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Cadmium (Cd) and Lead (Pb) Levels in Oysters *Saccostrea cucullata*, Water, and Sediment in the Cunda Strait of Lhokseumawe City, Indonesia

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Abstract

Lhokseumawe is a designated as an Economic Growth Center (EGC), making it very susceptible to producing heavy metals.This research aimed to measure the content of lead (Pb) and cadmium (Cd) in oysters (Saccostrea cucullata), water, and sediment in the Cunda Strait, as well as evaluate the relationship between heavy metals and environmental conditions. The experiment was conducted at five stations selected based on considerations of seawater inflow and outflow into the Cunda Strait and existing pollution sources. The results showed that high levels of Pb and Cd with 0.36 and 0.00 mg.kg^{-1} for S. cucullata, 0.07 and 0.01 mg.kg^{-1} for water, as well as 7.60 and 0.03 mg.kg^{-1} for sediment, were found at locations away from the inflow and outflow of the Malacca Strait. The analysis showed a positive pattern in the relationship between Pb metal levels in S. cucullata with water and sediment. This suggested that Pb pollution in S. cucullata came from Pb metal in sediment and water, showing a significant effect on aquatic organisms. However, no clear relationship was found between Cd metal in S. cucullata with sediment and water. The main differences in Pb and Cd between parts were observed in the levels of Pb in water (r= 0.59) and Cd in water (r= 0.71), where higher concentrations were found in central part of the Cunda Strait compared to the southern and northern. Contaminants of heavy metals in S. cucullata, water, and sediment were significantly influenced by temperature, sediment fraction, and organic matter.

Keywords: *Anthropogenic, Contaminants, Oysters, Saccostrea cucullata, Heavy metals*

Introduction

Heavy metals are generally non-biodegradable (Abdel-Rahman 2021; Kaur and Roy, 2021; Ramezani *et al.,* 2021; Jyoti *et al.,* 2022) and remain present in the environment (Briffa *et al.,* 2020; Kanwar *et al.,* 2020; Jiang *et al.,* 2021; Uddin *et al.,* 2021). However, they are also present in the food chain (Nkwunonwo *et al.,* 2020; Feszterova *et al.,* 2021) and the global ecosystem (Okereafor *et al.,* 2020; Ahmad *et al.,* 2021). High concentration of heavy metals poses a significant problem to the environment (Sall *et al.,* 2020; Yang *et al.,* 2020), led to high toxicity (Balali-Mood *et al.,* 2021; Zaynab *et al.,* 2022), persistence (Tufail *et al.* 2022) and bioaccumulation in the living organisms, generating high health risk in the long period of time (Wang *et al.,* 2021; Budi *et al.,* 2022), particularly for people relying on fishery resources. In addition to copper (Cu), manganese (Mn), nickel (Ni), zinc (Zn) and arsenic (As), heavy metals that are also often detected significantly in coastal waters are lead (Pb) and cadmium (Wu *et al.,* 2019; Tzempelikou *et al.,* 2021). Charkiewicz and Backstrand (2020) confirmed that Pb exhibits high toxicity, causing various health problem to several organisms (Collin *et al.,* 2022). Pb is a stable element (Zhao *et al.,* 2020), but also poses low solubility and limited translocation (Arshad *et al.,* 2020; Nawrot *et al.,* 2021) and passive transport (Descalzo *et al.,* 2021). Cd is considered non-essential heavy metal (Wang *et al.,* 2024), which is also toxic (Haider *et al.,* 2021), similar to As and Pb. Additionally, Cd has high bioavailability and activity (Li *et al.,* 2016).

Lhokseumawe City is bordered by Malacca Strait in the north and within the city there is a Cunda Strait, separating the main part of Lhokseumawe from the island of Sumatra, which is experiencing high level of water pollution due to combination of factors, including fishing and agricultural activities. The people living near the strait rely on fishing. They

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often utilize the resource of the sea for their livelihoods, where they use hydrocarbon products, likely fuel to power their vessels. They may also use anti-corrosion paints to protects their vessels from damaging effects of saltwater and marine environments. Agricultural and industrial runoffs are also responsible for this strait pollution, including fertilizers, pesticides and other chemical used in the industry. In addition, natural gas industry, residential areas and aquaculture operations also play a major role in water pollution. The study done by Emersida (2021) revealed that Pb, Zu and Zn have polluted coastal waters in Lhokseumawe, where Pb has been measured to exceed safe limits and quality standard in marine environments. This will significantly affect the accumulation of heavy metals in the tissues of aquatic organisms, such as filter feeders like oysters.

