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Geogenic versus Anthropogenic Sources of Hazardous Elements Pollution in Marine Sediment Samples: Case of Lampung Bay, Indonesia

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ABSTRACT

Hazardous elements in the marine environment potentially affect the safety of seafood production in the area. Some elements are considered as essential elements for humans in a low concentration, but some others are toxic and believed to induce cancer even though at a trace level. This paper has studied the source of hazardous elements contamination in Lampung Bay, Indonesia, whether anthropogenic or geogenic. Sampling was conducted at a one-mile distance from the shore. Some stations were also located in the river mouth to investigate how much inland pollution affects the bay. The mean enrichment factor (EF) for each hazardous element are 0.62, 3.09, 2.79, 4.18, 2.03, 6.10, and 2.05 for Cr, Ni, Cu, Zn, Cd, As and Pb, respectively, showing that all elements influenced by anthropogenic source except Cr. This result is proven by the lower geo-accumulation index (Igeo) normalisation, meaning the influence of geogenic sources is limited. Further statistical analysis using principal component analysis (PCA) showed that the river mouth sampling stations influenced the concentration of hazardous elements in the bay. Although the concentration of the elements is below the maximum level of the quality standard for marine sediment in almost all sampling stations, continuing monitoring of the environmental healthiness of the bay is encouraged to ensure the sustainability of fisheries production in this area.

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INTRODUCTION

In most cases, the ocean is the final disposal of all types of contaminants, whether as part of anthropogenic activities or natural resources. River runoff, rich in nutrition and contaminants, flows and evolves in the ocean. Bays are adjacent to land and open sea, have direct contact with surrounding rivers, and form an estuarine environment. Due to their semi-enclosed nature and proximity to land-based pollution sources, bays may experience higher concentrations of pollutants, posing risks to the environment and the food cycles (Chen et al., 2021). On the other hand, ocean minerals are also enriched by natural conditions such as volcanic eruptions, evaporation, and weathering (Kapoor & Singh, 2021; Tchounwou et al., 2012).

The accumulation of heavy metals and other hazardous elements in the marine sediments may affect the biological balance and increase bioaccumulation, which affects the food chain (Wang et al., 2022). Micro-nutrients such as iron, zinc, copper, and manganese will benefit humans at trace concentrations. However, if the concentration increases too high, it will be harmful and toxic (Xie et al., 2017). Marine nutrients, both micro and macronutrients and contaminants

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from the environment, mainly increase in the tropic levels, causing the accumulation of those elements in the highest level of food chains (Gao et al., 2021). Non-essential elements such as lead, cadmium, arsenic and mercury are toxic. Although present in a low concentration in the food chain, consuming hazardous elements contaminated food has to be controlled to the level of not exceeding the maximum daily tolerable (Tchounwou et al., 2012). The human metabolism system does not acknowledge those elements and usually stores and accumulates in the body, posing chronic effects (Tchounwou et al., 2012; Xie et al., 2017).

The presence of heavy metals and other hazardous elements in the oceans always lead to two questions: whether they are from natural sources or anthropological sources. The marine environment comprises many substances, and surrounding anthropogenic enhance the mobility of the contaminants (Wang et al., 2022). Therefore, environmental conditions often align with the metal accumulation in marine organisms. Elements from anthropogenic sources tend to have higher mobility than geogenic sources (Borůvka et al., 2005; Liu et al., 2018; Sappa et al., 2020). In most cases, bays directly interact with municipal activities, leading to higher contamination of anthropogenic sources than geogenic sources. Therefore, open oceans are more stable than near-shore waters because open oceans have less influence to the anthropogenic activities. The interaction of seawater with intertidal zones, including bays, is more effective in the nearshore areas, which will impact the variation in the psychochemical parameters (Wang et al., 2022; Zhao et al., 2019). Anthropogenic contaminants mostly come from mining activities, industries, and agricultural practices.

The effects of the contamination of hazardous elements on marine organisms often become the object of studies in relation to ecological risk assessment or human risk assessment from seafood consumption (Xie et al., 2017). Controlling the level of pollutants in urban and industrial wastewater is an effective method for mitigating the impacts of contaminants discharging into the ocean. However, in some areas, there is a lack of implementation of surveillance and monitoring. To improve the regulation based on scientific data, the source of contamination is a necessary knowledge. The data related to hazardous elements contamination in Lampung Bay is lacking although there are many essential aquaculture practices in the bay. There are several research publications related to the heavy metal contamination in Lampung Bay water (Permata et al., 2018), sediment (Permata et al., 2018; Tirta Sari et al., 2016) and biota (Aznardi et al., 2022). However, none of the current publications comprehensively analyse the sources of the contamination. Permata et al. (2018) used an enrichment factor (EF) in their study to assess the source of heavy metals contamination with a sampling point close to the industrial zone. However, this study is limited to two metals, i.e., Pb and Cu, and the sampling stations only cover one estuarine or river mouth. Budiyanto and Lestari (2015) evaluated the ecosystem changes caused by anthropogenic activities using the sediment quality guidelines quotient (SDG-Q). Geogenic and anthropogenic pollution sources are present in Lampung Bay, and both contamination sources have equal input to the increasing of hazardous elements pollution in the bay (Budiyanto & Lestari, 2015; Widiastuti et al., 2023). A comprehensive assessment of the contamination sources and wide range of hazardous elements, not only focusing to a few common heavy metal contaminations of Lampung Bay, is important. Therefore, this present study aims to analyse the concentration of hazardous elements surrounding Lampung Bay and assess the source of contamination, either from anthropogenic activities or geogenic sources. In this paper, we reported the contamination level of seven emerging hazardous elements, i.e., Cr, Ni, Cu, Zn, Cd, As and Pb and investigated their sources, anthropogenic or geogenic. This study is important for the decision-maker to mitigate the effect of long-term pollution in the bay if the concentration of certain elements is beyond the current maximum limit.

