Heavy Metals in Surface Sediments of the Coastal Area Around Daerah Istimewa Yogyakarta, Indonesia: Their Relations to Land-Use Types

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Abstract

The province of Daerah Istimewa Yogyakarta (DIY) has experienced significant changes in urbanization, industry, and tourism, making it one of Indonesia’s fastest-growing areas. Increased anthropogenic activity in the coastal region may cause heavy metal contamination in that zone to grow. Based on different land-use types, this study examined the distribution of heavy metals, namely cadmium (Cd), lead (Pb), copper (Cu), and zinc (Zn), in surface sediment. It assessed the feasibility of sediment quality standards based on the Canadian Sediment Quality Guidelines (CSQG). Nine stations made up the sampling site, each representing a different land-use type, including mangrove ecosystem, tourist attraction, airport, harbor, mining area, bare land, shrimp pond, agricultural land, and settlement. The concentrations of Cd in bare land, shrimp pond, agricultural land, and settlement (with values of 2.707, 2.955, 2.983, and 2.873, respectively), and Cu in the mangrove ecosystem (with values of 42.893) slightly exceeded the corresponding Threshold Effect Level (TEL) value of CSQG. Meanwhile, the content of other heavy metals in all land use types tends to be low, even below the Limit of Detection (LOD). The data on the level of heavy metal pollution in the study area shows no connection between heavy metal contamination and different land-use types. It is brought on by a variety of circumstances, such as the fact that human activity in the study area did not significantly contribute to heavy metal contamination or that heavy metals were contaminated and then spread to other forms of land-use types, in this case, the mangrove ecosystem, by runoff and wind. This is because variations in salinity, estuary flushing, physical mixing and dilution, and chemical processes, including sorption, complexation, cation exchange, and redox reactions, all affect how heavy metals are transported by water. The government should create environmental regulations, laws, quality norms and standards, more funding for cutting-edge scientific research, and technical tools to prevent heavy metal pollution in coastal areas.

Keywords: Sediment contamination; Cadmium; Lead; Copper; Zinc

1. Introduction

Heavy metal contamination has become a serious concern to the environment and food security due to the quick expansion of industry and agriculture and the disruption of the natural ecosystem brought on by the rapid growth in the industrial and residential areas of our planet. The increased anthropogenic activity in coastal regions may lead to heavy metal contamination, which can affect the environment, human health, and aquatic life. This study aimed to examine the distribution of heavy metals in surface sediments of the coastal area around Daerah Istimewa Yogyakarta, Indonesia, and to assess the feasibility of sediment quality standards based on the Canadian Sediment Quality Guidelines (CSQG) for these metals.

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by the enormous increase in the world’s population. Contrary to organic pollutants, which are overt, persistent, and reversible, heavy metal pollution is covert, persistent, and poses a severe threat to human and animal health and welfare due to its accumulation in the food chain. It also degrades the water bodies’ quality, food crops, and the atmosphere (Li et al., 2019). The weathering of the parent rocks and the movement, deposition, and erosion of soil in river beds are the sources of sediments. The organic waste and other mineral species moved upstream during the detritus process are combined. In addition to biological waste, heavy metals naturally occur in sediments. The sediment is contaminated because of the very concentrated heavy metals there. Heavy metal contamination of sediment is caused by anthropogenic and natural processes (Al-Dulaimi et al., 2021; Tunde and Oluwagbenga, 2020).

The aquatic environment has been severely contaminated by many human activities, and ongoing usage has made the health risks much worse (Trisnaning et al., 2022; Zamroni et al., 2022). Primary anthropogenic sources of heavy metals in coastal environments include municipal effluents, farming, sea transportation, fishing, mining, energy production and use, chemical and heavy industries, dredging and reclamation, oil exploration, infrastructural development, nuclear weapons, and power plants. While geological weathering, erosion, and terrestrial runoff are all natural sources of sediment contamination. While many heavy metals are hazardous in high amounts, most are necessary for life at low concentrations. This is due to their bioaccumulation and persistence traits, mainly if they are disposed of inappropriately (Al Rashdi et al., 2015; Tunde and Oluwagbenga, 2020). However, human activity’s influence on ecosystems has increased more quickly and significantly over the past 50 years than during any other time in human history. One of these activities, land-use change, directly affects the health and integrity of ecosystems, impacting ecosystem services’ availability (Akber et al., 2018). When human activities alter land-use patterns, several environmental components are altered. The rising levels of heavy metals are caused by changes in land-use and land cover near coastal areas (Xin et al., 2014). Different sorts of contamination are anticipated to result from different land-use categories. For instance, aquaculture practices may encourage the growth of organic enriched-sediment fluxes, whereas agricultural practices and sewage discharge from metropolitan areas may cause heavy metal contamination. Since most wastewater discharged today has not been treated, only natural processes may lower the pollutant loads. The environment, mainly marine organisms, may be harmed by wastewater or solid waste contaminated with heavy metals from land-use activities near the coast (Maanan et al., 2014).