Saccostrea cucullata (oyster) is a dominant bivalve species commonly found in the coastal waters of the Cunda Strait, Lhokseumawe. It is considered a high-value commodity, with increasing demand in both national and international markets (Grabowski et al., 2012; Botta et al., 2020). In Lhokseumawe, this species is frequently utilized in traditional Acehnese cuisine, notably as an ingredient in the distinguished regional dish Mie Aceh (RPPLH Kota Lhokseumawe, 2022). Erlangga *et al.* (2022) confirmed that the density of *S. cucullata* in Cunda Strait was between 2.33–4.11 ind.m^{-2} with its composition ranging from 46.67 to 61.67%. High levels of human activities in the area is seriously threatening the population of this species as locals also harvest oyster for food and as a livelihood. Therefore, given the socio-economic importance of *S. cucullata* fisheries in Lhokseumawe City, this study evaluates the variability of Pb and Cd concentrations in the tissues of this species at waters and sediments of Cunda Strait, Lhokseumawe, and to analyze the relationship between the levels of Pb and Cd in the water and its affect on the environmental conditions of Cunda Strait, where monitoring heavy metal concentrations in *S. cucullata* is an important attempt to safeguard the human health.

Materials and Methods

This research was conducted in October 2024 at five predetermined locations, as shown in Figure 1 and Table 1. The five observation stations were divided into three parts, namely the southern zone (St I and II), the central (St III and IV), and the northern (St V).