MATERIAL AND METHODS

Study site

Lampung Bay is located in the heart of Bandar Lampung, the capital city of Lampung Province. The bay is geographically located at latitude 105°10’E to 105°35’E and longitude 5°26’S to 5°50’S, but our sampling site only covered half of the bay from 105°15’E to 105°18’E and 5°26’S to 5°31’S (Figure 1). Lampung Bay has a total of area of 47 km^2 and a mean depth of 25 m (Pariwono, 1998). The bay is surrounded by several municipal activities, e.g., agriculture to the west, the big cities of Bandar Lampung to the north and industrial zone to the east. Lampung Bay meets the open oceans, the Indian Ocean, to the south and the Sunda Strait to the eastern south. Nutrient input comes to the bay from the residential surroundings and from the active volcano Anak Krakatoa in the south of the bay. Therefore, coral reef habitat and organism diversity are found in this bay.

Three districts are close to the bay, i.e., Pesawaran District, Bandar Lampung City and South Lampung District. Two out of the three districts are very dense areas (Bandar Lampung and South Lampung). Based on 2022 data, Pesawaran District, Bandar Lampung City, and South Lampung District have a population density of approximately 381/ km^2, 6586/ km^2, and 487/ km^{2,} respectively (*Statistics Lampung Province*, 2022).

Apart from capture fisheries from natural resources, many aquaculture activities also occurred in Lampung Bay. Aquaculture of coral reef fish such as grouper and pomfret is mostly found close to Pahawang Island, a small island in the west part of the bay. Lampung is the leading supplier for high demand on seafood from surrounding cities, including Jakarta, especially for coral reef fish, which usually sent through live transportation. A giant pearl shell culturing and industry is also established in the north end of the bay. There are five large rivers, i.e. Seputih, Sekampung, Mesuji, Tulang Bawang and Semangka rivers, and several small rivers flow

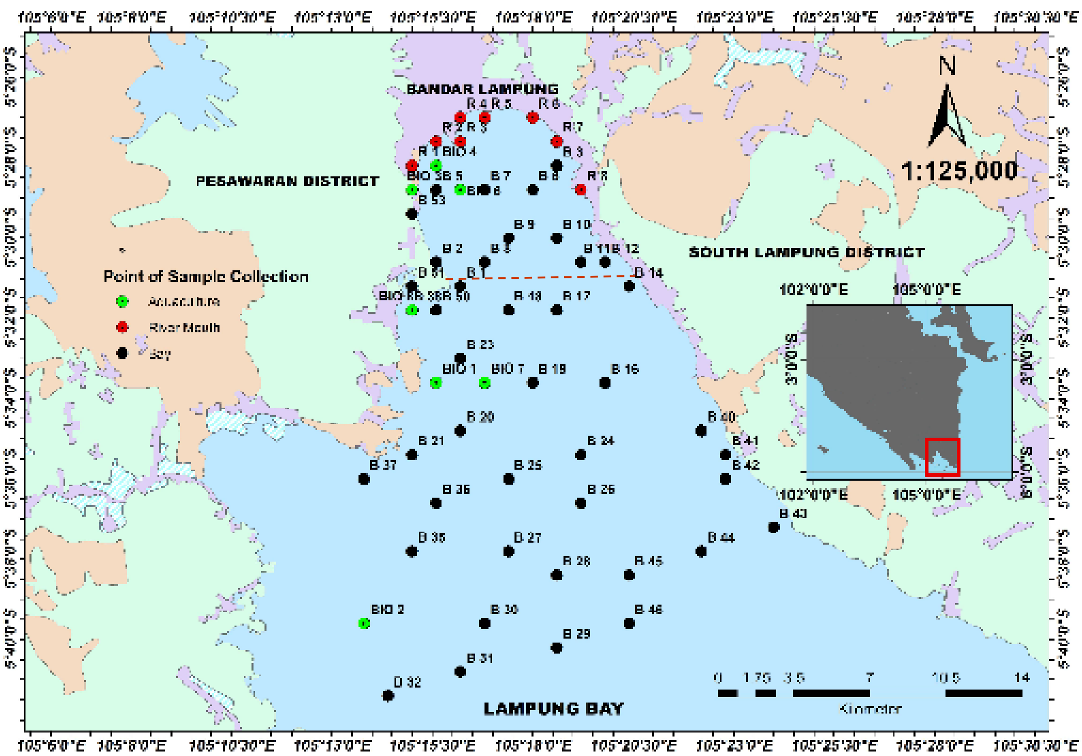

Fig. 1. The study area of Lampung Bay. This paper only reports sampling sites surrounding the river mouth, the outer sites are marked as red dashes.

through Lampung Province (Zieren et al., 1999). Among those rivers, only Sekampung riverine flows into Lampung Bay, which is divided into several small rivers: Sukamaju, Keteguhan, Belau, Ujung Bom, Kunyit and Kuala rivers. These riverine systems drain swamp and peat from surrounding residences including disposal from the capital city of Lampung Province, Bandar Lampung.