Indonesia is a maritime nation with 17,504 islands and a coastline of 95,181 km. Its ecosystems provide various ecosystem services that are crucial locally (such as a fishing ground) and globally (e.g., carbon sequestration). However, government plans focusing on sizable investments are putting strain on Indonesia’s coastal habitats. The Indonesian government has been forced to intensify and diversify the use of marine and coastal resources due to population growth, resulting in a decrease in their ecosystem service resources. Population growth has increased food needs, which has led to the overuse of resources and increased vulnerability of marine and coastal ecosystems (Lukman et al., 2021). With substantial changes in urbanization, industry, and tourism, Daerah Istimewa Yogyakarta (DIY) Province has emerged as one of Indonesia’s fastest-growing regions (Anwar et al., 2017). DIY Province is an overgrown region, particularly after building an airport in a coastal area close to the Indian Ocean (Zamroni et al., 2021a). Additionally, this province has had fast growth in various human endeavors such as housing, agriculture, mining, ports, and agriculture, particularly in the coastline region (Asih et al., 2022). The level of heavy metal contamination in that zone may rise due to increased anthropogenic activity in the coastal area. Because of their possible environmental consequences and the general public's concern over seafood safety, the levels of heavy metals in coastal ecosystems warrant considerable investigation. Therefore, the seafood business, public health issues, and the sustainable development of marine ecosystems need to understand better the current status of heavy metal contamination in coastal ecosystems (Wang et al., 2013). If not rigorously regulated, the industry’s
detrimental effects on ecological systems caused by the released waste, primarily made up of heavy metals, might be fatal for people and all living things (Qadoori and Al-Tawash, 2021). This study is a follow-up study from (Asih et al., 2022), who investigated the content of heavy metals in seawater in coastal areas around DIY Province. The content of heavy metals in sediments in the region has not been studied, so the objectives of this study were to investigate the distribution of heavy metals, namely Cadmium (Cd), Lead (Pb), Copper (Cu), and Zinc (Zn) in surface sediment based on land-use types and to assess the feasibility of sediment quality standards based on Canadian Sediment Quality Guidelines (CSQG).

2. Geology of the Study Area

The study area is located in the coastal regions around Daerah Istimewa Yogyakarta (DIY) Province, south of Java Island, Indonesia. DIY Province is a part of the Sunda Mountainous System, which is distinguished by a volcanic arc and a non-volcanic arc. The Indian-Australian plate forms the boundary of the Sunda Mountainous System, an extension of the Eurasian plate. As the margin of the plates collides, plates along the subduction zone are consumed, volcanic arcs are formed, and oblique-slip structures are compressed. The subduction zone and plate collision create a tectonic and seismic activity center. Due to DIY Province's proximity to the point where the Eurasian and Indo-Australian plates collide, the region's geology and geomorphology are defined by tectonic origin (Sutikno, 2016). The four formations in the study area are Andesite, Old Andesite Formation (OAF), Sentolo Formation (Lower Miocene to Middle Miocene), and Quarterly Alluvium, in that order (Fig. 1).

![Geological map of the study area](https://example.com/fig1.jpg)

Fig.1. Geological map of the study area (Modified from Rahardjo et al., 1995).

