Basin are moderately to highly contaminate with potentially toxic elements (PTEs), including Ti, Cr, Mn, Ni, Cu, Zn, As, Mo, Cd, and Pb. The contamination factors (CF) and geo-accumulation index (Igeo) values indicate significant pollution, with Igeo values ranging from class 2 to class 6. The contamination order: Pb>As>Zn>Mo>Mn>Cu>Ni>Cr>Ti>Cd in riverbank sediments and Cu>Pb>Zn>As>Mn>Cr>Ni>Mo>Ti>Cd in bottom sediments highlights a consistent presence of heavy metal inputs.

Pollution Load Index (PLI) values across all sites exceeded the critical threshold (PLI>1), confirming a deteriorated sediment quality. The highest contamination levels were found near the upper reaches of the river, particularly at sites closest to the Bagacay mining area, underscoring mining as a primary contributor. Downstream attenuation of PTE concentrations appears influenced by dilution and sedimentation dynamics.

Recommendations include the urgent need to rehabilitate the Bagacay mine site through acid mine drainage treatment, waste containment, and reforestation. Broader monitoring should also be implemented, encompassing groundwater and biotic components, to evaluate long-term ecological risks. Regular sediment quality assessments and the application of mining best practices must be institutionalized to mitigate further pollution. Finally, multi-stakeholder watershed management is critical to ensure the sustainable health of the Taft River and its surrounding communities.

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Conceptualization, Sabijon, Jessie. and Ultra, Venecio.; Methodology, Sabijon, Jessie, Espejon, Eduardo and Bollido, Marcos.; Software, Tan, Zaldee Nino.; Writing-Original Draft Preparation, Sabijon, Jessie.; Writing-Review and Editing, Ultra, Venecio.

## DECLARATION OF CONFLICT OF INTEREST

The authors have no competing interests to declare that are relevant to the content of this article.

## REFERENCES

Agency for Toxic Substances and Disease Registry (ATSDR). Toxicological Profile for Arsenic. Atlanta, GA: US Department of Health and Human Services, Public Health Service; 2007.

Arifin YI, Sakakibara M, Sera K. Impacts of artisanal and small-scale gold mining (ASGM) on environment and human health of Gorontalo Utara Regency, Gorontalo Province, Indonesia. Geosciences 2015;5(2):160-76.

Asio VB, Cabunos Jr CC, Chen ZS. Morphology, physiochemical characteristics, and fertility of soils from quaternary limestone in Leyte, Philippines. Soil Science 2006;171(8):648-61.

Belyaeva OA. Impact of mining enterprises of the city of Kapan on adjacent agroecosystems. Natural Science 2012; 2(19):26-30.

Basir, Kimijima S, Sakakibara M, Pateda SM, Sera K. Contamination level in geo-accumulation index of river sediments at artisanal and small-scale gold mining area in Gorontalo Province, Indonesia. International Journal of Environmental Research and Public Health 2022; 19(10):Article No. 6094.

Cabahug M, Ultra V, Morallos S, Lanuza N, Espejon E, Tan ZN, et al. Heavy metal concentrations in Mollusks and Crustaceans harvested from Eastern Samar's Taft River in the Philippine and the health risks posed to consumers. Philippine Journal of Science 2023;152(4):1349-62.

Cayanan EA, Estudillo CE. Characterization of the Climate of the Philippines based on the Latest 30-Year Normal (1981-2010) Data. Philippine Atmospheric, Geophysical, and Astronomical Services Administration (PAGASA); 2018.

Chen J, Lu J, Zhang Z, Zhao R. Assessment of heavy metal pollution and human health risk in urban river sediments: A case study of Fenhe River, China. Environmental Science and Pollution Research International 2020;27(26):26949-63.

da Silva Y, Cantalice J, do Nascimento C, Singh V, da Silva Y, Silva C, et al. Bedload as an indicator of heavy metal contamination in a Brazilian anthropized watershed. Catena 2017;153:106-13.

