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Ecological risk assessment through heavy metal concentrations of lead, copper, cadmium, zinc, and nickel in marine sediments of Maspari Island, South Sumatra Indonesia

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ABSTRACT

Heavy metals come from anthropogenic and geological activities. It is necessary to know the concentration of heavy metals in anticipation of pollution of marine ecosystems so this study aims to determine the content of heavy metals lead (Pb), copper (Cu), cadmium (Cd), zinc (Zn), and nickel (Ni) in the sediments of Maspari Island, South Sumatra. Samples were tested for heavy metal levels using atomic absorption spectroscopy (AAS) and processed using Microsoft Excel. All heavy metal geoaccumulation index (I_{geo}) values were negative, meaning they were less than 0 and categorized as unpolluted. The I_{geo} value closest to 0 is heavy metal Cd of -2.8 at station 8 which is sourced from agricultural runoff water and aquaculture. All heavy metal contamination factor (Cf) values are less than 1 which is included in the low contamination level criteria. The largest PLI value at station 5 is 0.000051425 which is categorized as unpolluted to lightly polluted. The concentrations of heavy metals Pb, Cu, Cd, Zn, and Ni from eight stations did not exceed the quality standards.

Keywords: heavy metals, ecological risk assessment, marine sediments.

INTRODUCTION

Anthropogenic pollution inputs, including home sewage and industry pollutants, are closely linked to heavy metals (Yang et al., 2020). Industrial, residential, and agricultural effluents are the primary human sources of heavy metal pollution in aquatic bodies (Kolarova dan Napiórkowski, 2021). The environment is producing excessive amounts of heavy metals due to the rapid development of the manufacturing and agricultural industries, as well as population growth (Okereafor et al., 2020; Gavhane et al., 2021; Leung et al., 2021; Ali et al., 2022; Asih et al., 2023). Heavy metal pollution in the marine environment originates from local industrial discharges and domestic activities through surface runoff carried by rivers to the sea (Huang et al., 2020; Mehr et al., 2020; Sun et al., 2020; Madzlan et al., 2023), as well as agricultural waste (Lv et al., 2021). These four metals nickel (Ni), copper (Cu), lead (Pb), and zinc (Zn) are frequently detected as contaminants in the marine environment. They are frequently the result of human activity, such as industrial processes and nautical operations (Bhuyan et al., 2023). The primary elements Ni, Cu, Zn, Cd, and Pb imply industrial sources (Ye et al., 2020). Anthropogenic sources are mostly responsible for the enrichment of Cd, Cu, Zn, Pb, and Ni (Kahal et al., 2020; Uddin et al., 2020; Mehr et al., 2020; Tian et al., 2020). Contents of Cu, Pb, and Zn as a result of human activity (Cai et al., 2021).

In addition to anthropogenic sources, heavy metals are also derived from geological processes such as Ni (Yang et al., 2020; Leung et al., 2021), Ni is derived from crustal material or natural weathering in the sea (Yang et al., 2020) which is associated with mixed lithogenic factor sources and sand intrusion (Kumar et al., 2020). Depending on the local geology and geomorphology, heavy metal zinc can come from a variety of geogenic sources (Asih et al., 2023). The natural sources of Zn are mostly mica clay minerals (Zhuang dan Zhou, 2021) and the availability of Cu is attributed to weathering from intermediate mafic rocks (El-sorogy et al., 2020), and mica clay minerals (Zhuang dan Zhou, 2021). According to Cao et al., (2020), the weathering of pre-cambrian bedrock as well as tertiary and quaternary rocks along the coastal area are the sources of Cd, Cu, and Zn. Statement (Youssef et al., 2020) the amount of terrigenous material, primarily from bedrock, is reflected in the composition of heavy metals Pb and Cd in sediments. Arienzo et al., (2020) and Yang, T. et al., (2020) to the existence of underwater hydrothermal springs results in fluids that contain heavy and possibly harmful metals including Cu, Pb, and Cd. This alters the chemistry of coastal marine waters and increases pollution.