Sample collection

A sampling network of 48 stations inside the bay and seven stations as close as possible to the river mouth which flows into the bay were conducted in April and September 2015 (Figure 1). However, in this paper we only reports sediment samples from river sites and sampling stations close to the river mouth (marked as red dashes in Figure 1). Sampling times were followed the monsoon system in Lampung; April typical of the dry season and September represent the wet season. The data is reported as the mean of both seasons. Sites were positioned along a transect using Garmin 585 global positioning system (GPS) with a resolution of about 3.5 m. Sediments were collected using van Veen grab, representing only surface sediment. Samples were stored in polypropylene bottles and kept at low temperature on board. Physicochemical properties of the bay, e.g., pH, salinity, temperature, turbidity, DO, and water depth, were measured on-site.

Sample preparation and instrument analysis

Samples were prepared and analysed in the Chemistry and Instrument Laboratory, Research Centre for Marine and Fisheries Product Processing and Biotechnology, Jakarta. All laboratory equipment was cleaned using 2% nitric acid (HNO_3), pro analysis (Merck, USA), prior to analysis. Sample digestion and analysis were performed following the manufacturer manual, microwave destruction (Berghoff, Germany) and Inductively Coupled Plasma Mass Spectrometry (ICPMS) analysis (Agilent 7700X, USA).

Sediment samples were dried at room temperature for three days, then ground to blend the material in the sample and sieved (2 mm polyethylene sieve) to remove oversized materials and ensure sample homogenisation. Around 100 gr sediment aliquots were placed in the digestion vessel, then 8 ml of 65% HNO_3 supra pure (Merck, USA) and 2 ml of 40% HF (Pro analysis, Merck, USA) were added. After 2 minutes, all bubbles disappeared, then the lids were closed, and samples were digested in a microwave oven (Berghoff speed two, Germany) using a previous program (Siregar et al., 2016). Upon cooling, 1 ml of extract was diluted with 9 ml of 1% HNO_3 and ready for ICPMS analysis.

ICPMS performance optimisation was carried out following the manufacturer's instruction. Calibration was performed using a series of defined standard solutions (multi elements standards, Agilent, USA). Certified reference material (CRM) Mess-3 (NRC, Canada) was used during the analysis as a standard for hazardous element-containing marine sediments stuff. The analysis of CRM was performed to calculate the accuracy of the analysis. Blank samples consisted of reagents only (without sediment samples) prepared and digested in parallel with samples to control background noise from reagents and to detect any potential contamination. The pre-treatment procedure is detailed in (Siregar et al., 2016). The acid extraction of Mess-3 using microwave digestion followed by ICPMS analysis determined the total concentration of elements in dry mass (n=4, ± standard deviation) were 99.4 ± 1.0 mg/kg, 33.6 ± 0.2 mg/g, 11.1 ± 0.5 mg/kg, 41.6 ± 0.2 mg/kg, 31,7 ± 0.2 mg/kg, 100 ± 0.6 mg/kg, 19.1 ± 0.4 mg/kg, 0.5 ± 0.02 mg/kg, 25.1 ± 0.5 mg/kg respectively for Cr, Fe, Co, Ni, Cu, Zn, As, Cd and Pb. All units are in mg/kg except for Fe in mg/g. Replicate analysis of both blank and reference material showed good accuracy with the recovery rate of CRM within 85-116% within the acceptable recovery range for the analysis (Burns et al., 2002) except for Cd and Zn, the percentage recovery is 190 and 68, respectively, both outside of the acceptable range. The instrument limit of detection (LoD) was calculated using three times background equivalent concentration times standard deviation (equation 1). The limit of quantification (LoQ) was calculated using LoD data (equation 2).

$$LoD = 3\ x\ BEC\ x\ SD\ \ LoD = 3\ x\ BEC\ x\ SD \tag{1}$$

$$LoQ = 3.3\ x\ LoDLoQ = 3.3\ x\ LoD \tag{2}$$

The value of LoD were 0.1381 µg/L, 0.3355 µg/L, 0.0076 µg/L, 0.1149 µg/L, 0.0322 µg/L, 0.5238 µg/L, 0.1857 µg/L, 0.0192 µg/L, 0.0440 µg/L, respectively for Cr, Fe, Co, Ni, Cu, Zn, As, Cd and Pb. The LoQ value were 0.4143 µg/L, 1.0065 µg/L, 0.0228 µg/L, 0.3447 µg/L, 0.0966 µg/L, 1.5714 µg/L, 0.5571 µg/L, 0.0576 µg/L, 0.1320 µg/L respectively for Cr, Fe, Co, Ni, Cu, Zn, As, Cd and Pb.

