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Heavy metals concentration in sediment and their bioaccumulation in several organisms in Benoa Bay and Lembongan Island, Bali, Indonesia

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Abstract. *Putri PYA, Rastina, Prartono T, Ismet MS. 2024. Heavy metals concentration in sediment and their bioaccumulation in several organisms in Benoa Bay and Lembongan Island, Bali, Indonesia. Biodiversitas 25: 3230-3238.* Human activities could be responsible for introducing heavy metals into coastal areas, and it can contaminate coastal waters such as the tourism area of Benoa Bay and coastal ecosystems of Lembongan Island, Bali, Indonesia. This study aimed to assess the extent of heavy metals on the sediment of those area and their accumulation rate in several marine organisms, including macro-algae (*Ulva* sp.), seagrass (*Thalassia hemprichii*), and sea urchin (*Diadema* sp.). Samples of surface sediments and marine organisms were collected at six stations for both areas and the presence of five heavy metals (Fe, Pb, Cd, Cu, and Cr) was determined using the AAS method. The concentration those metals varied significantly across the six stations. The geo-accumulation index showed that the sediment has been contaminated by Pb and Cd. The ecological risk of heavy metals contamination in Benoa Bay was apparently higher compared to that in Lembongan Island. Marine organisms in Benoa Bay also significantly accumulated heavy metals than those observed in Lembongan Island. Bioconcentration factor (BCF) shows that Cd, Cr, and Pb were the most accumulated heavy metals in marine organisms (BCF>1). It, therefore, suggest that future studies of the bioavailability of heavy metals and exploration the varying capacities of marine organisms are required. Such important information can be used to predict the accumulation of heavy metals in human bodies, and the possibly daily consumption of marine organisms caught from Benoa Bay and Lembongan Island waters.

Keywords: Bioaccumulation, coastal, heavy metals, marine organisms, sediment assessment

INTRODUCTION

Increasing anthropogenic activities and urbanization in coastal areas have negative environmental impacts on coastal waters due to contamination and pollution (Ding et al. 2018). Disposal of waste containing dangerous compounds, such as heavy metals, will impact the sustainability of marine ecosystem. Although heavy metals exist naturally in marine waters, they are in low concentrations and hence, has no deterioration effect to marine ecosystems and the human life (Algül and Beyhan 2020). However, uncontrolled anthropogenic activities may cause the increase of heavy metal entering the coastal area, and they will persist and be accumulated in the sediment (Ali et al. 2019).

Heavy metals in waters can easily associate with organic materials and settle at the bottom of the waters. However, some heavy metals might dissolve in water depending on their speciation due to water characteristics. Sediment is a significant sink for heavy metals and is usually used as indicator for monitoring pollutants in aquatic environments (Khan et al. 2017; Mwatsahu et al 2020). Assessing the level of heavy metals in sediment can inform the impacts of pollution on ecosystem because heavy metals quickly accumulate in organisms (Mehana et al. 2020). Apart from being deposited in sediments, heavy metals can also be re-suspended in the water column due to turbulence processes which affect the bottom of the waters or due to the movement of organisms in surface of sediments. The high concentration of heavy metals in aquatic environment can be bio-accumulated in organisms through the food webs.

Macroalgae and seagrass are marine organisms that have the ability to accumulate heavy metals (Tupan and Uneputty 2017; Hidayat et al. 2021). Even though they absorb heavy metals in their bodies, some macroalgae species can remain growing throughout the year without any symptoms of toxification (Mantiri et al. 2019). Heavy metals in of macroalgae and seagrass tissues come from the environment where they live (Hidayat et al. 2021). Seagrass absorbs heavy metals from its leaves and roots (Nguyen et al. 2017). Beside macroalgae and seagrass, which are classified as plants, some marine animals can also accumulate heavy metals, for example sea urchins. Sea urchins are generally omnivores, grazes, and detritus feeders which ingest substrates, and scrape macroalgae on hard sediment surfaces (Muthiga and McClanahan 2020).

Bali region in Indonesia is increasingly pressured by human activities, especially from tourism sector. As the consequence, there is possibility of pollution of its coastal waters including in Benoa Bay and Lembongan Island. These two coastal waters have different characteristics. In the waters of Benoa Bay, six rivers flow into the bay (Suteja et al. 2020). High anthropogenic activities surrounding the onshore of the bay might contain many pollutants entering the bay waters and deposit at the sediment since the Bay is a semi-enclosed bay. The busy Benoa port activities are also a possible source of pollutants (Sudarmawan et al. 2020). Lembongan Island is a small island nearby Bali Island along with other small islands, such as Penida Island and Ceningan Island. Different with the waters in Benoa Bay, Lembongan Island has more open water characteristics with no river flows, and is less pollution from the onshore. The island has three coastal ecosystems, namely mangrove, seagrass, and coral reef.