Heavy metal pollution is a global problem with implications for ecosystem functioning (Okereafor et al., 2020; Nyarko et al., 2023). High levels of heavy metals at a site reflect ecological threats (Boboria et al., 2021; Halawani et al., 2022). A considerable and open ecological risk is the potential threat of Ni, Cu, Cd, Pb and Zn heavy metal contamination (Aljahdali and Alhassan, 2020; Hong et al., 2020). Due to increased toxicity and bioaccumulation in marine organisms, increased sediment heavy metal content will put marine life at greater risk. This could have detrimental effects on biogeochemical cycles and jeopardize biodiversity survival (Aljahdali and Alhassan, 2020; Kibria et al., 2021). Heavy metals pose a severe toxicity risk (Huang et al., 2020; Chen et al., 2022) because they collect more in sediments than in the water column after migrating to the sea (Liu et al., 2021), so the influence of sediments on biological quality is much greater than that of water (Fan et al., 2020). Many benthic creatures, including crabs and other crustaceans, echinoderms, bivalves, polychaete worms, and turbellaria, call sediments home (Hasimuna et al., 2021). Organisms will eat up heavy metals deposited in sediments (Haddout et al., 2021). Heavy metals are among the often discovered components of pollutants. A thorough index must be used to classify pollution levels that are directly linked to future management choices in order to determine the condition of heavy metals and their distribution in coastal sediments (Halawani et al., 2022). Similarly, Maspari Island may eventually be developed as a tourist destination. Because of the distance to the site and the paucity of research publications on heavy metals on Maspari Island, the island has not been used to its full potential. Because there is currently very little information available concerning heavy metals in the research area, the purpose of this study is to ascertain the concentration of lead, copper, cadmium, zinc, and nickel in the sediments of Maspari Island, South Sumatra. In order for the findings of this study to predict future ecosystem pollution from heavy metals, information on the five types of heavy metals in the study area can be used as preliminary data to predict the level of pollution by heavy metals Pb, Cu, Cd, Zn, and Ni.

MATERIALS AND METHOD

Study area and sampling

The mangrove and coral reef habitats of Marpari Island, Tulung Selapan, Ogan Komering Ilir, South Sumatra, were sampled in February 2023. The research area was split up into 8 stations (Figure 1 and Table 1), which were distributed around Maspari Island and were meant to represent the region where the concentrations of the heavy metals Pb, Cu, Cd, Zn, and Ni in sediments were to be measured. The study was carried out at the South Sumatra Province's Environment and Land Agency's Environmental Laboratory. Using a 500 g Ekman grab, sediment samples were collected, placed in plastic clips, and labeled with a marker. Samples were delivered to the lab for examination after being kept in a coolbox.

Data processing

Samples of sediment collected from the field were weighed using analytical scales and up to 3 g dry weight was added to a 100 mL Erlenmeyer. Following the addition of 25 mL of distilled water and a thorough stirring of 10 mL of concentrated HNO_3, the mixture was covered with a watch glass. In addition, the sample was heated on a hot plate set at 105 °C until the volume reached around 10

Figure 1. Research location on Maspari Island, South Sumatra (Google earth software, 2024)

Table 1. Coordinates of the research station

Station	Longitude	Latitude
1	106°12' 53.98" BT	3°12'57.25" LS
2	106°12'55.78" BT	3°13'09.71" LS
3	106°13'02.36" BT	3°13'14.86" LS
4	106°13'15.58" BT	3°13'07.18" LS
5	106°12'48.99" BT	3°12'54.31" LS
6	106°12'53.14" BT	3°13'12.44" LS
7	106°13'0.67" BT	3°13'17.28" LS
8	106°13'16.99" BT	3°13'06.83" LS

milliliters. After that, it was taken out and allowed to cool. The next step is to add 3 mL of aqua regia and 5 mL of pure HNO_3. Once more, the sample is heated until clear sample solution appears and white smoke appears. The heating process lasts for about thirty minutes. Following a 0.45 µm filter paper filter, the sample solution was transferred into a 100 mL volumetric flask, distilled water was added up to the limit mark, and the sample was homogenized. This work step is in accordance with the Indonesian National Standard. With wavelength provisions for Pb 283.3 nm (Salimi et al., 2020), Cu 324.8 nm (Bhuyan et al., 2023), Cd 228.8 nm (Salimi et al., 2020), Zn 213.9 nm (Bhuyan et al., 2023), and Ni 232.0 nm (Bhuyan et al., 2023), samples were tested for heavy metal levels using AAS (atomic absorption spectroscopy) (Shimadzu AA-7000).