Data analysis

Contamination of hazardous elements in the sediment samples was assessed using the enrichment factors (EF) and geo-accumulation index (Igeo) to understand their sources. EF value is obtained by comparing the concentration of metal in the sample divided by the concentration of reference metal in the sample against the concentration of metal divided by the concentration of reference in the background (equation 3). Iron (Fe) is used as a reference element because it has been widely used in marine and estuarine sediments (Barbieri, 2016). Furthermore, Fe is abundant in nature, and its value is all inlier (Hızlı et al., 2023). The background values are the concentration of the element and the reference in the geochemical rock. Data from previous research (Budiyanto & Lestari, 2015) have been used as background value for EF calcukation.

$$\text{F} = \frac{\left(\frac{Metal}{Reference}\right)sample\ \ \left(\frac{Metal}{Reference}\right)sample}{\left(\frac{Metal}{Reference}\right)background\left(\frac{Metal}{Reference}\right)background} \tag{3}$$

$$\text{Igeo} = log2\,\frac{Cn}{1.5Bn}log2\,\frac{Cn}{1.5Bn} \tag{4}$$

The natural geo index (Igeo) expressed in equation 4 was first defined by Muller (1979) for metal concentration in specific layers of marine sediments. Later, this index was developed and used globally. Cn is the metal concentration in the sediment sample, while Bn is the metal concentration in the geochemical background extracted from previous research data (Budiyanto & Lestari, 2015). Ecological factor (EF) and Igeo indices are defined in 6 classes (Table 1) (Yongming et al., 2006).

Descriptive analysis was done prior to further statistical data analysis. Data were tabulated in a group of sampling station variations and then assessed using principal component analysis (PCA) to define the pattern of the hazardous elements in each pollutant source. The PCA analysis was conducted using PAST statistical software version 4.0.

Table 1. EF and Igeo category classes of marine sediment quality.

EF values	**Sediment quality**	**Igeo value**	**Sediment quality**
EF<2	Minimal enrichment	Igeo<0	Uncontaminated
2<EF>5	Moderate enrichment	0<Igeo<1	Uncontaminated to moderate
5<EF<20	Significant enrichment	1<Igeo<3	Moderately contaminated
20<EF<40	Heavily enrichment	3<Igeo<5	Heavily contaminated
40<EF	Extremely enrichment	5<Igeo	Extremely contaminated

EF and Igeo classification were derived from Yongming et al. (2006)

RESULT AND DISCUSSION

The concentration of selected elements between the lowest and the highest were 6.4 – 55.4 mg/kg, 8.8 – 47.7 mg/kg, 13.8 – 180.5 mg/kg, 60.3 – 525.5 mg/kg, 3.7 – 27.6 mg/kg, 0.1 – 1.6 mg/kg, 22.2 – 131.7 mg/kg, respectively for Cr, Ni, Cu, Zn, As, Cd and Pb (Table 2). The concentration of the elements in the Bay station points did not differ significantly from the concentration of elements in the river mouth in most of the sampling stations ($p>0.05$, PAST 4.0), except for some elements (Cu and Zn) in certain river sampling station (R3-R6).

There are extremely high concentrations of elements in several river mouths, i.e., Cu (R5) and Zn (R3-R6), showing that might be influence of disposal from the riverine system to the bay. The closed water system, such as the sampling stations in Lampung Bay, trapped the contaminant within the location because there is no penetration of open access water from the ocean therefore, the pollutant stayed within the same area (Gao & Chen, 2012; Zhao et al., 2019). The sampling stations are relatively closed, surrounded by lands on three sides, which reduce the mixing and exchange of pollutants with the water outside the bay. Moreover, the

Table 2. The concentration of several hazardous elements in the marine sediments of Lampung Bay[1)] ± standard deviation[2)]. B bay stations, R= river mouth stations, Aq= aquaculture stations.