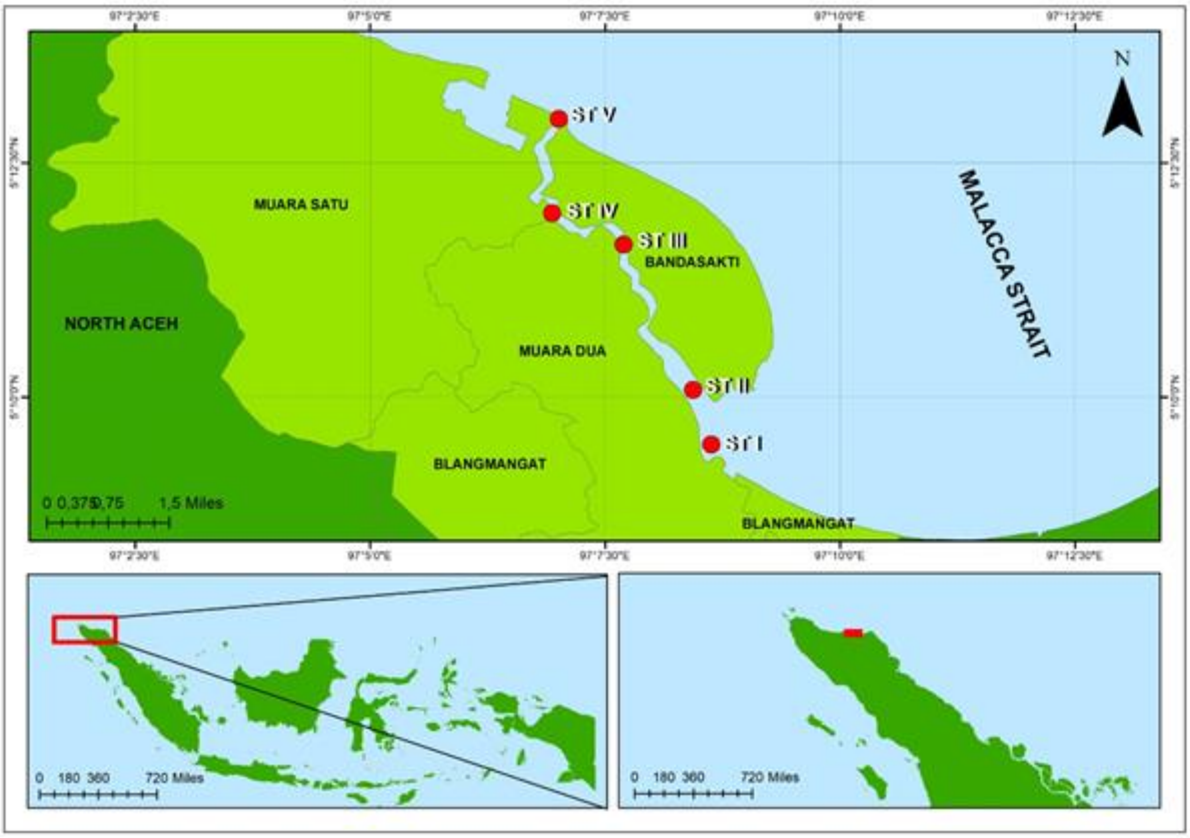

Figure 1. Study locations in Cunda Strait water of Lhokseumawe City, Indonesia

Table 1. Coordinates of the Pb and Cd heavy metal observation stations in the Cunda Strait water of Lhokseumawe City

Station	Location	Characteristic	Districts	Coordinates	
				N	E
I	Cut Mamplam	Fish farm	Muara Dua	5°09'22.4"	97°08'34.1"
II	Keude Cunda	Downtown	Muara Dua	5°09'55.2"	97°08'32.7"
III	Banda Masen	Settlement	Banda Sakti	5°11'36.0"	97°07'38.8"
IV	Blang Panyang	Clam catching	Muara Satu	5°12'02.6"	97°06'46.7"
V	Ujong Blang	Fish landing base	Banda Sakti	5°12'56.9"	97°07'20.0"

Samples collection

Samples of *S. cucullata*, water, and sediment were collected at each observation station consisting of three repetitions. *S. cucullata* were collected by free diving into the water and individuals were selected randomly. Samples of sediment were collected using a PVC pipe core sampler at a depth of 0-20 cm, while seawater was obtained from polyethylene bottles immersed at a depth of 0-1 m. The collected samples were labeled and put into a cool box for analysis in the laboratory.

Measurement of Pb and Cd concentration in the tissues of *S. cucullata* was performed by collecting the flesh of the oyster 1 gr, followed by Pb and Cd assessment in water and sediment by collecting 100 ml of water and 1 gr sediment. Pb and Cd levels were analyzed by using Atomic Absorption Spectrophotometry (AAS) Thermo Scientific iCE 3000, where the detection limit in *S. cucullata* and sediment was 0.001 mg.kg^{-1} and 0.001 mg.L^{-1} in water for both Pb and Cd.

Environmental variables

Water quality parameters were measured in-situ consisting of temperature, brightness, current velocity, salinity, pH, turbidity, and dissolved oxygen (DO). Measurement of texture, total N, and organic C sediments were carried out ex-situ, where total N was analyzed using the Kjeldhal method, organic C was examined with Walkley and Black method (BPT, 2005), sediment texture calculations were based on Folk and Ward (1957), and sediment type determination followed the Shepard triangle (Shepard, 1954). Each in-situ and ex-situ parameters collected were repeated three times at the observation station.

Statistical analysis

The average values of Pb and Cd in *S. cucullata*, water, and sediment at each observation station. The water of the Cunda Strait, Lhokseumawe City was compared using one-way ANOVA statistics that had previously been checked for Shapiro-Wilk and Kolmogorov-Smirnov normality and Levene's homogeneity test. After the ANOVA analysis, the analysis was continued with the Duncan multirange test to determine the similarity of each heavy metal content between observation stations. A simple linear regression analysis was also carried out to determine the relationship between heavy metal levels in *S. cucullata* and water, *S. cucullata* and sediment, as well as water and sediment. Heavy metals that made a major contribution to water were analyzed using the Similarity Percentage (SIMPER) statistic. Subsequently, Principal Component Analysis (PCA) was performed to distinguish between the characteristics of Pb and Cd with the interaction of environmental parameters.