DATA ANALYSIS

Quality standards

Following investigation, the quantities of heavy metals in the sediments were compared to Table 2's quality standard values (ANZECC dan ARMCANZ, 2000). Microsoft Excel was used to compare heavy metal concentrations and evaluate the ecological concerns associated with heavy metals.

Index of geoaccumulation (I_{geo})

The Igeo is used to classify and identify environmental controls imposed by anthropogenic activities (Okonkwo et al., 2023). The determination of the geoaccumulation index value and its criteria refer to (Muller, 1969) as follows:

$$I_{geo} = log2\left(\frac{Cx}{1.5\,Bn}\right) \quad (1)$$

Table 2. Heavy metal quality standards in sediment

Pb	Cu	Cd	Zn	Ni
50 mg/kg	65 mg/kg	1.5 mg/kg	200 mg/kg	21 mg/kg

where: I_{geo} – geoaccumulation index; Cx – heavy metal concentration in sediment sample; 1.5 = constant; Bn – normal concentration of heavy metal in nature (background).

I_{geo} value criteria, namely $I_{geo} < 0$ – not polluted; $0 < I_{geo} <$ – mildly polluted; $1 < I_{geo} < 2$ – moderately polluted; $2 < I_{geo} < 3$ – moderately polluted; $3 < I_{geo} < 4$ – severely polluted; $4 < I_{geo} < 5$ – extremely severely polluted; $I_{geo} > 5$ – extremely severely polluted.

Contamination factor (Cf)

Cf is a quantitative evaluation of the level and source of contaminants (Okonkwo et al., 2023). Cf is the ratio of the measured concentration over the background value (Arikibe dan Prasad, 2020). The determination of the contamination factor value and its criteria refers to (Hakanson, 1980) as follows.

$$Cf = \frac{Cx}{Bn} \quad (2)$$

where: Cf – contamination factor; Cx – heavy metal concentration in sediment; Bn – normal concentration of heavy metals in nature (background).

Criteria for contamination factors, namely Cf < 1 – low contamination level; 1 < Cf < 3 – medium contamination level; 3 < Cf < 6 – moderate contamination level; Cf > 6 – very high contamination level.

Pollution load index

Pollution load index (PLI) offers a straightforward but subjective way to assess whether a location is suitable for human well-being (Okonkwo et al., 2023). An indicator of the total toxicity level of heavy metals in a given sample is the PLI value, which shows how many times the metal content in the sediment surpasses the typical background concentration (Madzlan et al., 2023). The PLI value and its criteria refer to (Hakanson, 1980) as follows:

$$PLI = [Cf1 \times Cf2 \times Cf3 \times \ldots .. \times Cfn]^{1/n} \quad (3)$$

where: PLI – pollution load index; Cf – heavy metal contamination factor; n – amount of heavy metals.

PLI criteria, namely PLI < 0 – not polluted; PLI 0–2 – not polluted to lightly polluted; PLI 2–4 – moderately polluted; PLI 4–6 – severely polluted; PLI 6–8 – very severely polluted; PLI 8–10 – extremely severely polluted.

RESULTS

Environmental conditions

Maspari Island is one of the outermost islands in South Sumatra Province, Indonesia and is a habitat for various types of biota because there is a mangrove ecosystem. In addition, this area in the future also has the potential for tourism activities because of its natural beauty which has sandy and rocky beaches can be seen in Figure 2.

Heavy metal concentration

Figure 3 shows the concentration of the heavy metals Pb, Cu, Cd, Zn, and Ni at each location. Pb concentrations in the sediments of Maspari Island range from 0.0142 mg/kg at station 1 to 0.1022 mg/kg at station 5, with the lowest concentrations found at that location. Maspari Island's sediments had the lowest concentration of the heavy metal Cu, 0.0054 mg/kg, at station 2, and the highest concentration, 0.0652 mg/kg, at station 3. The concentration of the heavy metal Cd in the sediments of Maspari Island was found to be lowest at station 3 (0.0032 mg/kg) and greatest at station 8 (0.3211 mg/kg). Zn, a heavy metal, has the lowest concentration in the sediments of Maspari Island at station 4, measuring 0.1058 mg/kg, and the highest concentration at station 5, measuring 1.0252 mg/kg. Station 4 has the lowest concentration of Ni heavy metal in the sediment of Maspari Island, at 0.0016 mg/kg, while station 2 has the greatest concentration, at 0.0432 mg/kg. The quality standard values of Pb, Cu, Cd, Zn, and Ni were 50 mg/kg, 65 mg/kg, 1.5 mg/kg, 200 mg/kg, and 21 mg/kg, respectively. Overall, the accumulation levels of these heavy metals in the sediments of Maspari Island Waters did not surpass the environmental safety criteria established by (ANZECC dan ARMCANZ, 2000). Because the research site is an outer island region of South Sumatra Province and fairly remote from the pollution source, the heavy metal concentrations are minimal.