Dayang JR. Revegetating Bagacay Mining Site: A review of potential tropical species for phytoremediation of non-essential heavy metals. Journal of Degraded and Mining Lands Management 2017;4(3):807-14.

Decena C, Sanita M, Liporada R. Assessing heavy metal contamination in surface sediments in an urban river in the Philippines. Polish Journal of Environmental Studies 2018;27(5):1983-95.

Duncan AE, de Vries N, Nyarko KB. Assessment of heavy metal pollution in the sediments of the River Pra and its tributaries. Water, Air, and Soil Pollution 2018;229(1):Article No. 272.

Edokpayi J, Nkhumeleni M, Enitan-Folami A, Olaniyi F. Water quality assessment and potential ecological risk of trace metals in sediments of some selected rivers in Vhembe District, South Africa. Physics and Chemistry of the Earth, Parts A/B/C 2022;126:Article No. 103111.

United States Environmental Protection Agency (US EPA). Method 3050B: Acid Digestion of Sediments, Sludges, and Soils. Report No:SW-846. Washington (DC): US EPA; 1996.

Eze PN, Zhang Y, Wang L. Using geostatistics and GIS techniques to assess heavy metal contamination in soils around a coal mine area in South Africa. Environmental Earth Science 2018;77(6):Article No. 230.

World Health Organization (WHO). Environmental Health Criteria 24-Titanium. International Programme on Chemical Safety; 1982.

Feng W, Tao Y, Liu M, Deng Y, Yang F, Liao H, et al. Distribution and risk assessment of nutrients and heavy metals from sediments in the world-class water transfer projects. Environmental Sciences Europe 2024;36(1):Article No. 140.

Gabrielyan A, Shahnazaryan G, Minasyan S. Distribution and identification of sources of heavy metals in the Voghji River basin impacted by mining activities (Armenia). Journal of Chemistry 2018;1:Article No. 7172426.

Islam MS, Ahmed MK, Habibullah-Al-Mamun M, Islam KN, Ibrahim M, Masunaga S. Arsenic and lead in foods: A potential threat to human health in Bangladesh. Food Additives and Contaminants: Part A 2014;31(12):1982-92.

Kabata-Pendias A. Trace Elements in Soils and Plants. 2nd ed. CRC Press; 2001.

Kang M, Tian Y, Zhang H, Lan Q. Distribution, ecological risk assessment, and source identification of heavy metals in river sediments from Hai River and its tributaries, Tianjin, China. Water, Air, and Soil Pollution 2020;231:Arcticle No. 38.

Lei P, Zhang H, Shan BQ. Analysis of heavy metals pollution and ecological risk assessment in the sediments from the representative river mouths and tributaries of the Danjiangkou Reservoir. Resources and Environment in the Yangtze Basin 2013;22(1):110-7.

Luo C, Routh J, Dario M, Sarkar S, Wei L, Luo D, et al. Distribution and mobilization of heavy metals at an acid mine drainage affected region in South China, a post-remediation study. Science of the Total Environment 2020;724: Article No. 138122.

Manullang CY, Lestari TY, Arifin Z. Assessment of Fe, Cu, Zn, Pb, Cd, and Hg in Ambon Bay surface sediments. Marine Research in Indonesia 2017;42(2):77-86.

Mineral Resources and Geosciences Bureau (MGB). Environmental Impact Assessment of Mining Operations in the Philippines. Manila: Department of Environment and Natural Resources; 2005.

Müller G. Heavy metals in the sediments of the Rhine - changes since 1979. Review in Science and Technology 1981; 81(24):778-83.

Sabijon J, Ultra Jr V, Bollido M, Openiano M, Poliquit D, Aquino R, et al. Nutrients and heavy metal contents on surface of agricultural soils in the flood-plains of Taft River Basin impacted by Bagacay Mines, Philippines. Philippine Journal of Science 2024;153(1):375-90.

Salomons W, Forstner U. Metals in the Hydrocycle. Berlin, Heidelberg, New York: Springer-Verlag; 1984. p. 349.