S. cucullata consumption safety standards

Determination of consumption requirements based on heavy metals content in *S. cucullata* referred to the provisions of the National Standardization Agency SNI 7387:2009 and the Directorate General of Drug and Food Control BPOM (2009) Ministry of Health of Indonesia No.03725/B/SK/1989 Concerning the Maximum Limit of Heavy Metal Contamination in Food with a maximum threshold for Pb= 2.0 µg.g^{-1} and Cd= 2.0 µg.g^{-1}.

Results and Discussion

Intra-location variability

The levels of Pb in *S. cucullata*, water, and sediment in the Cunda Strait water showed varying values compared to Cd, as presented in Table 2. The results of the ANOVA test at five observation stations obtained a $P<0.05$ for Pb in water and sediment, while $P>0.05$ for *S. cucullata* (Table 3). Duncan's further test analysis showed that the levels of Pb in *S. cucullata* had high similarities at Stations I and II as well as III and IV. Pb levels in water had high similarities at Stations I and V as well as II and IV, while sediment was at I and V (Table 2).

For Cd, the ANOVA test results showed that the significance value was not detected in *S. cucullata*, while in water and sediment showed a $P<0.05$ (Table 4). The significance value of the undetected Cd levels was caused by the measured values at each observation station being the same. Duncan's further test analysis showed that the Cd levels in water had high similarities at Stations II and V, while that of Cd was in Stations I and V as well as III and IV. Furthermore, Table 2 showed that high Pb and Cd levels in *S. cucullata*, water, and sediment were found at locations far from the entry and exit areas of the Malacca Strait seawater (Station III) (Figure 1). This showed that Pb and Cd in the Cunda Strait water could be associated with input from land. According to Sany *et al.* (2013), high levels of Pb and Cd in water generally come from land contaminants, which entered through the food chain (Sonone *et al.,* 2021) by the wind (Punia, 2021) or rain (Zhang and Wang, 2020), especially land adjacent to agricultural activities, application of chemical fertilizers and pesticides (Khayan *et al.,* 2019), the oil industry (Ajarem *et al.,* 2022) and hydrocarbon-based power plants (Wang *et al.,* 2022). Alengebawy *et al.* (2021), Wang *et al.* (2022), and Khatun *et al.* (2022) stated that pesticides and fertilizers contained Pb and Cd. Similarly, hydrocarbon oil produced by the petroleum industry and all other products contained Pb (Mohebian *et al.,* 2021; Adebiyi and Ayeni, 2022; Meneceur *et al.,* 2023).

Intra-metallic variability

Heavy metals in *S. cucullata*, water, and sediment in the Cunda Strait water of Lhokseumawe City were found to have Pb > Cd concentrations (Table 5). Similar results were also found by Vazquez-Sauceda *et al.* (2011) in Mexico, Mirzaei *et al.* (2016) in Iran, and Rajeshkumar *et al.* (2018) in China. For Pb in *S. cucullata*, the levels were lower compared to sediment and Cd. Although Pb in water was higher, the content of Cd was lower compared to sediment, showing the same Cd value as in *S. cucullata*. Table 5 also shows that the concentration of Pb in *S. cucullata*, water, and sediment in the Cunda Strait Water of Lhokseumawe City has a minimum to maximum value of 0.00-0.45 $mg.kg^{-1}$,

Table 2. Levels of heavy metals in *S. cucullata*, water, and sediment based on different sampling locations in the Cunda Strait water of Lhokseumawe City