Zn, Ni, Pb, and Cr heavy metal concentrations in the Modaomen estuary's surface sediments rose sharply in 2015 as compared to 2003, but Cu and Cd concentrations fell. Cu concentration barely changed in 2021, whereas Zn and Cd dropped while Pb, Ni, and Cr rose. Both natural and man-made

Figure 2. Maspari Island neighbourhood

agricultural sources had an impact on sediment heavy metal levels in 2003. In addition to natural sources, human-related industrial, traffic, and agricultural activities had an impact on sediment heavy metal levels between 2015 and 2021. The notable successes of environmental restoration and protection in cities upstream of the Modaomen estuary throughout the sampling period were the cause of the fluctuations in Cd and Zn (He et al., 2024). According to enrichment factor (EF) values > 7 for Cu, anthropogenic activities caused moderate to severe contamination in western Matsushima Bay in every sampling year between 2012 and 2016 (Ota et al., 2021). The geographically and temporally distinct buildup of heavy metals in areas with varying industries is demonstrated by another study on the EF values of heavy metals in sediment cores from China's peripheral waters. The temporal variability of heavy metal pollution over the last century roughly corresponds to China's economic development stage. The majority of China's coastal seas have seen a decrease in offshore sediment pollution since the 2000s. The evolution and source-sink dynamics of heavy metals in offshore sediments, as well as the anthropogenic consequences over time, are of reference significance (Yang et al., 2021).

Four stages – pre-1950, 1950–1976, 1976–2000, and post-2000 – can be distinguished in the distribution of heavy metals in sediment cores. These stages correspond to changes in the Pearl River Delta's environment and anthropogenic activity throughout the previous century. Over time, anthropogenic metals (Zn and Pb) gradually increased their contribution to sediments. However, since 2010, the concentrations, enrichment factors, and fluxes of heavy metals