The OAF is composed of andesite volcanic breccia, tuff, andesite lava flow pieces, lapilli volcanic breccia, volcanic sandstone fragments, and agglomerates. Limestone, marl tuff-boarded conglomerate, marl sandstone, and glass tuff make up the Sentolo Formation. It is constructed of volcanic material that resulted from the development of volcanic OAFs. As they ascended, these rocks changed into a
well-layered, foraminifer-rich limestone. Quarterly Alluvium consists primarily of the alluvial deposits found along big rivers and coastal plains. These deposits are gravel, sand, silt, and clay. Volcanic rock and alluvial soil make up the alluvial plain. The Kulonprogro plain has alluvial deposits on its east, west, and south sides. The alluvial sand deposits south of DIY Province on the coast (Irzon et al., 2017; Widagdo et al., 2016; Zamroni et al., 2021a). In DIY Province, there are also two different kinds of sand sediment. Gray sand, composed of quartz, mafic minerals, and coral reef fragments, is type 1, whereas black sand, predominantly iron sand and has a low quartz mineral concentration, is type 2 (Noviadi and Setiady, 2020; Zamroni et al., 2021b). The Quarterly Alluvium, which consists of type 1 and type 2 sand sediment, includes the sediment sampling locations.

3. Materials and Methods

Sampling was carried out in July 2022 (dry season). The sampling site (Fig. 2) consisted of 9 stations characterizing the land-use types, namely “mangrove ecosystem (A), tourist attraction (B), airport (C), harbor (D), mining area (E), bare land (F), shrimp pond (G), agricultural land (H), and settlement (I)”. Each sample was placed in a fresh polyethylene zipper bag after being taken from the top 0–50 cm of sediment at each sampling location. Following collection, the samples were kept in a refrigerator until analysis (Prartono et al., 2016). Atomic Absorption Spectrophotometer (AAS) measurements of the concentrations of cadmium (Cd), lead (Pb), copper (Cu), and zinc (Zn) were made at Balai Besar Teknik Kesehatan Lingkungan dan Pengendalian Penyakit (BBTKLPP) (English: Center for Environmental Health and Disease Control Engineering) Yogyakarta, Indonesia. Using a Varian, SpectraAA atomic absorption spectrophotometer, the heavy metals content was evaluated using the US EPA SW-846 7000B method for flame atomic absorption spectroscopy analysis (United States Environmental Protection Agency, 2007). The data was analyzed by contrasting the laboratory results with the Canadian Sediment Quality Guidelines (CSQG). It was created by the Canadian Council of Ministers of the Environment as a broad protection mechanism to support the functioning of healthy aquatic ecosystems (CCME, 2001). Since the Indonesian government lacks a guideline for sediment quality, the Canadian Sediment Quality Guidelines (CSQG) were utilized to determine risk. Each sediment sample has been evaluated using the Threshold Effect Level (TEL) and Probable Effect Level (PEL) concentrations of CSQG. TEL is the concentration of an element or chemical in the sediment below where harmful biological effects are infrequently experienced (Gao et al., 2015). PEL, or the upper value, designates the threshold at which it is anticipated that harmful impacts on aquatic life will usually occur (Brasher and Anthony, 2000). The sediment has been severely contaminated and is extremely dangerous if the concentration of heavy metals in the sediments exceeds the PEL (Ayedun et al., 2019). The sediment may have been mildly polluted or unpolluted if the concentration of heavy metals is lower than the TEL.
4. Results and Discussion

4.1. Heavy Metal Concentrations in Coastal Sediments

The results of the analysis of heavy metal concentrations in coastal sediments in the study area are shown in Table 1.

Table 1 shows that the concentrations of Cd (in mangrove ecosystem, tourist attraction, airport, harbor, and mining area) and Pb and Zn (in all land-use types, except mangrove ecosystem) were below the Limit of Detection (LOD). LOD, which typically equals the standard deviation of the blank solution times a constant, is the most negligible mass of analyte that can be separated from stochastic fluctuation in a blank (Bedasa and Assosa, 2016). LOD depends on the instrument's sensitivity and the analyzed sample matrix's background level (Ali, 2016). In that order, the land-use types with the highest concentrations of Cd were agricultural land, shrimp ponds, settlements, and bare land. Where there are more anthropogenic activities, the levels of Cd tend to be more significant. Cd is an ingredient in insecticides, fertilizers, and feed used in shrimp farming, where it is present in relatively high amounts. Additionally, Cd comes from settlement sources such as electronic waste, packaging goods (apart from food), and colors in ceramics, paints, and coating materials. This means that more settlements will increase the concentration of Cd in the sediment. Meanwhile, it is assumed that the sediment from other land-use types transported by runoff and wind deposited in that location is responsible for Cd concentration in bare land. The Cd contents in this study were substantially higher than the TEL value (2.707-2.983 mg/kg), which is known to have harmful biological effects on aquatic creatures. Quantifying the contribution of anthropogenic Pb is quite interesting. But overall, Pb concentration is typically thought of as the totality of Pb coming from both natural and human sources. Fuels, namely gasoline, are the primary source of Pb (Sepúlveda et al., 2022). Since this location was close to a popular tourist destination, the source of Pb in the mangrove environment was assumed to be from nearby traffic, the corrosion of scrap metal, and the resuspension of lead-contaminated soil dust. Runoff and
wind carried the Pb contaminants, which then accumulated in the mangrove ecosystem. However, that Pb value is relatively safe because it does not exceed the TEL value.