Sampling stations	Hazardous elements concentration (mg/kg)						
	Cr	Ni	Cu	Zn	As	Cd	Pb
B 1	55.4 ± 2.2	37.6 ± 0.6	33.3 ± 1.6	140.8 ± 2.7	11.4 ± 0.4	1.0 ± 0.0	48.9 ± 0.5
B 2	45.1 ± 1.6	37.6 ± 1.2	32.2 ± 0.6	122.8 ± 1.7	11.3 ± 0.2	1.0 ± 0.0	41.8 ± 0.4
B 4	45.1 ± 1.7	17.1 ± 1.0	37.8 ± 0.7	114.5 ± 0.7	19.3 ± 0.5	0.8 ± 0.0	42.1 ± 0.7
B 5	45.1 ± 1.8	18.9 ± 0.7	34.4 ± 1.6	125.1 ± 1.3	11.1 ± 0.4	0.5 ± 0.0	46.5 ± 0.9
B 6	45.1 ± 1.9	28.4 ± 0.4	30.7 ± 1.2	131.8 ± 1.6	14.6 ± 0.2	1.0 ± 0.0	77.0 ± 1.2
B 7	45.1 ± 1.1	34.8 ± 2.1	42.5 ± 1.9	134.4 ± 3.5	14.6 ± 0.5	1.0 ± 0.0	48.0 ± 0.5
B 8	45.1 ± 1.1	38.6 ± 1.0	25.6 ± 1.0	108.7 ± 1.5	9.8 ± 0.2	0.7 ± 0.0	50.2 ± 0.4
B 9	45.1 ± 1.1	28.1 ± 0.7	53.5 ± 1.0	188.6 ± 3.0	10.1 ± 0.5	1.3 ± 0.0	125.3 ± 1.1
B 10	45.1 ± 1.1	33.3 ± 0.6	23.5 ± 1.2	99.4 ± 0.4	10.1 ± 0.7	1.0 ± 0.0	40.7 ± 1.2
B 11	45.1 ± 1.1	47.7 ± 2.3	40.0 ± 0.7	166.2 ± 3.8	18.1 ± 0.4	1.4 ± 0.0	63.6 ± 1.8
B 12	45.1 ± 1.2	41.3 ± 1.8	66.2 ± 1.6	370.7 ± 11.4	18.8 ± 0.2	1.1 ± 0.0	75.6 ± 3.2
B 13	45.1 ± 1.2	31.7 ± 1.6	31.3 ± 1.0	132.1 ± 1.9	14.0 ± 0.2	0.7 ± 0.0	51.0 ± 0.9
B 14	45.1 ± 1.2	31.3 ± 2.9	22.9 ± 1.1	101.1 ± 2.7	9.6 ± 0.5	0.4 ± 0.0	38.4 ± 1.0
R 1	33.0 ± 1.5	17.3 ± 0.6	40.2 ± 2.2	128.3 ± 1.7	11.4 ± 0.1	1.6 ± 0.0	37.9 ± 1.0
R 2	25.2 ± 1.0	11.5 ± 0.5	22.4 ± 0.2	108.7 ± 1.6	20.7 ± 0.5	1.0 ± 0.0	22.2 ± 0.2
R 3	11.3 ± 0.3	8.8 ± 0.3	35.0 ± 1.7	328.5 ± 11.6	3.7 ± 0.3	0.7 ± 0.0	36.7 ± 0.6
R 4	22.5 ± 0.8	11.6 ± 0.9	88.6 ± 1.7	238.7 ± 4.4	20.3 ± 0.4	1.3 ± 0.0	63.9 ± 1.5
R 5	39.4 ± 0.6	16.4 ± 0.6	180.5 ± 2.9	525.5 ± 8.1	11.4 ± 0.8	1.5 ± 0.0	131.7 ± 0.4
R 6	32.2 ± 1.3	12.9 ± 0.5	99.2 ± 2.7	339.7 ± 3.3	13.6 ± 0.2	1.3 ± 0.0	102.2 ± 0.5
R 7	19.9 ± 1.0	12.4 ± 0.7	58.3 ± 2.0	137.9 ± 0.6	17.8 ± 0.5	1.5 ± 0.0	59.4 ± 1.2
R 8	11.7 ± 0.5	17.5 ± 0.7	36.2 ± 0.8	134.2 ± 1.1	11.9 ± 0.5	0.4 ± 0.0	49.4 ± 0.5
Aq 1	19.9 ± 1.4	11.7 ± 0.2	33.9 ± 0.6	101.7 ± 0.9	20.8 ± 0.4	0.7 ± 0.0	36.1 ± 1.4
Aq 5	20.0 ± 0.7	12.0 ± 0.4	37.9 ± 1.4	140.7 ± 0.6	27.6 ± 0.9	1.0 ± 0.0	38.7 ± 0.3
Aq 6	6.35 ± 1.5	10.0 ± 1.1	13.8 ± 0.5	60.3 ± 0.9	5.4 ± 0.5	0.1 ± 0.0	22.2 ± 0.6
ANZECC range	80-370	21-52	65-270	200-410	20-70	1.5-10	50-220
WAC max limit	260	Na	390	410	57	5.1	450

[1)]Values are mean value of both seasons, season 1 (April) and season 2 (September)
[2)]Standard deviations derive from the deviation from both season values.

sampling stations have direct water exchange with a land discharge system through the eight rivers within the sampling area.

The concentration of hazardous elements in the selected Lampung Bay area are mostly below or within the range of guidance value standards of Australia and New Zealand standard (ANZECC & ARMCANZ, 2000) and USA standard (WAC, 2013) for marine sediment (Table 3). In this study, we used sediment standards from abroad because of the limited data and standards related to hazardous elements in marine sediment from the local or national government of Indonesia. Based on both standards, hazardous elements in Lampung Bay are within the range of Australian and New Zealand standards (ANZECC & ARMCANZ, 2000) or below the maximum limit of USA standard (WAC, 2013) except for zinc (Zn) in one location (R5) exceeded the maximum limit for both standards. The river mouth of R5 is close to Sukaraja Beach. This beach has been acquired as the most polluted beach for the last five years due to the high accumulation of household garbage (Kompas, 2023). Calculating the enrichment factor (EF) in the following two sections will interpret the source of the high Zn in this area, either from geogenic or anthropogenic (human activities) sources.