Metal	Sampling Site				
	I	II	III	IV	V
S. cucullata ($mg.kg^{-1}$)					
Pb	0.14 ± 0.20^{ab}	0.15 ± 0.05^{ab}	0.36 ± 0.12^{b}	0.30 ± 0.02^{b}	0.00 ± 0.00^{a}
Cd	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
Water ($mg.L^{-1}$)					
Pb	0.03 ± 0.01^{a}	0.04 ± 0.01^{b}	0.07 ± 0.01^{c}	0.06 ± 0.00^{b}	0.02 ± 0.01^{a}
Cd	0.00 ± 0.00^{a}	0.00 ± 0.00^{ab}	0.01 ± 0.00^{c}	0.01 ± 0.00^{b}	0.00 ± 0.00^{ab}
Sediment ($mg.kg^{-1}$)					
Pb	1.70 ± 0.06^{a}	2.61 ± 0.71^{ab}	7.60 ± 0.58^{c}	3.93 ± 0.35^{b}	1.90 ± 0.51^{a}
Cd	0.00 ± 0.00^{a}	0.01 ± 0.01^{ab}	0.03 ± 0.01^{b}	0.02 ± 0.00^{b}	0.00 ± 0.00^{a}

Table 3. ANOVA of Pb metal levels in *S. cucullata*, water, and sediment in the Cunda Strait water of Lhokseumawe City

Station	I	II	III	IV	V
S. cucullata					
I	-				
II	1.000	-			
III	0.373	0.373	-		
IV	0.665	0.665	0.961	-	
V	0.688	0.688	0.950	0.184	-
Water					
I	-				
II	0.162	-			
III	0.005	0.040	-		
IV	0.040	0.646	0.162	-	
V	1.000	0.162	0.005	0.040	-
Sediment					
I	-				
II	0.538	-			
III	0.001	0.002	-		
IV	0.520	0.271	0.007	-	
V	0.995	0.715	0.001	0.073	-

Table 4. ANOVA of Cd metal levels in *S. cucullata*, water, and sediment in the Cunda Strait water of Lhokseumawe City

Station	I	II	III	IV	V
S. cucullata					
I	-				
II	ND	-			
III	ND	ND	-		
IV	ND	ND	ND	-	
V	ND	ND	ND	ND	-
Water					
I	-				
II	0.972	-			
III	0.008	0.012	-		
IV	0.132	0.242	0.103	-	
V	0.985	1.000	0.011	0.218	-
Sediment					
I	-				
II	0.646	-			
III	0.079	0.336	-		
IV	0.162	0.646	0.946	-	
V	1.000	0.646	0.079	0.162	-

ND = Not detected

0.02-0.08 mg.L^{-1} and 1.27-8.01 mg.kg^{-1}, respectively. For the concentration of Cd, the minimum to maximum values were 0.00 mg.kg^{-1} (*S. cucullata*), 0.00–0.01 mg.L^{-1} (water), and 0.00–0.03 mg.kg^{-1} (sediment). The levels of Pb measured in *S. cucullata* in different individuals were highly dependent on eating habits (Lacerda *et al.,* 2020; Gao *et al.,* 2021; Jiang *et al.,* 2022)ecological and metabolic needs of the body (Valkova *et al.,* 2022; Stota *et al.,* 2022), age and body size factors (Jiang *et al.,* 2022; Balzani *et al.,* 2022), as well as habitat conditions (Jiang *et al.,* 2022). The results also showed that the levels of Pb were detected below the seawater quality standards of the port (<0.05 mg.L^{-1}) but above the marine tourism (>0.005 mg.L^{-1}) and biota (>0.008 mg.L^{-1}). For Cd, the levels were detected below the established quality standards both in marine biota (<0.008 mg.L^{-1}), marine tourism (<0.002 mg.L^{-1}), and seawater of the port (<0.01 mg.L^{-1}).

The relationship between Pb and Cd metal levels in *S. cucullata* with water, *S. cucullata* with sediment, and water with sediment appeared positive. However, there was an exception for the relationship between Cd metal in *S. cucullata* with sediment and water, as presented in Figure 2. This shows that the source of Cd in the body of *S. cucullata* was from sediment and water column due to their nature as filter feeders (Aslam *et al.,* 2020; Vieira *et al.,* 2021). Pb and Cd are xenobiotic metals (Ieshko *et al.,* 2023) that tend to accumulate in the body of organisms through bioaccumulation from the environment (water and sediment) or the food chain (Miglani *et al.,* 2022). Similarly, de Astudillo *et al.* (2005) and Vazquez-Sauceda *et al.* (2011) found that the levels of heavy metals in *S. cucullata* were positively correlated with sediment.