**Table 1.** Heavy metal concentrations in coastal sediments in the study area.

<table>
<thead>
<tr>
<th>Land-use type</th>
<th>Coordinate Easting</th>
<th>Coordinate Northing</th>
<th>Elevation (MASL)</th>
<th>Cd (mg/kg)</th>
<th>Pb (mg/kg)</th>
<th>Cu (mg/kg)</th>
<th>Zn (mg/kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mangrove ecosystem (A)</td>
<td>392876.83</td>
<td>9127025.25</td>
<td>3</td>
<td>&lt;0.848</td>
<td>5.415</td>
<td>42.893</td>
<td>56.174</td>
</tr>
<tr>
<td>Tourist attraction (B)</td>
<td>393563.89</td>
<td>9126582.48</td>
<td>7</td>
<td>&lt;0.848</td>
<td>&lt;3.251</td>
<td>7.106</td>
<td>&lt;13.542</td>
</tr>
<tr>
<td>Airport (C)</td>
<td>395735.71</td>
<td>9125776.78</td>
<td>1</td>
<td>&lt;0.848</td>
<td>&lt;3.251</td>
<td>7.143</td>
<td>&lt;13.542</td>
</tr>
<tr>
<td>Harbor (D)</td>
<td>398300.60</td>
<td>9124598.05</td>
<td>0</td>
<td>&lt;0.848</td>
<td>&lt;3.251</td>
<td>6.558</td>
<td>&lt;13.542</td>
</tr>
<tr>
<td>Mining area (E)</td>
<td>400450.95</td>
<td>9123685.75</td>
<td>1</td>
<td>&lt;0.848</td>
<td>&lt;3.251</td>
<td>4.935</td>
<td>&lt;13.542</td>
</tr>
<tr>
<td>Bare land (F)</td>
<td>401344.11</td>
<td>9123351.45</td>
<td>2</td>
<td>2.707</td>
<td>&lt;3.251</td>
<td>10.331</td>
<td>&lt;13.542</td>
</tr>
<tr>
<td>Shrimp pond (G)</td>
<td>401708.30</td>
<td>9123203.86</td>
<td>3</td>
<td>2.955</td>
<td>&lt;3.251</td>
<td>12.310</td>
<td>&lt;13.542</td>
</tr>
<tr>
<td>Agricultural land (H)</td>
<td>405852.92</td>
<td>9121352.45</td>
<td>7</td>
<td>2.983</td>
<td>&lt;3.251</td>
<td>10.422</td>
<td>&lt;13.542</td>
</tr>
<tr>
<td>Settlement (I)</td>
<td>410726.67</td>
<td>9118679.00</td>
<td>8</td>
<td>2.873</td>
<td>&lt;3.251</td>
<td>11.971</td>
<td>&lt;13.542</td>
</tr>
<tr>
<td>CSQG (TEL)</td>
<td></td>
<td></td>
<td>0.7</td>
<td>30.2</td>
<td>18.7</td>
<td>124</td>
<td></td>
</tr>
<tr>
<td>CSQG (PEL)</td>
<td></td>
<td></td>
<td>4.2</td>
<td>112</td>
<td>108</td>
<td>271</td>
<td></td>
</tr>
</tbody>
</table>