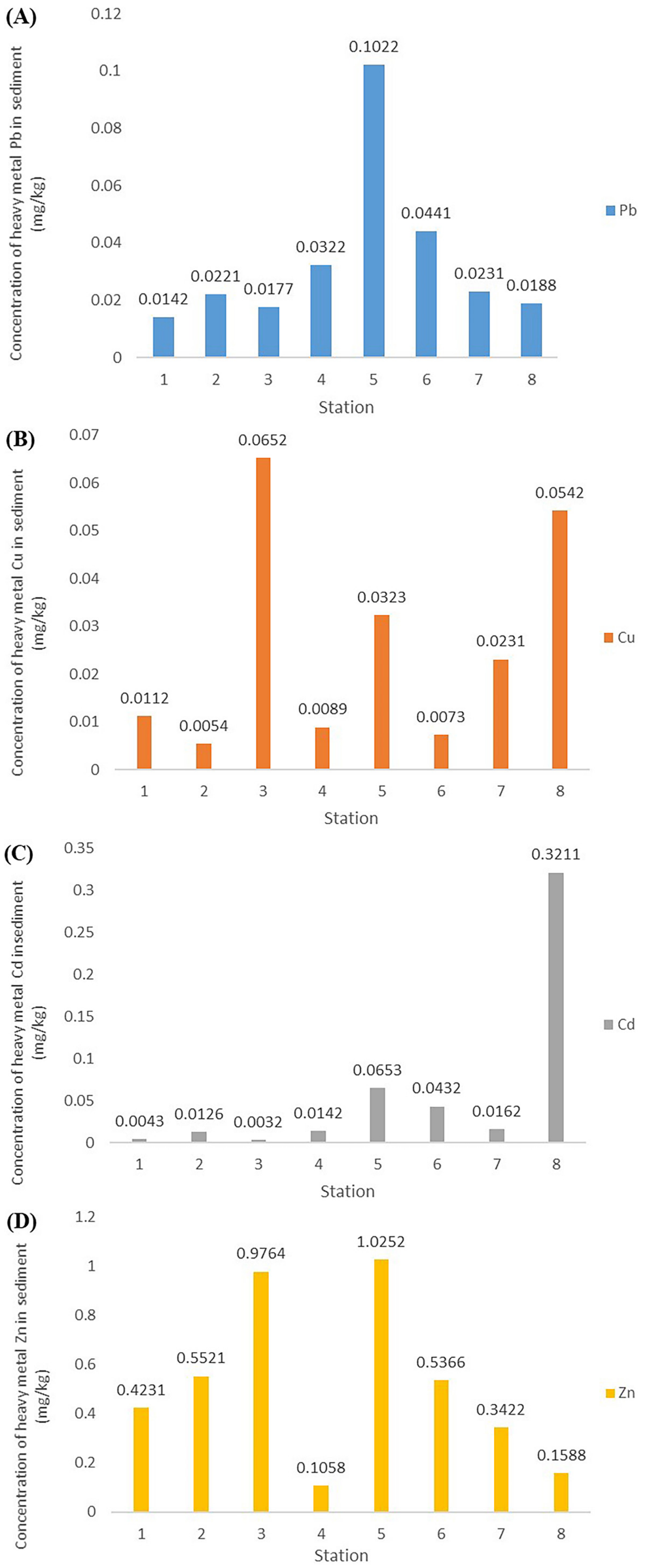
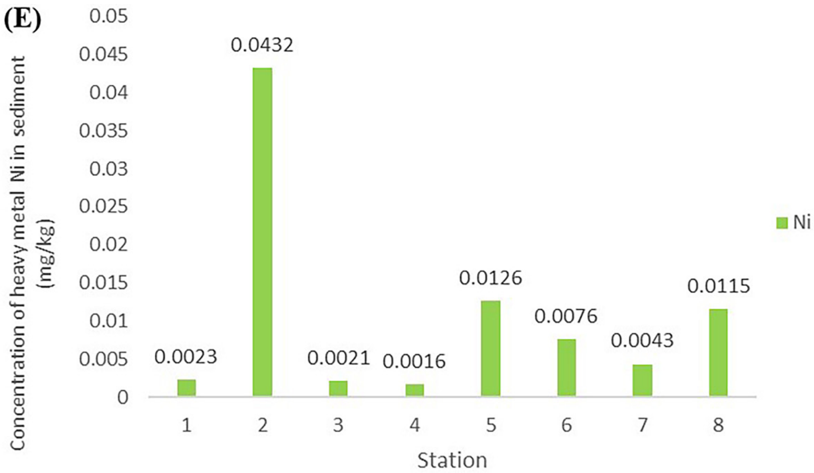


Figure 3. Heavy metal concentrations in Maspari Island sediments (A) Pb, (B) Cu, (C) Cd, (D) Zn, and (E) Ni



Cont. Figure 3. Heavy metal concentrations in Maspari Island sediments (A) Pb, (B) Cu, (C) Cd, (D) Zn, and (E) Ni

in sediments have all shown a decreased trend, suggesting that the stringent emission reduction regulations put in place over the past ten years have reduced the input of metal pollutants (Shi et al., 2022). Laguna Mar Menor is a significant economic engine since it combines biological production with excellent environmental quality. However, its ecological integrity is in danger due to the impact of human activities. The mining activity, which has been documented since the Roman era approximately 3500 years ago and peaked in the 20th century, is the oldest environmental impact. It supplied heavy metals to the lagoon sediments for nearly 30 centuries. Hydrographic and biogeochemical processes, the solubility of different elements, and coastal works in harbors and on beaches will determine the recent evolution of heavy metal concentrations and their spatial redistribution after direct discharges to the lagoon ceased in the 1950s (Pérez-Ruzafa et al., 2023). It is known from the previously mentioned research that heavy metals will give rise to temporal and spatial trends that occur, so preliminary data is needed to anticipate heavy metal pollution through regular monitoring on Maspari Island.