Several studies on heavy metals have been carried out in the waters of Benoa Bay and Lembongan Island, including on sediment (Suteja et al. 2020; Lubis et al. 2023), seagrass (Wijayanti and Giri Putra 2019; Nyupu et al. 2020), mangroves and crabs (Suteja and Dirgayusa 2018). Previous report showed that heavy metal concentrations in fishes caught from Benoa Bay waters and their processed products have exceeded the maximum limit for heavy metal contamination Cd and Pb based on SNI 7387:2009 quality standards (Mardani et al. 2018). However, such studies only focused on the concentration and accumulation of heavy metals in organisms. This study is to provide further information on the level of heavy metals concentration in the sediment of Benoa Bay and Lembongan Island waters and their accumulation in several marine organisms. The results of this study are expected to provide insights regarding the risk of heavy metals pollution and their bioaccumulation in tourism important areas of Bali.

MATERIALS AND METHODS

Study period and area

This research was conducted in September-December 2023 in the Benoa Bay and Lembongan Island waters, Bali, Indonesia (Figure 1). Benoa Bay is a semi-enclosed bay with the presence of six rivers, in which four rivers (i.e. Sama, Mati, Badung, and Buaji) have continuous flow throughout the year, while the other two have intermittent streams which only flow during the rainy season. There are fishing and shipping ports in Benoa Bay. In contrast, Lembongan Island is a small island opposite of an open sea, no input of the rivers, and only few boat tourism activities. In the Benoa Bay, four sampling stations were chosen, including a station in the estuary, and two sampling stations were chosen in the Lembongan Island. All sampling materials such as sediments, macroalgae, seagrass, and sea urchins were collected except in the estuarine station which only collected for sediment sample only.

Data collection procedure

Environmental parameters, such as temperature, pH, salinity, and DO, were measured in situ using a water quality meter. Sediment was collected as many as ±1 kg in wet weight using a PVC pipe with a diameter of 10 cm and a depth of 10 cm from the surface of the sediment. Samples of macroalgae and seagrass, each ± 500 g wet weight, were also taken then were put into a ziplock bag with a label and stored in a cooling box before being taken to the laboratory. Samples of sea urchins with a diameter of >4cm (15 individuals at each station) were taken using tongs, wood/ iron, and stored in a container box containing sea water and an aerator; then, all samples were analyzed in the laboratory.

The sediment was then dried using an oven at a temperature of 60°C until it reached a constant mass. It was crushed using a mortar and about 3 g of that sediment was analyzed for organic content using the Loss-on Ignition (LOI) method (Jensen et al. 2018; Kumar et al. 2019). Sediment fraction analysis was carried out using the sieving method using an ABM test sieve analysis, and the clay and silt fraction were carried out using the pipetting method (Jensen et al. 2018; Prartono et al. 2024).