The concentration of Cu from the highest to the lowest was in the land-use types of mangrove ecosystem, shrimp pond, settlement, agricultural land, bare land, airport, tourist attraction, harbor, and mining area. The Cu sources would have included anthropogenic sources (mainly industrial plants and effluent), culinary utensils, living and dead biological material, antifouling coatings, textile manufacture, electrical conductors, plumbing fixtures, and pipelines (Kaonga et al., 2017; Yap et al., 2018). According to Rodriguez Martin et al. (2007), some manures also include levels of copper that may considerably contribute to the concentration of copper in soils. These anthropogenic sources are possible drivers of Cu concentrations in the study area. The high value of Cu concentrations in the mangrove ecosystem, as high as those of Pb, is probably due to Cu from other land-use types transported by runoff and wind and deposited in the area. However, the value of Cu in the mangrove ecosystem exceeds the TEL value and is quite dangerous for marine biota. Material sources account for most new anthropogenic Zn additions to the environment today. Most commercial metal goods (such as brass, bronze, castings, and galvanized metal) contain zinc, added to car tires as zinc oxide (ZnO) as a vulcanization process accelerator. Zn is also a typical pollutant in food and agricultural waste. Zn emissions from coal fly ash are significant; they are almost twice as large as Pb emissions. The primary source of anthropogenic Zn emissions worldwide is the combustion of fossil fuels (Callender and Rice, 2000). Anthropogenic activities from other land-use types, such as fertilizers and pesticides in agricultural land, wastewater in settlements, and fossil fuel from transportation activities in the tourist attraction, harbor, and airport, were used to estimate the concentrations of Zn in mangrove ecosystems.

Runoff and wind carried Zn, contaminating and accumulating in the mangrove habitat. However, the concentration of Zn in these locations tends to be safe because it does not exceed the TEL value.

Meanwhile, the number of heavy metal concentrations in other land-use types was insignificant, even below the LOD; it was estimated that those heavy metal concentration sources were derived from nature. Cd in the environment originates primarily from natural sources like geological settings. Natural sources of heavy metal contamination are related to the geological setting. The geological setting
defines the tectonic motion, basin settings, volcanic activities, lithological features, and mineral contents (Prasetya et al., 2021; Suprapto et al., 2017). Usually, heavy metals are found in ultramafic, basaltic, and metamorphic rocks (Widiatmoko et al., 2021). The presence of heavy metal contamination in nature might tell the mineral content in lithology that has been erosion and sedimentation processes (Zamroni et al., 2020). Natural rock weathering could have a minor impact on how much Cd is present in sediments. The trace Cd concentrations stored in the continental crust and mantle can naturally be mobilized by volcanic eruptions, physical and chemical weathering of the source rock material or derived soils, sea salt spray, and the production of marine biogenic aerosols (Cullen and Maldonado, 2013). Human activities that steadily increase the flow of Cd from the continents to the atmosphere, seas, rivers, and oceans have changed the normal biogeochemical cycle of Cd. Cd becomes adsorbent to or connected with surface sediments in the marine environment. This gradually causes sediments to become more enriched in Cd (Ningjing et al., 2017). Due to its similar ionic radius, Cd can substitute for divalent cations like Ca, Zn, Fe, Pb, and Co in various minerals, including carbonate and phosphate rocks. Zn can be replaced by Cd in smithsonite or sphalerite (ZnS) (Zn(CO$_3$)$_2$). Sulfide minerals, such as pyrite (FeS$_2$), are necessary components of reduced systems, resulting in significant sources and sinks of Cd. The maximum Cd content in pyrite is 52 mg/kg. Additionally, hydrous oxides like Fe(III) hydrous oxide, which can be a significant source of Cd for the aqueous phase when redox conditions shift from oxygenated to reducing, can adsorb Cd. In apatite, the primary component of phosphorite, Cd, can also replace Ca (Kubier et al., 2019). The natural biogeochemical cycle and the pyrite minerals in the iron sand (a component of Quarterly Alluvium) are suggested to be the sources of the low Cd concentration in some sampling locations. Most alluvial deposits along significant rivers and coastal plains make up Quarterly Alluvium. These sediments are clay, gravel, sand, and silt. The soil of the alluvial plain is made of volcanic rock (Zamroni et al., 2021). Pb is naturally created as parent rocks decompose (Lin et al., 2013). Pb is a bluish-gray metal that belongs to the periodic table’s IV group and is in period 6. It occurs naturally in the form of a mineral that also contains other elements, such as sulfides with sulfur (PbS, PbSO$_4$) or oxides with oxygen (PbCO$_3$) (Mishra et al., 2019). Lithological factors most likely caused the research area’s Pb concentrations. The DIY province’s iron sand’s coastal region has more Cu and Pb elements than is typically found in most rocks. In the study area, iron sand contained the metallic mineral vanadinite (Pb$_5$(VO$_4$)$_3$Cl), which provided Pb (Nurcholis and Mulyanto, 2017). It implies that the amount of lead in sediment in the study area was also estimated from the amount of Pb in iron sand (a part of Quarterly Alluvium).