The psychochemical properties at Lampung Bay are within the acceptable level according to the standards (Table 4). There was no significant gap between the sampling stations. Correlation analysis using SPSS Pearson correlation (PAST 4.0) shows there was no correlation between the concentration of hazardous elements in Lampung Bay and the psychochemical parameters of the seawater (Table 5). However, the value of the Pearson correlation coefficient closer to 1 shows a strong positive correlation between the elements. The pairs of elements that have a positive correlation such as Cr and Ni (r=0.82), Cu and Zn (r=0.87), Cu and Pb (r=0.78), and Pb and Zn (r=0.70). This correlation between several elements is possible because they come from the same sources. For example, Chromium (Cr) and nickel (Ni) co-existence in the sediments is mostly related to the enrichment of the same sources from anthropogenic or geogenic sources. In the coastal area close to human activities, the concentration of Cr and Ni might arise from the automobile, while in the marine area, the strong attribution could be influenced by natural

Table 4. The range of psychochemical properties of Lampung Bay water during the sampling campaign

Parameters	Unit	Sampling campaign (in range)	
		April	September
Temperature	°C	29.0-31.0	29.1-30.9
Acidity	pH	8.1-8.3	8.0-8.4
Salinity	‰	30.0-36.0	33.0-40.0
Dissolved oxygen	mg/l	5.0-8.6	7.1-8.3

Table 5. Pearson correlation between the concentration of elements and the water psychochemical properties of Lampung Bay (p<0.05).

	52 Cr	*56 Fe*	*59 Co*	*60 Ni*	*63 Cu*	*66 Zn*	*75 As*	*111 Cd*	*208 Pb*	*Salinity*	*DO*	*Depth*
52 Cr	1.00											
56 Fe	0.14	1.00										
59 Co	0.11	**0.86**	1.00									
60 Ni	**0.82**	-0.27	-0.18	1.00								
63 Cu	0.09	0.47	0.37	-0.19	1.00							
66 Zn	0.14	0.46	0.48	-0.11	**0.87**	1.00						
75 As	0.05	0.36	0.31	-0.11	0.08	-0.05	1.00					
111 Cd	0.46	0.73	0.67	0.08	0.55	0.43	0.36	1.00				
208 Pb	0.37	0.21	0.13	0.12	**0.78**	**0.70**	-0.05	0.54	1.00			
Salinity	-0.59	0.16	0.11	-0.73	0.23	0.04	0.21	0.02	-0.15	1.00		
DO	0.21	0.22	0.09	0.04	0.45	0.13	0.28	0.44	0.47	0.07	1.00	
Depth	0.41	-0.37	-0.41	0.52	-0.18	-0.26	-0.03	-0.01	0.07	-0.12	0.22	1.00

backgrounds such as geochemical affinity and sediment geochemistry (Lwin et al., 2022; Poznanović Spahić et al., 2019; Wang & Zhang, 2018). Compared to other elements that exist in the environment, Cr and Ni exhibit relatively lower toxicity. However, their concentration in highly populated areas increasing recently, creating a serious concern for their co-existence (Lwin et al., 2022). Similar enrichment sources also found in other pairs of elements such as, Cu-Zn, Cu-Pb, and Zn-Pb. Heavy metals such as Cu and Pb are among the toxic contaminants and often affect the quality and safety of seafood harvested from the polluted region (ref). Although it serves as an essential nutrient, in excess concentration Zn might become a burden to the quality and safety of the infected area's environment and ecology, and in the end will cause harmful to humans who consume seafood from that area (Plum et al., 2010; Yung et al., 2014).

Two sediments pollutant indices were applied to normalise the sediment pollution concentration of potentially hazardous elements in Lampung Bay, i.e., enrichment factor (EF) and geo-accumulation index (Igeo). While EF is commonly used to assess the anthropogenic source, Igeo is related to the geogenic source. There is a potentially high enrichment factor from human activities in several sampling stations of Lampung Bay (Figure 2).

The quality of sediments based on EF value (Table 1), if EF ≥ 5 implied that there is a significant to high human activities enrichment to the concentration of hazardous elements in the Lampung Bay. Cadmium (Cd) has a high enrichment factor in all sampling stations, which showed that the Cd concentration closely related to the anthropogenic enrichment sources. Zinc (Zn) is also enriched in several stations, such as Bay 4 and River 8, while Cu is enriched at Bay 4. All potential hazardous elements enriched at Bay 14 showed the strong influence of human activities on the increasing concentration of those elements in the sampling sites. The high enrichment factor of hazardous elements in these sampling stations is expected in relation to the condition of the sites close to a coal stockpile from a coal mining company. Disposal effluents from the coal production contain not only fine coal particles suspension but also many toxic elements from the ore impurities, including Cr, Ni, Cu, Zn, As, Cd, and Pb (Vaseem et al., 2017). Although this washery effluent should be treated before discharging to the water