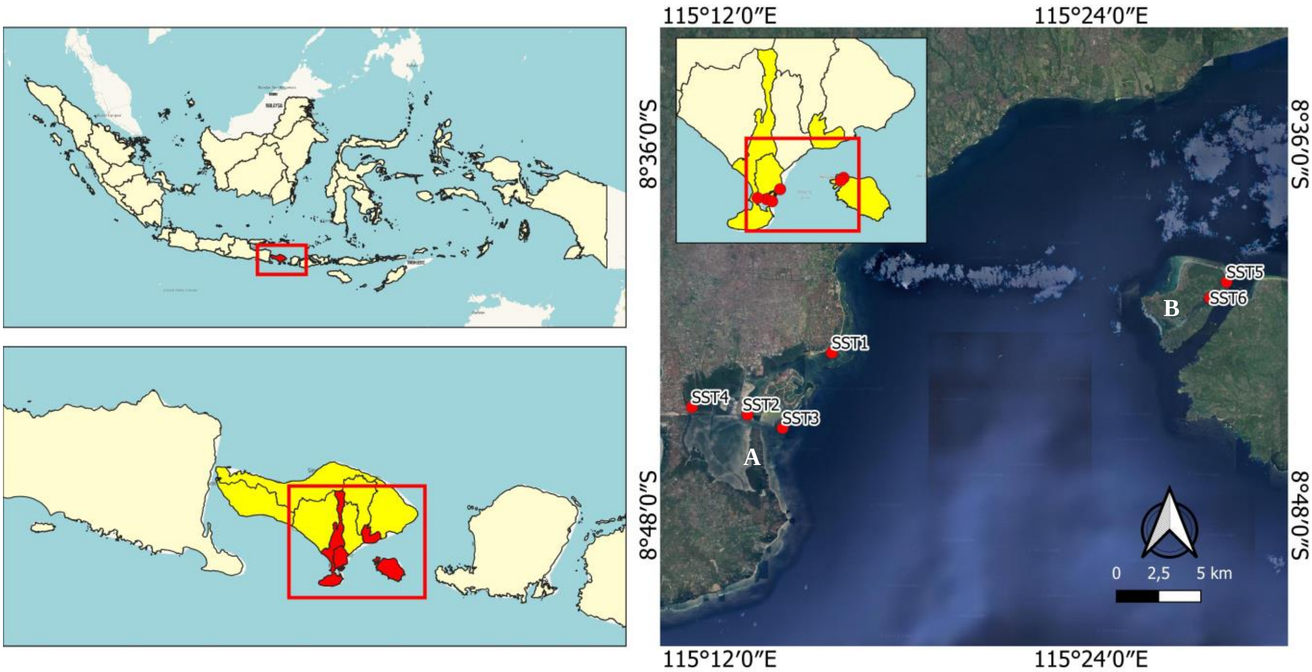

Figure 1. Map of study area showing sampling stations in Bali Province, Indonesia: A. Benoa Bay; B. Lembongan Island

Sea urchin, seagrass, and macroalgae samples were cleaned up. Sea urchin samples were opened to collect its gonad; all samples were dried using an oven at 60°C for 48 hours. The heavy metal analysis followed APHA 2012 (Riani et al. 2018). Sediment samples of 2 g of dry weight were destruction with H_2SO_4, H_2O_2 and HCl, a dried sample of macroalgae (500 mg) and seagrass (500 mg) were destroyed using $HClO_4$ and HNO_3, 25 g of the gonad of sea urchin was furnace at a temperature of 500°C for 6 hours destruction with HCL and HNO_3 (3:1), all destruction sample was filtered with Whatman filter paper No. 42 (2.5 μm), and the filter results were measured with aquades until the sample volume was 50 mL. Heavy metal concentrations were measured in Integrated Laboratory of IPB University, Indonesia using a flame Atomic Absorption Spectrometers Agilent 200 series AA (AAS).

Data analysis

The level of pollution in sediment was analyzed using the Contamination Factor (CF), Pollutant Load Index (PLI), Geo-Accumulation (Igeo), Enrichment Factor (EF), and Potential Ecological Risk index (RI) used in many research (Guo et al. 2010; Syakti et al. 2015; Jahan and Strezov 2018; Liu et al. 2021; Lubis et al. 2023; Prartono et al. 2023;).

Contamination factor and pollutant load index

The contamination factor was used as a reference to determine the level of contamination of certain types of heavy metals based on the level of heavy metal concentration in the sediment (Syakti et al. 2015). The pollution load index was calculated using the contamination factor value to determine the measured metals' pollution status. The following is the equation for calculating the contamination factor and pollution load index:

$$CF = \frac{M_c}{B_c}$$

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

Where, Mc was the concentration of heavy metals in the sediment, Bc is the natural concentration in the sediment (background value) (Hakanson 1980). Background value was based on Taylor (1964) at Pb 12.5 mg kg^{-1}, Cd 0.2 mg kg^{-1}, Cu 55 mg kg^{-1}, Cr 100 mg kg^{-1} and Fe 56300 mg kg^{-1}.

Categories of heavy metal contamination and pollution were based on Syakti et al. (2015) where contamination are as: CF<1: low contamination, 1<CF<3: moderate contamination, 3<CF<6: high contamination, CF>6: very high contamination; and pollution are as PLI <1: not polluted with heavy metals and PLI>1 is polluted with heavy metals.

Geo-accumulation

The geo-accumulation index was used to determine the pollution level in coastal sediments by considering the effects of variations in the earth's layers (lithosphere) (Syakti et al. 2015) and was calculated as follow:

$$Igeo = log\ _2\left(\frac{M_c}{1,5 \times B_c}\right)$$

The value of 1.5 was a constant value that allows us to analyze natural fluctuations in the content of certain substances in the environment and the value of 1.5 was a constant value that allows us to analyze natural fluctuations in the content of certain substances in the environment and to detect very small anthropogenic influences (Yona et al. 2018). Heavy metal geo-accumulation categories were as follows: Igeo ≤ 0 not polluted; 0< Igeo ≤ 1 not polluted to moderate; 1< Igeo ≤ 2 moderately polluted; 2< Igeo ≤ 3 moderate to heavily polluted; 3< Igeo ≤ 4 heavily polluted; 4< Igeo ≤ 5 heavily to very heavily polluted; Igeo > 5 is very heavily polluted (Liu et al. 2021).