Windblown soils, volcanoes, forest fires, sea spray, and biogenic processes are some sources of naturally occurring Cu atmospheric deposition (Roshan and Wu, 2015). Sulfide minerals such as copper can be found in nature. Only four deposit types—sediment-hosted copper, porphyry copper, magmatic nickel, and iron-oxide copper-gold—have shown very large Cu deposits, which restricts the potential locations of big copper sources due to the geologic settings of deposit types (Singer, 2017). For Cu, sediment serves as a significant sink and repository. The primary sources of copper in sediment are soil particles transported by runoff and erosion processes (Baillie et al., 2017). The iron sand composition of Quarterly Alluvium was used to determine the natural Cu content in numerous sampling locations. The earlier volcanic activity produced the iron sand. This was similar to the earlier study (Nurcholis and Mulyanto, 2017), which explained that the coastal region around DIY Province had a higher Cu concentration than the value for most rocks. Rarely occurring in nature, zinc necessitates extremely harsh reducing environments. Instead, Zn typically exists as a variety of geogenic minerals, primarily as sphalerite (zinc sulfide), willemite (zinc silicate), zinctite (zinc oxide), smithsonite (zinc carbonate), and hemimorphite (zinc silicate). In soil and sediment conditions at or below, sorption is the predominant response mechanism controlling the fate and transport of Zn. Zn comes from various geogenic sources, depending on the local geology and geomorphology. Pedogenic changes and Zn minerals in the source material will control the speciation of Zn in the soil. Zn levels in the soil are often low compared to
contaminated soils and are probably close to or higher than the typical crustal abundance of Zn (70 mg/kg). A significant amount of the Zn was leached from the soil profile, as evidenced by the difference in speciation between the source material and soil and the soil’s declining Zn level (Luxton et al., 2013). Since Zn does not fit into plagioclase, the other primary phenocryst phase must be enhanced in the glass phase relative to olivine. Zn is a mildly incompatible element. Spinel, magnetite, and titanomagnetite are likely the oxides most enriched in the source of Zn (Doe, 1994). According to a recent study (Fahmiati et al., 2017), iron sand in the coastal area of DIY Province contains a ZnO compound insignificantly. It means that the Zn sources naturally in the sediment sample locations were derived from iron sand in the study area.

The data on the amount of heavy metal contamination in the study area shows that heavy metal contamination cannot be linked based on land-use types. It is caused by several factors, such as anthropogenic activities around the study area not significantly producing heavy metal contamination, or it contaminated heavy metals, then transported by runoff and wind and deposited into other types of land-use, in this case, in the mangrove ecosystem. This is because variations in salinity, estuary flushing, physical mixing and dilution, and chemical processes, including sorption, complexation, cation exchange, and redox reactions, all affect how heavy metals are transported by water (Maniquiz-Redillas et al., 2019). In addition, some types of heavy metals are mobile. Cd is relatively mobile and potentially more bioavailable in sediments and freshwater systems when compared to other metals, and its concentrations in ocean surface waters are elevated compared to crustal concentrations (Abdallah and Mohamed, 2019; Cullen and Maldonado, 2013). Increasing the runoff volume was also at risk of increasing the dilution of heavy metals, making heavy metals easier to move. In a previous study (Asih et al., 2022), heavy metal contamination in the study area was insignificant in seawater. Still, in this study, heavy metal contamination tends to be high in coastal sediments. Algül and Beyhan (2020) explained that when heavy metals enter a water body, they can stay there for a while since the environment does not easily break them down. Heavy metals are often found in small amounts in aquatic systems, but significant concentrations in sediments may be due to their poor solubility in water; heavy metals tend to sorb to suspended particles that settle as sediment. In addition, the total metal concentration often indicates sediment pollution. However, the distribution, mobility, and/or bioavailability of metals in sediments should be discussed. Contrarily, sequential extraction methods offer extra, helpful information about the location of the primary metal-binding sites, the degree of metal binding to particulates, and the phase associations of trace elements in soils, sediments, or dust, which aids in understanding the geochemical processes governing metal mobilization and any associated risks (Gabarrón et al., 2019). In cases where the elements interspersed within the mineral structure is difficult to release into the environment, it proposes using the sequential extraction procedures in the upcoming study to assess the danger of environmental pollution. Therefore, it will be possible to identify the relevant mobilized portion of these elements via a sequential extraction process. The sketch of the study result is shown in Fig. 3.
Fig. 3. The sketch of heavy metal concentration in surface sediments in the study area (This sketch has been designed using assets from freepik.com and flaticon.com).