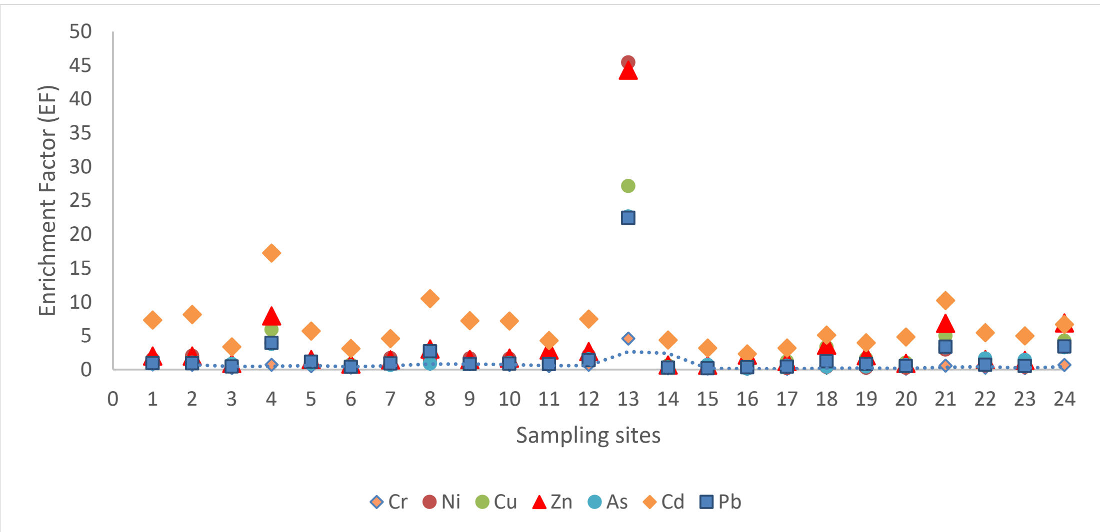

Fig. 2. Enrichment factor (EF) of hazardous elements in Lampung Bay. Sampling sites explanation corresponding to map in Figure 1: 1= Bay 1, 2= Bay2, 3=Bay 4, 4 = Bay 5, 5 = Bay 6, 6 = Bay 7, 7 = Bay 8, 9 = Bay 10, 10 = Bay 11, 11 = Bay 12, 12 = Bay 13, 13 = Bay 14, 14 = River 1, 15 = River 2, 16 = River 3, 17 = River 4, 18 = River 5, 19 = River 6, 20 = River 7, 21 = River 8, 22 = Aquaculture 1, 23 = Aquaculture 2, 24 = Aquaculture 3. Please see the map in Figure 1 and the index in Table 1. Values derive from mean of both sampling campaigns (April and September)

system, leaking from the production process is unavoidable. Furthermore, the removal process of these hazardous elements in most cases is ineffective and expensive (Wang & Chen, 2006), that some companies might be reluctant to follow the toxic impurities removal. The EF values for each element in minimum to maximum range are 0.07-4.59, 0.19-45.43, 0.37-27.15, 0.66-44.29, 0.33-22.61, 2.31-17.25, 0.18-22.43 for Cr, Ni, Cu, Zn, Cd, As and Pb, respectively. The enrichment factor values above 1.5 showing that there are numerous hazardous elements in the Bay are from anthropogenic sources. An enrichment factor higher than 1.5 indicates that the source of pollution comes from human activities (Yilgor et al., 2012).

The Geochemical index (Igeo) of the hazardous elements in Lampung Bay is categorized as uncontaminated or moderate for most elements in all sampling stations. The exception is Cd, which is heavily contaminated in all sampling stations (Figure 3). Compared to the EF factor, the Igeo factor is relatively uncontaminated, which means the possibility of the pollutant sources coming from human activities. Although Lampung Bay has an active volcano namely Anak Krakatoa, based on the EF value, the influence of geogenic sources to concentration of the hazardous elements in the bay is low (Soltani-Gerdefaramarzi et al., 2021). This is possible as the location of the volcano is relatively far from the sampling stations. Moreover, the sampling condition of the stations, like a bowl which, lower the possibility of high impact.

The sampling stations include three aquaculture sites that supply seafood demand not only to the local market in Bandar Lampung but also to Jakarta. From two pollutant indices, none of the aquaculture sites are extremely polluted from the hazardous elements. This condition is suitable for short term, however, monitoring from the local government to maintain the environmental quality is highly needed to ensure the seafood safety issue in this area.

Principal component analysis (PCA) was further used to identify if there were different characteristics between the sampling stations (Figure 4, table 6). Aquacultures and bay sampling stations were clustered together, showing the similarities of characteristics between the same group (PC1 = 87%, Table 6). The clustering from PCA analysis (Figure 4) showed a