Enrichment factor

Enrichment factor analysis aims to determine the level of metal enrichment in a body of water and whether the metal contained in sediment originates from natural or anthropogenic processes (Jahan and Strezov 2018) and was calculated as follow:

$$EF = \frac{(M/Fe)_{sediment}}{(\mathrm{M/Fe})_{background}}$$

Where the category of heavy metal enrichment levels are as follows: EF<2 low; 2<EF<5 medium; 5<EF<20 significant; 20<EF<40 heavy; EF>40 very heavy

Potential Ecological Risk Index (RI)

Potential ecological risk was calculated to determine the ecological risk from heavy metal pollution to coastal ecosystems (Guo et al. 2010). The potential ecological risk index (RI) was calculated using the total value of each metal's total risk potential as follow:

$$C_f^i = C_s^i / C_n^i$$

$$E_r^i = T_r^i \times C_f^i$$

$$RI = \sum E_r^i$$

Where, C_f^i is the pollution coefficient of certain types of metals, $C_s^i$is the concentration of heavy metals in sediment, C_n^i is the background concentration, E_r^i is the value of the potential ecological risk of each heavy metal, T_r^i is the respective toxic factor -each metal (Pb, Cu = 5; Cr = 2; Cd = 30) (Jahan and Strezov 2018).

Potential pollution risk categories based on each metal E<40 are low; 40 ≤ E < 80 moderate; 80 ≤ E< 160 high; 160 ≤ E < 320 very high; 320 ≤ E serious; the potential risk of ecological pollution from overall metal RI < 150 is low; 150 ≤ RI < 300 moderate; 300 ≤ RI < 600 high; 600 ≤ serious RI (Guo et al. 2010).

Bioconcentration factor

The level of accumulation of heavy metals Fe, Pb, Cd, Cu, and Cr in algae and sea urchins was carried out using bioconcentration analysis (Wijayanti and Giri Putra 2019) and calculated as follow:

$$BCF = \frac{\mathrm{M}_{organism}}{\mathrm{M}_{sediment}}$$

If the BCF value is >1, the organism is an accumulator benthic (a good absorber of pollutants).

RESULTS AND DISCUSSION

Water and soil parameters

The results of measurement on water quality parameters included temperature, pH, salinity, DO, sediment pH, and total organic matter in Benoa Bay and Lembongan Island waters (Table 1). Generally, the water quality parameters in Benoa Bay and Lembongan Island waters are within the normal range for sea waters when compared with seawater quality standards PP No. 22 of 2021 (Table 1). Differences in salinity values occurred at SST 4 in Benoa Bay, where it had the lowest value and is below the standard for seawater quality.

The sediment characteristics in Benoa Bay and Lembongan Island waters were generally composed of coarse sand with different compositions at each station. The largest proportion of sediment size was medium sand (82-92%), gravel (2-14%), silt (2-8%), and clay (1-3%) (Figure 2). Benoa Bay had a sandy loam sediment type, while Lembongan Island had a sand sediment type. The estuary in Benoa Bay (SST4) station had the finest sediment characteristics compared to other stations.

The waters of Benoa Bay and Lembongan Island had pH values ranging from normal to alkaline. The pH value for supporting the survival of aquatic ecosystems is between 6.5 and 8 (Retnaningdyah et al. 2022). This range supports a diverse community of benthic organisms. Extreme pH levels (either too acidic or alkaline) can harm benthic organisms. Physical and chemical parameters such as soil pH and availability of organic matter will influence the availability, speciation, and transport of pollutants such as heavy metals. The difference in salinity values at SST 4 was likely caused by freshwater input from the estuary flowing into the waters of Benoa Bay, so the salinity values were lower. According to Suteja et al. (2021), the average salinity value in Benoa Bay was 27.01±11.39 ppt, while in the river area, the salinity ranged from 10.50 to 26.50 ppt. Benoa Bay sediments had a finer fraction size than Lembongan Island because the semi-enclosed shape of the bay waters causes more fine sediment to settle. According to Maharta et al. (2018), the highest sedimentation in the waters of Benoa Bay occurred in the river estuary and bay mouth areas. Lembongan Island is an open water, so organic materials and fine sediments will be more easily suspended in the water column and carried away by the current. In research by (Putra et al. 2020), the waters between Lembongan Island and Nusa Penida had a relatively longer residence time for particles than the surrounding waters, so the potential for deposition will be smaller.

Heavy metals content in sediment and marine organisms

Generally, heavy metals in Benoa Bay and Lembongan Island varied in concentrations (Figure 3). Heavy metals Fe, Cd, and Cu concentrations in Benoa Bay sediments were higher than those in Lembongan Island waters. On the other hand, the heavy metals Pb and Cr were higher in Lembongan Island than those in Benoa Bay. Generally, the highest concentration of heavy metals in Benoa Bay was found at the mouth of the bay (SST 3), and the lowest was found at the estuary (SST 4).