Spatial variability

Based on SIMPER analysis, spatial variability of Pb and Cd between parts of the Cunda Strait shows that water Pb and water Cd are the main differentiators, as presented in Tables 6 and 7. For water Pb metal, the contribution between the southern and northern, southern and central, as well as central and northern parts is 91.35%, 78.15%, and 77.87%, respectively. Meanwhile, for water Cd metal, the contribution between the southern and central, central and northern, as well as southern and northern parts is 12.34%, 11.83%, and 3.65%, respectively. Tables 6 and 7 also show that the highest differentiating contribution is owned by water Pb. This suggests that human activities on land, particularly agriculture, plantations, and the natural gas industry are suspected to have significant potential contributing to Pb metal contamination in Cunda Strait water. However, activities from fishermen who use paint for the safety of their ships from corrosion, fish farming, and the application of detergent to clean clothes do not have much potential to contribute to Cd metal contamination. ANOVA results of Pb levels in the water between parts have a $P > 0.05$, while Cd shows $P < 0.05$.

PCA analysis showed that the total variation value was 100% for the two Principal Components (PC) of Pb and Cd, as presented in Table 8. The first

Table 5. Levels of heavy metals *S. cucullata*, water, and sediment based on metal type in the Cunda Strait water of Lhokseumawe City

	This Research		WQC[a]			Other Research Results		
Metal	AM ± SD	Min-Max	HB	MT	MB	China[b]	Mexico[c]	Iranian[d]
S. cucullata (mg.kg^{-1})								
Pb	0.19±0.16	0.00-0.45	-	-	0.008	1.49±1.20	0.80±0.05	8.99±5.28
Cd	0.00±0.00	0.00	-	-	0.001	0.20±0.08	2.27±0.05	0.19±0.15
Water (mg.L^{-1})								
Pb	0.04±0.02	0.02-0.08	0.05	0.005	-	3.40±3.40	0.49±0.13	2.10±1.47
Cd	0.00±0.00	0.00-0.01	0.01	0.002	-	0.31±0.29	0.31±0.02	0.11±0.03
Sediment (mg.kg^{-1})								
Pb	3.55±2.33	1.27-8.01	-	-	-	3.61±3.98	0.95±0.05	17.59±6.89
Cd	0.01±0.01	0.00-0.03	-	-	-	0.24±0.16	1.09±0.02	0.34±0.14

AM= Arithmetic mean; SD= Standard deviation; Min-max= Minimum-maximum levels; WQC= Water quality criteria; HB= Harbor; MT= Marine tourism; MB= Marine biota; a= PPRI (2021); b= Rajeshkumar *et al.* (2018); c= Vazquez-Sauceda *et al.* (2011); d= Mirzaei *et al*. (2016)