Samaniego JO, Gibaga CR, Tanciongco AM, Quierrez RN. Abandoned and inactive mines in the Philippines: Current environmental conditions, ongoing rehabilitation efforts and future opportunities. In: Derelict Mines. CRC Press; 2024. p. 189-207.

Shen F, Mao L, Sun R, Du J, Tan Z, Ding M. Contamination evaluation and source identification of heavy metals in the sediments from the Lishui River Watershed, Southern China. International Journal of Environmental Research and Public Health 2019;16(3):Article No. 336.

Sun Z, Xie X, Wang P, Hu Y, Cheng H. Heavy metal pollution caused by small-scale metal ore mining activities: A case study from a polymetallic mine in South China. Science of the Total Environment 2018;639:217-27.

Tomlinson D, Wilson J, Harris C, Jeffrey D. Problems in the assessment of heavy-metal levels in estuaries and the formation of a pollution index. Helgoländer Meeresuntersuchungen 1980;33:566-75.

Tupan C, Herawati EY, Arfiati D. Detection of phytochelatin and glutathione in seagrass *Thalassia hemprichii* as a detoxification mechanism due to lead heavy metal exposure. Aquatic Science and Technology 2014;2(1):67-78.

Ultra Jr VU. Fly ash and compost amendments and Mycorrhizal inoculation enhanced the survival and growth of *Delonix regia* in Cu-Ni mine tailings. Philippine Journal of Science 2020;149(3):479-89.

Vodyanitskii YN. Standards for the contents of heavy metals in soils of some states. Annals of Agrarian Science 2016; 14(3):257-63.

Wang J, Liu R, Zhang P, Yu W, Shen Z, Feng C. Spatial variation, environmental assessment and source identification of heavy metals in sediments of the Yangtze River Estuary. Marine Pollution Bulletin 2014;87(1-2):364-73.

Weber CJ, Opp C. Spatial patterns of mesoplastics and coarse microplastics in floodplain soils as resulting from land use and fluvial processes. Environmental Pollution 2020;267:Article No. 115390.

Yang Y, Chen F, Zhang L, Liu J, Wu S, Kang M. Comprehensive assessment of heavy metal contamination in sediment of the Pearl River Estuary and adjacent shelf. Marine Pollution Bulletin 2012;64(9):1947-55.

Zahra A, Hashmi MZ, Malik RN, Ahmed Z. Enrichment and geo-accumulation of heavy metals and risk assessment of sediments of the Kurang Nallah-feeding tributary of the Rawal Lake Reservoir, Pakistan. Science of the Total Environment 2014;470:925-33.

Zhang M, He P, Qiao G, Huang J, Yuan X, Li Q. Heavy metal contamination assessment of surface sediments of the Subei Shoal, China: Spatial distribution, source apportionment and ecological risk. Chemosphere 2019;223:211-22.

Zhang C, Selinus O, Sjövall K. Geostatistical interpolation of heavy metals in soils using the OK and IDW methods in a coal mining area. Environmental Monitoring Assessment 2011;176(1-4):361-77.

Zhao D, Wan S, Yu Z, Huang J. Distribution, enrichment and sources of heavy metals in surface sediments of Hainan Island rivers, China. Environmental Earth Sciences 2015;74: 5097-110.

Zheng NA, Wang Q, Liang Z, Zheng D. Characterization of heavy metal concentrations in the sediments of three freshwater rivers in Huludao City, Northeast China. Environmental Pollution 2008;154(1):135-42.

Zhou F, Li P, Xing XL, Weng MZ, Liu L, Zhang Y, et al. Distribution characteristics and ecological risk assessment of heavy metals in sediments of Longyang Lake and Moshui Lake in Wuhan. China Environmental Science 2023;43: 5433-43.

Zhu D, Wu S, Han J, Wang L, Qi M. Evaluation of nutrients and heavy metals in the sediments of the Heer River, Shenzhen, China. Environmental Monitoring and Assessment 2018;190(7):Article No. 380.