The high concentration of heavy metals in SST 3 is likely caused by the high sedimentation occurring at the mouth of Benoa Bay, in addition to the fact that the mouth of Benoa Bay is a main route for shipping activities in Benoa Bay. The high concentration of Pb and Cr on Lembongan Island is likely caused by the port activities on Nusa Penida Island that are carried by currents to Lembongan Island. According to Nugraha et al. (2014), the influence of tidal simulation on the sea current patterns around the waters of Nusa Penida ranged from 0.1-2.5 m.s^{-1} with a dominant direction towards the west to the southwest from Lembongan Island.

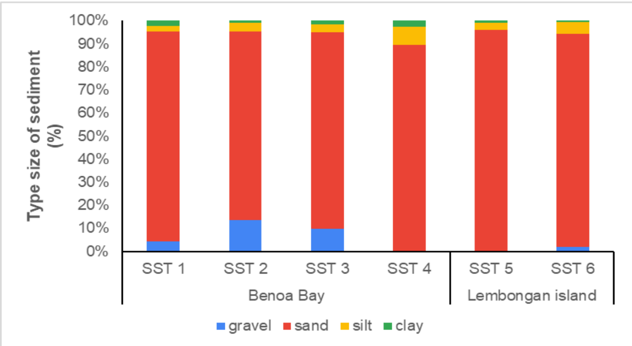

Figure 2. Type size of sediment in Benoa Bay and Lembongan Island of Bali Province, Indonesia

Table 1. Water parameters in Benoa Bay and Lembongan Island of Bali Province, Indonesia compared to quality standards based on Indonesian Government Regulation No. 22 (2021)

Location/station		Parameter					
		Temperature (ºC)	Water pH	Salinity (ppt)	DO (mg.L^{-1})	Soil pH	TOM (%)
Benoa Bay	SST1	27.63	8.38	34.67	7.09	7.67	5.16
	SST2	27.77	8.41	33.40	9.34	7.80	5.49
	SST3	27.27	8.30	33.70	5.44	7.89	5.06
	SST4	28.43	7.86	24.03	7.13	7.12	4.33
Lembongan Island	SST5	29.13	7.62	33.60	5.02	7.42	4.38
	SST6	26.40	8.15	32.93	5.09	7.49	4.39
Quality standards		28-30	7-8.5	33-34	>5	-	-

When compared to the heavy metal quality standards of Australian and New Zealand Guidelines (ANZECC/ARMCANZ), concentrations of heavy metals Pb, Cu, and Cr are below the quality standards, namely 50 $mg.kg^{-1}$, 65 $mg.kg^{-1}$, 80 $mg.kg^{-1}$, while the concentration of the heavy metal Cd at SST 3 is at above the quality standards set by ANZECC/ARMCANZ in 2000, namely 1.5 $mg.kg^{-1}$. In this study, the average heavy metal concentrations in the Pb, Cd, Cu, and Cr sediments concentrations in the sediment of Pb, Cd, Cu, and Cr were 20.20 $mg.kg^{-1}$, 1.12 $mg.kg^{-1}$, 4.02 $mg.kg^{-1}$, and 18.54 $mg.kg^{-1}$ respectively. These concentrations are generally higher than those in several studies conducted in Indonesia, such as those on Sembilan Island, Madura Waters, and North Sumatra (Yona et al. 2021; Rosalina et al. 2022; Prartono et al. 2023) (Table 2).

The concentration of heavy metals in macroalgae, seagrass, and sea urchins among stations had different values. The analysis revealed that the concentrations of heavy metals Fe, Pb, Cd, and Cu in benthic in the waters of Benoa Bay were higher than those in Lembongan Island. In contrast, the concentration of heavy metal Cr was higher on Lembongan Island (Figure 3). This suggests that the heavy metal sources in Benoa Bay are more diverse than Lembongan Island, where Benoa Bay gets input from river flows and port activities, which are quite busy. The concentrations of heavy metals in macroalgae and seagrass at Benoa Bay showed that Fe>Cu>Pb>Cd>Cr and Lembongan Island Fe>Cr>Pb>Cu>Cd as presented in Figure 3. The concentration of heavy metals in Sea urchin in Benoa Bay showed that Fe>Pb>Cu>Cd and Lembongan Island Fe>Pb>Cu>Cd.