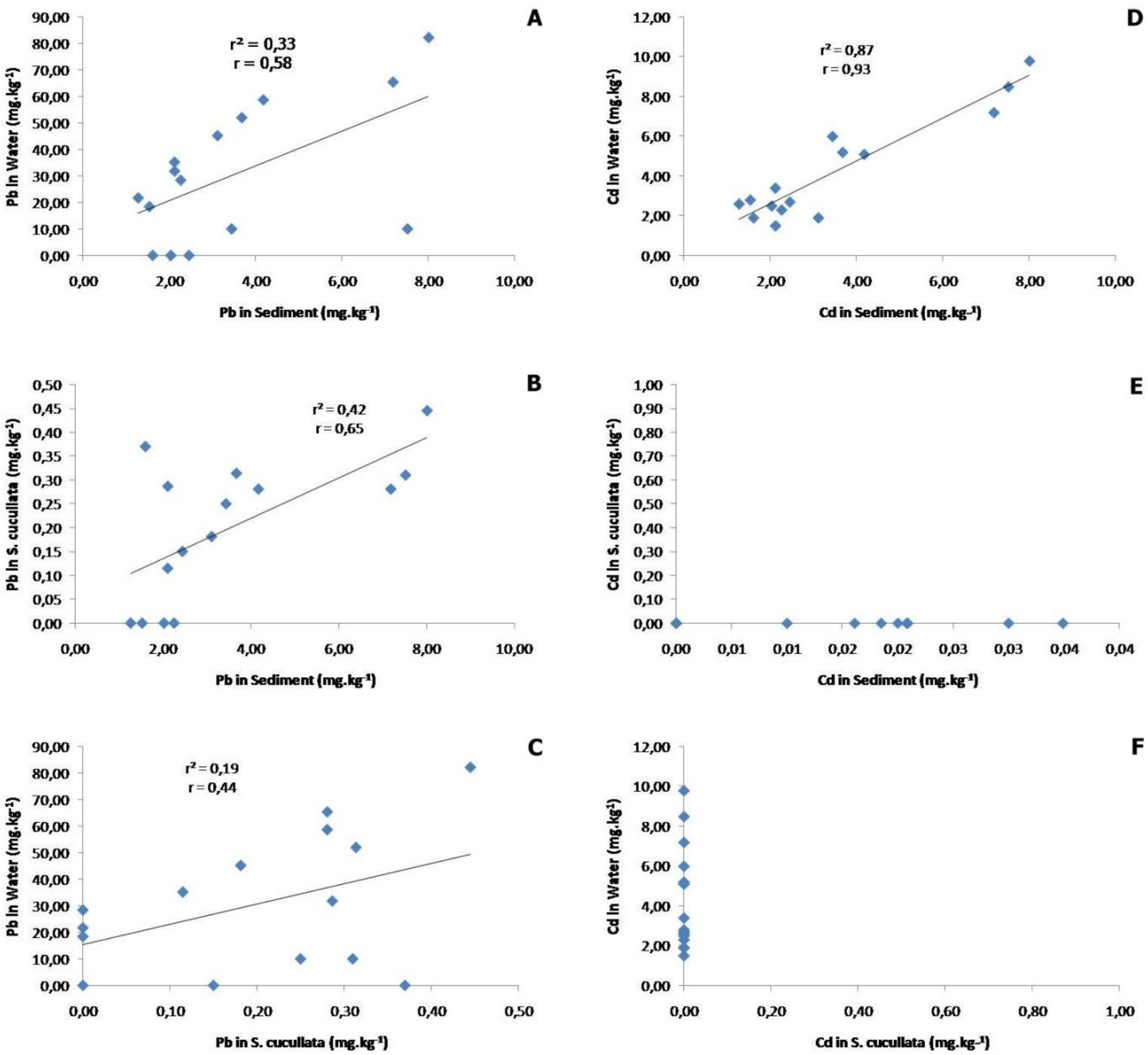

Figure 2. Linear relationship of heavy metal levels; A= Pb sediment and Pb water; B= Pb sediment and Pb *S. cucullata*; C= Pb *S. cucullata* and Pb water; D= Cd sediment and Cd water; B= Cd sediment and Cd *S. cucullata*; C= Cd *S. cucullata* and Cd water

Table 6. SIMPER analysis of differences in Pb metal between parts in the Cunda Strait water of Lhokseumawe City

No	Metal	South vs Central		South vs North		Central vs North	
		Dissimilarity (%)	Contribution (%)	Dissimilarity (%)	Contribution (%)	Dissimilarity (%)	Contribution (%)
1	Pb Water	41.81	78.15	40.87	91.35	44.53	77.87
2	Pb Sediment	4.85	9.07	1.54	3.45	5.39	9.42
3	Pb *S.cucullata*	0.21	0.39	0.68	1.52	0.47	0.81

Table 7. SIMPER analysis of differences in Cd metal between parts in the Cunda Strait water of Lhokseumawe City

No	Metal	South vs Central		South vs North		Central vs North	
		Dissimilarity (%)	Contribution (%)	Dissimilarity (%)	Contribution (%)	Dissimilarity (%)	Contribution (%)
1	Cd Water	6.60	12.34	1.63	3.65	6.77	11.83
2	Cd Sediment	0.03	0.05	0.01	0.03	0.04	0.06
3	Cd *S.cucullata*	0.00	0.00	0.00	0.00	0.00	0.00