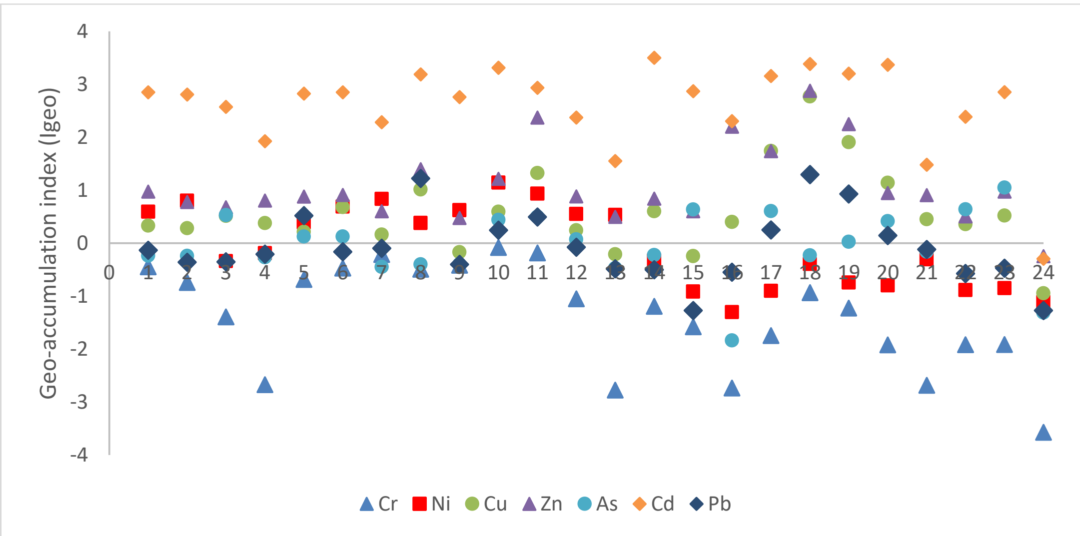

Fig. 3. Geo-accumulation index (Igeo) of hazardous elements in sampling stations of Lampung Bay. Sampling stations 1= Bay 1, 2= Bay2, 3=Bay 4, 4 = Bay 5, 5 = Bay 6, 6 = Bay 7, 7 = Bay 8, 9 = Bay 10, 10 = Bay 11, 11 = Bay 12, 12 = Bay 13, 13 = Bay 14, 14 = River 1, 15 = River 2, 16 = River 3, 17 = River 4, 18 = River 5, 19 = River 6, 20 = River 7, 21 = River 8, 22 = Aquaculture 1, 23 = Aquaculture 2, 24 = Aquaculture 3. Please see the map in Figure 1 and the index in Table 1. Data derived from the mean of two sampling seasons.

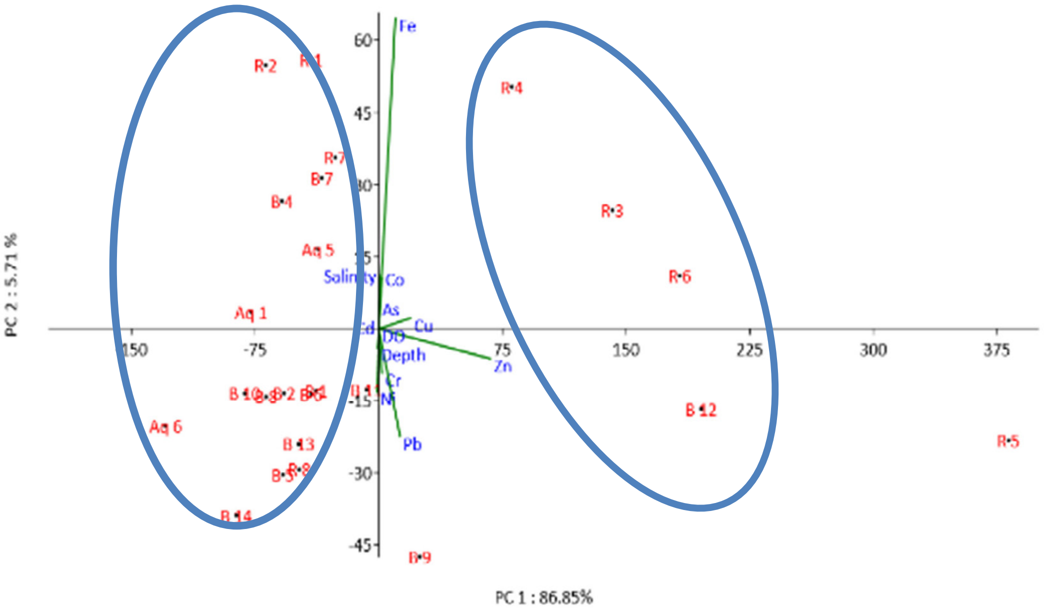

Fig. 4. Principal Component Analysis of hazardous elements against the sampling locations. River and bays have different clusters showing the different characteristics of river and bay stations

Table 6. Principal Component Analysis (PCA) result for grouping of sampling sites based on the hazardous element concentration in the sites.

PC	Eigenvalue	% variance
1	13637.5	86.853
2	897.292	5.7146
3	601.63	3.83
4	409.42	2.608
5	110.852	0.706

difference characteristic between the river mouth and inside the bay stations. Although there is no significant relationship between the physicochemical condition of both groups (Table 5), the PCA result showed that the concentration of the hazardous elements in the river mouth tend to be higher than in the bay, particularly the concentration of Zn (Figure 4).

Some hazardous elements have low solubility, therefore, there is high possibility to release their deposit from the sediment to the water column then water through wave transfer the hazardous elements move further to the bay then deposit the elements back in the sediment (Zhao et al., 2019). However, due to the closed condition of our sampling stations in Lampung Bay, like a bowl, the transportation of the elements is recycling in the bay without influence from open seas.

CONCLUSION

Hazardous elements in sediment of Lampung Bay are mostly below the maximum level of international sediment standard. Sediment quality assessment using two pollutant indices showed that hazardous elements in the sampling station of Lampung Bay mostly coming from anthropogenic activities. The condition of the bay as a closed proximity to the big city increases the load of pollution from municipal disposal to the bay. Although the concentration of the elements are below the maximum level of the quality standard for marine sediment in almost all sampling station, initiative from local government is highly encouraged to prevent further damage to the marine ecology.

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CONFLICT OF INTEREST

The authors declare that there is no any conflict of interests regarding the publication of this manuscript. In addition, the ethical issues, including plagiarism, informed consent, misconduct, data fabrication and/ or falsification, double publication and/or submission, and redundancy has been completely observed by the authors.

LIFE SCIENCE REPORTING

No life science threat was practiced in this research.

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