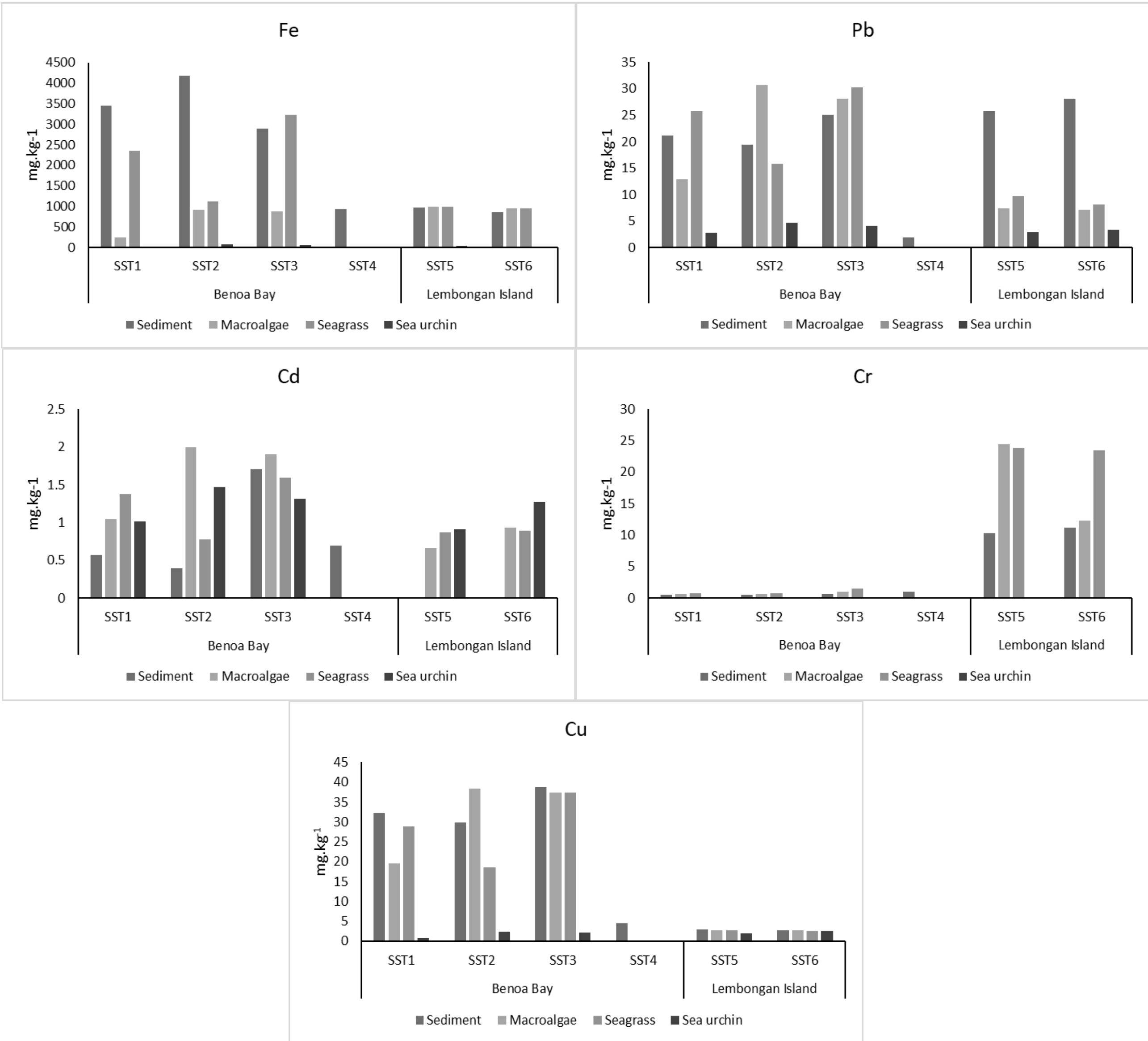

Figure 3. Heavy metal concentration in sediment and organisms (macroalgae, seagrass, sea urchin) in Benoa Bay and Lembongan Island of Bali Province, Indonesia

The concentration of heavy metals in marine organisms is indirectly influenced by heavy metals found in the environment. According to Hidayat et al. (2021), macroalgae absorb heavy metals in sediment and water. In this study, Cr metal in sea urchin gonads was not detected because it was below the instrument reading limit (<0.005 mg/kg^{-1}). In general, the concentration of heavy metals in sea urchins was lower compared to macroalgae and seagrass because the analysis of heavy metal concentration was only carried out in the gonad tissue of sea urchins. In the research of Al Najjar et al. (2018), the concentration of heavy metals in sea urchin soft organ tissue was lower than in the shell, spines, teeth, and skeleton.

The concentration of Fe metal in macroalgae, seagrass, and sea urchins was higher compared to the concentration of other heavy metals because Fe is an essential metal that organisms need to help activate the work of enzymes in the respiration and photosynthesis processes (Rosyida et al. 2014). The presence of Fe in chloroplasts has an important role in plant metabolism (Kobayashi et al. 2018). In sea urchins, Fe metal is very important in enzymatic processes (Al Najjar et al. 2018).