4.2. Comparison with Sediment Quality Standard

Sediment assessors and managers can better understand sediment quality by comparing the amounts of pollutants in sediments with the associated quality recommendations. By screening sediment chemical data, this operation can find contaminants of concern and highlight priority problem areas that could harm aquatic life (Sahli et al., 2021).

According to the heavy metal concentrations in each sediment sample (Table 1), the surface sediments for most of the sites were in good condition because no sample sites exceeded the PEL value. Nevertheless, the concentrations of Cd in shrimp pond, bare land, agricultural land, settlement, and Cu in the mangrove ecosystem slightly exceeded the corresponding TEL value. The sampling site's surface sediments have minimal anthropogenic pollution. Heavy metal contamination should be controlled and avoided by formulating environmental regulations, laws, quality norms, and standards and increasing funding for cutting-edge scientific research and technical tools to prevent heavy metal pollution in coastal areas. All stakeholders must work together to prevent heavy metal pollution, such as the government making regulations and monitoring their implementation in industrial, agricultural, and tourism business actors comply with regulations in waste management, and the community actively participates in taking actions to reduce heavy metal pollution.

5. Conclusions

The concentrations of Cd in bare land, shrimp pond, agricultural land, and settlement (with values of 2.707, 2.955, 2.983, and 2.873, respectively), and Cu in the mangrove ecosystem (with values of 42.893) slightly exceeded the corresponding TEL value of CSQG. Meanwhile, the content of other heavy metals in all land use types tends to be low, even below the LOD. The sources of CD concentration in the study area are insecticides, fertilizers, and feed used in shrimp farming, settlement sources such as electronic waste, packaging goods (apart from food), and colors in ceramics, paints, and coating materials. This means that more settlements will increase the concentration of Cd in the sediment. Meanwhile, it was assumed that the sediment from other land-use types transported by runoff and wind deposited in that location is responsible for Cd concentration in bare land. The source of Pb in the mangrove environment was assumed to be from nearby traffic, the corrosion of scrap metal, and the resuspension of lead-contaminated soil dust. The Cu sources in the study area would have included anthropogenic sources (mainly industrial plants and effluent), culinary utensils, living and dead biological material, antifouling coatings, textile manufacture, electrical conductors, plumbing fixtures,
pipelines, and manures. In addition, anthropogenic activities from other land-use types, such as fertilizers and pesticides in agricultural land, wastewater in settlements, and fossil fuel from the transportation activities in the tourist attraction, harbor, and airport, were used to estimate the concentrations of Zn in mangrove ecosystems. Runoff and wind carried Cu, Pb, and Zn, contaminating and accumulating in the mangrove ecosystem. However, the number of heavy metal concentrations in other land-use types was negligible, even below the LOD; it was thought that those sources of heavy metal concentration came from nature, particularly the mineral content in iron sand (a part of Quarterly Alluvium where sediment samples were located). Because no sample site surpassed the PEL value, the surface sediments for most locations were in good condition. However, the concentrations of Cd in settlements, agricultural land, shrimp pond, and bare land, and Cu concentration in mangrove ecosystem marginally surpass the corresponding TEL value of CSQG. Heavy metal contamination should be controlled and avoided by formulating environmental regulations, laws, quality norms, and standards and increasing funding for cutting-edge scientific research and technical tools to prevent heavy metal pollution in coastal areas. The distribution, mobility, and/or bioavailability of metals in sediments should be discussed. Contrarily, sequential extraction methods offer extra, helpful information about the location of the primary metal-binding sites, the degree of metal binding to particulates, and the phase associations of trace elements in soils, sediments, or dust, which aids in understanding the geochemical processes governing metal mobilization and any associated risks. In cases where the element interspersed within the mineral structure is difficult to release into the environment, it proposes using the sequential extraction procedures in the upcoming study to assess the danger of environmental pollution. Therefore, it will be possible to identify the relevant mobilized portion of these elements via a sequential extraction process.

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