Human activities that alter the environment are the cause of the buildup of heavy metals in marine sediments (Yang et al., 2021; Shi et al., 2022; Pérez-Ruzafa et al., 2023; He et al., 2024). These results may serve as references for the prevention, control, and management of heavy metal contamination in the research area and other river-dominated estuaries, as humans continue to have an impact on river inputs worldwide (He et al., 2024). Because of their bioaccumulation, non-biodegradability, toxicity, and persistence, heavy metal contamination of marine sediments has caused worry worldwide and affected human health (Ota et al., 2021; Kumar et al., 2022). To choose the best remediation strategies for managing heavy metals in sediments, one must have a basic understanding of the sources of heavy metals, their chemistry, and the possible threats they bring to the environment and to people. Governments and nongovernmental organizations should start public awareness campaigns to curb activities that lead to sediment contamination in order to restore the ecological stability and economic viability of sediments and soils (Kumar et al., 2022). The true dangers of human intervention in regions susceptible to heavy metal contamination can only be evaluated and appropriate preventive or remedial measures may be implemented with understanding of these processes (Pérez-Ruzafa et al., 2023). In the future, strict regulations to reduce heavy metal pollution will still be required (Yang et al., 2021; Pérez-Ruzafa et al., 2023). The study of heavy metal data in Maspari Island an initial step to anticipate pollution, considering that the current heavy metal value of Maspari Island is relatively small compared to other island heavy metal data contained in Table 3. This is because Maspari Island has not been inhabited by residents or become a tourism object considering that transportation access takes about 8 hours from Palembang as the city centre of South Sumatra Province to Maspari Island via land and water access. However, in the future Maspari Island is expected to become a tourist attraction of South Sumatra Province

Table 3. Heavy metal concentration in Island Sediments

Location	Heavy metal concentration average (mg/kg)					Reference
	Pb	Cu	Cd	Zn	Ni	
Maspari Island	0.03	0.02	0.06	0.51	0.01	This study
Zhoushan Islands	33.93	67.84	0.20	107.76		(Zhai et al., 2021)
Big Giftun Island	0.62	0.13	1.17	0.08	0.69	(Abdelaal et al., 2024)
Abu Minqar Island	1.19	0.27	0.13	2.89	0.76	(Abdelaal et al., 2024)
Kavaratti Island	47.95	5.52	7.76	19.07	9.44	(Antony et al., 2022)
Saint Martin's Island	5.88	3.76		27.17	29.6	(Bhuyan et al., 2023)
Hainan Island	26.82	14.97		70.50	25.26	(Cai et al., 2021)
Hainan Island	20.61	8.92	0.06	29.13		(Zhao et al., 2020)
Hainan Island	28.1	16.9	0.082	85.3		(Zhang et al., 2023)
Qizhou Island	21.02	11.31	0.091	55.38	21.55	(Fan, J. et al., 2024)
Western Miao Islands	15.68	16.62	0.13	50.83	23.20	(Wang et al., 2024)
Nijhum Dweep Island	5.63	36.97	0.29	20.65	9.26	(Rahman et al., 2022)
Upolu Island	7.4	29.0	0.13	98.5	161	(Jeong dan Ra, 2023)
Mallorca Island	10.10	1.16	0.50	8.87	1.69	(Ardila et al., 2023)
Ardley Island	1.47	163.24	1.04	130.23		(Lin et al., 2021)
Hare Island			0.02			(Arisekar et al., 2021)
Solomon Islands	153	274	30			(Boboria et al., 2021b)

because it can help the community's economy and regional income. Even the government has promoted Maspari Island information through online news dissemination.

ECOLOGICAL RISK ASSESSMENT

Index of geoaccumulation (I_{geo})

The geoaccumulation index was used to assess the enrichment of heavy metals in sediments. The level of metal pollution in core sediments is indicated by I_{geo} values (Singh et al., 2020). According to the study data, all eight stations' Index of I_{geo} values for the heavy metals Pb, Cu, Cd, Zn, and Ni were negative, or less than 0 (Table 4). In accordance with the I_{geo} criteria (Muller, 1969), an area is considered unpolluted if its Igeo value is less than 0. But according to the data, heavy metal Cd had the I_{geo} value that was closest to 0 at station 8 (-2.8). According to Lv et al. (2021) there are two causes of Cd: natural and human. However, presumably as a result of human activity, the geoaccumulation index value of Cd in this study is larger than that of other metals. According to Cao et al. (2020), there is a significant chance that heavy metal Cd will accumulate as a result of agricultural land and fish farming pollution. Ogan Komering Ilir Regency is the site of this study. According to data from the Central Bureau of Statistics of Ogan Komering Ilir Complete Enumeration of the Agricultural Census in 2023, the region has plantation crops like coconut, robusta