Table 2 shows that the concentrations of heavy metals in sediments appear to be lower than those observed in intensively anthropogenic impacted areas such as the Red Sea, Sudan and the Coast of Sicily, Italy. Compared with the results of Elhariri et al. (2020) research on Benghazi Beach, macroalgae had a higher concentration of Cd metal. In contrast, Pb and Cr metals were lower (Table 2). According to Nguyen et al. (2017) seagrass can absorb heavy metals found in water through leaves and sediment through roots. When compared with research by Rosalina et al. (2022), the Cd concentration in this study was lower than that in seagrass on Sembilan Island, South Sulawesi; conversely, the concentration of Pb metal in this study was higher (Table 2).

Sediment assessment

According to the results of the heavy metal enrichment factor (EF), the sequential enrichment of heavy metals in Benoa Bay showed Cd>Pb>Cu>Cr, while that in Lembongan Island Pb>Cr>Cu (Table 3). The heavy metal enrichment occurs due to the large amount of input from anthropogenic activities in the waters of Benoa Bay and Lembongan Island. Geo-accumulation Pb and Cd (Igeo>1), while Fe, Cu, and Cr (Igeo<0) in Benoa Bay and Lembongan Island. Contamination factors Fe, Cu, and Cr were in low category, Pb was moderate, and Cd was moderate to high in Benoa Bay. The PLI (pollution load index) value at all sampling locations was categorized as unpolluted (PLI<1).

Lubis et al. (2023) state that heavy metal enrichment comes from anthropogenic activities if the EF value is >1.5. The magnitude of the ecological pollution risk value for each of the metals Pb, Cu, and Cr has a low risk of ecological pollution. However, Cd metal in the waters of Benoa Bay was in the moderate to serious category. In the waters of Lembongan Island, all metals were in the low ecological risk category. Generally, the analysis results of potential ecological risks in Benoa Bay and Lembongan Island waters had a low-risk potential. However, SST 3 was not included in the high-risk category if we look at the risk of each metal. Cd had the contamination value that causes a high risk of pollution in SST 3.

Table 2. Reference for comparison of heavy metal concentrations in previous research

Location	Sample	Heavy metal concentration (mg/kg)					References
		Fe	Pb	Cd	Cr	Cu	
Benoa Bay and Lembongan Island, Bali, Indonesia	Sediment	2212.32	20.20	1.12	4.02	18.54	*This research*
	Seagrass	1731.80	17.96	1.10	10.06	18.03	
	Macroalgae	804.57	17.24	1.31	7.82	20.13	
	Sea urchin	45.09	3.54	1.20	N/A	1.95	
Red Sea, Sudan	Sediment	N/A	60.5	0.22	146.65	N/A	(Gaiballa, 2023)
	Seagrass		26.25	0.90	0.495		
North Sumatra, Indonesia	Sediment	N/A	12.15	0.37	16.29	6.95	(Prartono et al. 2023)
Surigao del Norte, Philippines	Seagrass	2855	5.40	3.07	34.6	N/A	(Orboc et al. 2022)
Sembilan Island, South Sulawesi, Indonesia	Sediment	N/A	6.86	3.94	N/A	N/A	(Rosalina et al. 2022)
	Seagrass		1.31	0.27			
Madura Waters, Indonesia	Sediment	N/A	2.01	N/A	N/A	4.35	(Yona et al. 2021)
Coast of Sicily, Italy	Sediment	N/A	8.91	25.6	11.89	64.4	(Bonanno et al. 2020)
	Macroalga (Ulvaceae)		5.77	0.26	2.21	10.4	
Benghazi Coast	Macroalga	N/A	14.31	3.07	N/A	3.07	(Elhariri et al. 2020)
Palau	Sediment	N/A	1.0	0.02	61.1	8.0	(Jeong et al. 2021)
	Seagrass leaves/ roots (*E. acoroides*)		0.5	0.05	4.1	3.0	
Gulf of Suez, Egypt	Sediment	2384	17.3	0.55	N/A	5.10	(Nour and El-Sorogy 2020)
Gulf of Aqaba	Sea urchin (soft organs)	708.58	8.61	1.11	3.89	NA	(Al Najjar et al. 2018)

Table 3. Enrichment factor, geo-accumulation, contamination factor, enrichment factor, pollutant load index, and potential ecological risk index in Benoa Bay and Lembongan Island of Bali Province, Indonesia

Sediment evaluation		Benoa bay				Lembongan island	
		ST 1	ST 2	ST 3	ST 4	ST 5	ST 6
EF	Pb	27.649	20.936	39.016	8.935	119.875	145.024
	Cd	46.572	26.345	379.951	208.347	N/A	N/A
	Cu	9.582	7.345	13.763	4.976	3.025	3.327
	Cr	0.090	0.062	0.117	0.604	5.998	7.245
Igeo	Fe	-4.615	-4.341	-4.869	-6.501	-6.445	-6.600
	Pb	0.174	0.047	0.417	-3.342	0.460	0.580
	Cd	0.926	0.379	3.700	1.202	N/A	N/A
	Cu	-1.355	-1.464	-1.086	-4.186	-4.848	-4.865
	Cr	-8.091	-8.349	-7.966	-7.229	-3.861	-3.743
CF	Fe	0.061	0.074	0.051	0.017	0.017	0.015
	Pb	1.692	1.550	2.002	0.148	2.063	2.243
	Cd	2.850	1.950	19.500	3.450	N/A	N/A
	Cu	0.586	0.544	0.706	0.082	0.052	0.051
	Cr	0.006	0.005	0.006	0.010	0.103	0.112
ER	Pb	8.460	7.748	10.012	0.740	10.316	11.215
	Cd	85.500	58.500	585.000	103.500	0.000	0.000
	Cu	2.932	2.718	3.532	0.412	0.260	0.257
	Cr	0.011	0.009	0.012	0.020	0.206	0.224
PLI		0.0002	0.0001	0.0017	0.0001	0.0037	0.0043
RI		96.909	68.975	598.556	104.672	10.783	11.696

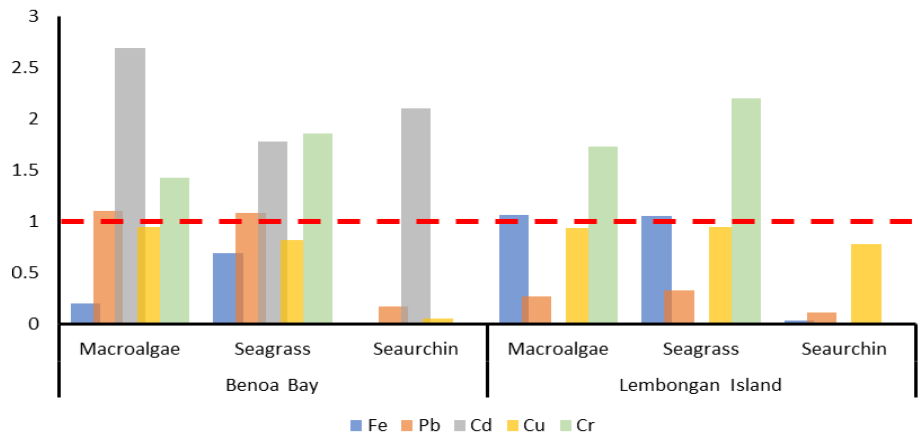

Figure 4. Bioaccumulation value macroalgae, seagrass, sea urchin in Benoa Bay and Lembongan Island of Bali Province, Indonesia

Bioaccumulation

The bioaccumulation value can inform whether an organism has the potential to be a heavy metal accumulator or only accumulates in small amounts. Generally, the bioaccumulation value of each metal varies at each station, and the accumulation ability of organisms in Benoa Bay was higher than that in Lembongan Island (Figure 4). From the analysis results, it was found that macroalgae (*Ulva* sp.) and seagrass (*Thalassia hemprichii*) were able to accumulate heavy metals (BCF>1) for Cd, Cr, and Pb in Benoa Bay, meanwhile in Lembongan Island accumulated Fe and Cr.

Metal availability and speciation are factors in the amount of metal that can be absorbed and accumulated in organism's body (Bo et al. 2015). Sea urchins (*Diadema* sp.) can only accumulate very small amounts in the gonads. Bielmyer et al. (2012) stated that sea urchin gonads did not accumulate substantial heavy metals during the 2-week exposure duration and would probably accumulate more if exposed longer.

In conclusion, although the concentrations of Pb and Cd were lower in Benoa Bay, the level of geo-accumulation, contamination, and potential risk of Pb and Cd pollution is higher than Fe, Cr, and Cu. However, the same thing was found in Nusa Lembongan, but the concentration of Cd is under the detection limit. Benoa Bay had a higher risk of ecological disturbance than Lembongan Island due to the high contamination factor of the heavy metal Cd and poorer water conditions. *Ulva* sp. and *Thalassia hemprichii* was able to accumulate Pb, Cd and Cr. The bioaccumulation ability of heavy metals in marine organisms in Benoa Bay was higher compared to Lembongan Island. It suggest that future studies of the bioavailability of heavy metals and exploration the varying capacities of marine organisms are required. Such important information can be used to predict the accumulation of heavy metals in human bodies, and the possibly daily consumption of marine organisms caught from Benoa Bay and Lembongan Island waters.

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