Table 4. Heavy metal geoaccumulation index (I_{geo}) values of Maspari Island sediments

Station	Pb	Cu	Cd	Zn	Ni
1	-12.4	-13.1	-9.0	-9.5	-13.7
2	-11.7	-14.1	-7.5	-9.1	-9.5
3	-12.0	-10.5	-9.5	-8.3	-13.9
4	-11.2	-13.4	-7.3	-11.5	-14.3
5	-9.5	-11.6	-5.1	-8.2	-11.3
6	-10.7	-13.7	-5.7	-9.1	-12.0
7	-11.7	-12.0	-7.1	-9.8	-12.8
8	-12.0	-10.8	-2.8	-10.9	-11.4

coffee, cloves, tobacco, and kapok; horticulture, which includes vegetables; and food crop commodities, which include rice, corn, soybeans, peanuts, green beans, cassava, and sweet potatoes. Due to the extensive use of pesticides and fertilizers, these agricultural practices are believed to be a source of heavy metals (Ustaoğlu et al., 2020). After being carried by the current from the agricultural land, fertilizers will raise the amount of metals in the water (Boboria et al., 2021; Asih et al., 2023). Agricultural fertilizers and pesticides that are carried into the sea by surface runoff can also provide cadmium (Algül dan Beyhan, 2020; Zhuang dan Zhou, 2021; Asih et al., 2023). The extent of Cd contamination in coastal sediments is reflected in the distribution of Cd concentration (Al-mur, 2020; Bhuyan et al., 2023).

In addition to agriculture, aquaculture is practiced (Cao et al., 2020; Asih et al., 2023). The coastal regions of Ogan Komering Ilir Regency are home to traditional and semi-traditional ponds that are used for the production of tiger shrimp and milkfish. Although it is still categorized as not contaminated or safe, this activity is also thought to be the reason why the Cd geoaccumulation index was identified at the research site in larger proportions than other metals. However, this state must be monitored because, even at very low concentrations, the heavy metal Cd can be extremely hazardous, accumulate in the human body, and alter critical metabolic processes if it continues to rise to contaminated standards (Thakare et al., 2021). The survival of nearby biota, including fish, turtles, and bottom-dwelling biota, will be jeopardized if this occurs.

Contamination factor and pollution load index

The degree of metal pollution in sediments is determined by the pollution index (Cf and PLI) (Singh et al., 2020). The highest Cf value of heavy metal Cd at station 8 is 0.214, as shown in Figure 4. A low level of contamination is indicated by all

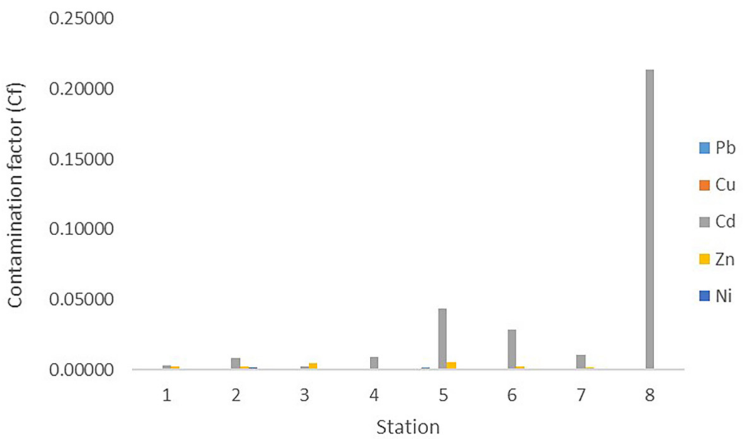


Figure 4. Graph of Cf of Maspari Island Sediment

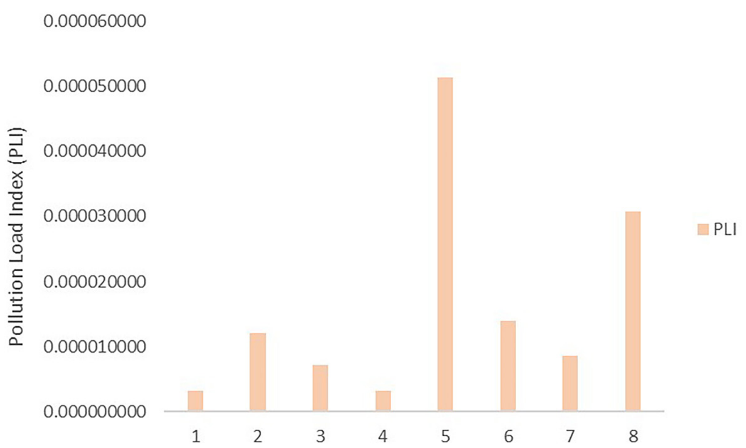


Figure 5. Graph of sediment pollution load index of Maspari Island

Table 5. Cf and PLI values of heavy metals in Maspari Island sediments

Station	Cf Pb	Cf Cu	Cf Cd	Cf Zn	Cf Ni	PLI
1	0.00028	0.00017	0.00287	0.00212	0.00011	0.000003191
2	0.00044	0.00008	0.00840	0.00276	0.00206	0.000012054
3	0.00035	0.00100	0.00213	0.00488	0.00010	0.000007178
4	0.00064	0.00014	0.00947	0.00053	0.00008	0.000003228
5	0.00204	0.00050	0.04353	0.00513	0.00060	0.000051425
6	0.00088	0.00011	0.02880	0.00268	0.00036	0.000014044
7	0.00046	0.00036	0.01080	0.00171	0.00020	0.000008533
8	0.00038	0.00083	0.21407	0.00079	0.00055	0.000030787

heavy metal Cf values for Pb, Cu, Cd, Zn, and Ni being less than 1 (Hakanson, 1980). Station 1 has the lowest PLI value, 0.000003191, while station 5 has the highest PLI value, 0.000051425 (Figure 5), which falls between unpolluted and mildly contaminated (Hakanson, 1980). Table 5 provides specific values for the PLI and Cf for the heavy metals Pb, Cu, Cd, and Zn.

Heavy metals can be found in sediments both as good reservoirs and carriers. Rock, organic matter, and minerals are all found in sediments, which are created by the deposition process. Before they build up and settle on the bottom, sediments are thought to serve as filters for a variety of metals that come from the land (Wardani et al., 2020). Many intricate processes, including adsorption, hydrolysis, and coprecipitation, are responsible for the majority of free metal ions' incorporation into sediments (Behera et al., 2021). Coastal regions are thought to serve as locations where different pollutants produced by urban and commercial activity can be sequestered (Halawani et al., 2022). The residences of the local populace are the direct source of heavy metals found in wastewater (Ustaoğlu et al., 2020). In addition to housing and community facilities like marketplaces and fishing ports, the downstream region is crowded and has workshops that may release heavy metal pollution (Nasir et al., 2021). Estuarine areas are strongly impacted by human activity, as evidenced by the significantly greater levels of heavy metals in these areas compared to marine areas (Tian et al., 2020). According to this study, heavy metals do not directly originate from human activity. Low levels of heavy metal concentration were discovered in marine or coastal sediments by similar research (Abbasi dan Mirekhtiary, 2020; Ferrans et al., 2021; Harmesa dan Cordova, 2021; Lv et al., 2021).

CONCLUSIONS

The amounts of Pb, Cu, Cd, Zn, and Ni, among other heavy metals, were all within the quality limits at all eight locations. All eight stations' I_{geo} values for the heavy metals Pb, Cu, Cd, Zn, and Ni are negative, meaning they are less than 0 and are classified as unpolluted. Heavy metal Cd of -2.8 at station 8 has the Igeo value that is closest to zero. For the heavy metals Pb, Cu, Cd, Zn, and Ni, all Cf values are less than 1, indicating low contamination. At station 5, the highest PLI score is 0.000051425, so it is classified as either mildly or unpolluted. The range of concentrations of various heavy metals in the study area can serve as preliminary data that can be used to anticipate the level of pollution by heavy metals Pb, Cu, Cd, Zn, and Ni in the future.

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