PC axis for Pb metal had a value of 94.32% and the second was 5.68%. Meanwhile, for Cd metal, the first PC axis was 92.32% and the second was 7.68%. The main differentiator of variation in the first PC of Pb metal was observed in water (r= 0.59) and the second PC was in *S. cucullata* (r = 0.79). Based on the results, it was also observed that the main differentiator of variation in the first and second PC for Cd metal was in water and sediment (each r= 0.71) (Table 9). The Pb and Cd levels in the center of the Cunda Strait water were higher compared to the southern and northern parts that were on the negative axis of PC1, as presented in Figure 3. The high levels of Pb in the center of the Cunda Strait water were due to agricultural and plantation activities as the dominant contributors of contaminants. However, the high levels of Cd in the center of the Cunda Strait water were attributed to aquaculture activities and residential areas as the dominant contributors of contaminants.

Environmental parameters

High temperatures (average 29.66±0.54) along with moderate salinity (average 25.50±0.33) show the significant influence of fresh water (Cunillera-Montcusí *et al.,* 2022) on Pb and Cd in the Cunda Strait water of Lhokseumawe City. This is due to human activities on land including agriculture, plantations, industry, and settlements, as presented in Table 10. The current velocity parameters are higher in the parts adjacent to the inlet and outlet areas of the Malacca Strait, where the southern and northern parts are 0.16 m.s^{-1} respectively. However, water pH is low (south: 7.79 and north: 7.65) due to fresh water from the mainland which carries a higher sand fraction (south: 69.17% and north: 88.00%), causing a reduction in total N content in the southern (0.08%) and northern (0.03%) parts and affecting phytoplankton life. Disruption of phytoplankton life will affect the absorption of heavy metals in the environment. Since *S. cucullata* mainly consumes phytoplankton, their exposure to heavy metals will lead to the accumulation of toxins (Glibert, 2021), thereby polluting the environment, particularly at high concentrations (Abioye *et al.,* 2020; Du *et al.,* 2022). The parameters of brightness, turbidity, and DO were observed to vary between parts of the Cunda Strait waterof Lhokseumawe City (38.58-79.00 cm, 441.50 - 862.83 NTU and 4.79-7.30 mg.L^{-1}). This is similar to the organic C content of the sediment (0.25-2.64%), which significantly determines the Cation Exchange Capacity (CEC) contributing to the negative charge. A higher CEC value in the sediment leads to greater absorption of positively charged ions in metals (Khasanah *et al.,* 2021) such as Hg, Pb, and Cd (Shtepliuk *et al.,* 2017), thereby causing a decrease in high metals.

Interaction of environmental parameters with heavy metals

Pb and Cd contaminants have a strong relationship with organic matter content and sediment texture in the Cunda Strait water in the central part of Lhokseumawe City (Figure 4). Based on the results, content of the total N, organic C, and dust fractions correlate significantly with Pb in *S. cucullata,* water, and sediment, as well as Cd in water and sediment. In the southern part, the high parameters of salinity, DO, turbidity, and pH do not have a significant effect on the heavy metals. This indicates that the heavy metals Pb and Cd in the southern waters of the Cunda Strait do not affect the high levels of salinity, dissolved oxygen, turbidity, and pH. Likewise in the northern part of the Cunda Strait water of Lhokseumawe City, namely the parameters of current speed, brightness, temperature, high clay, and sand fractions do not have a significant effect on heavy metals in *S. cucullata,* water, and sediment. The results of PCA analysis show that Pb and Cd contaminants in *S. cucullata*, water, and sediment are significantly influenced by temperature, clay sediment fraction, and organic C content as key factors (Table 11). This can be observed from the variation of data owned by temperature, clay sediment fraction, and organic C content which are higher (69.63%; located on PC1) than sand, dust sediment fractions, and current speed (30.37%; located on PC2).

Table 8. PCA of Pb and Cd metals showing the percentage of variance on the first axis between sections in the Cunda Strait water of Lhokseumawe City

No	Principal Component	Eigenvalue	% Variance
Pb Metal			
1	1	2.83	94.32
2	2	0.17	5.68
Cd Metal			
3	1	1.85	92.32
4	2	0.15	7.68

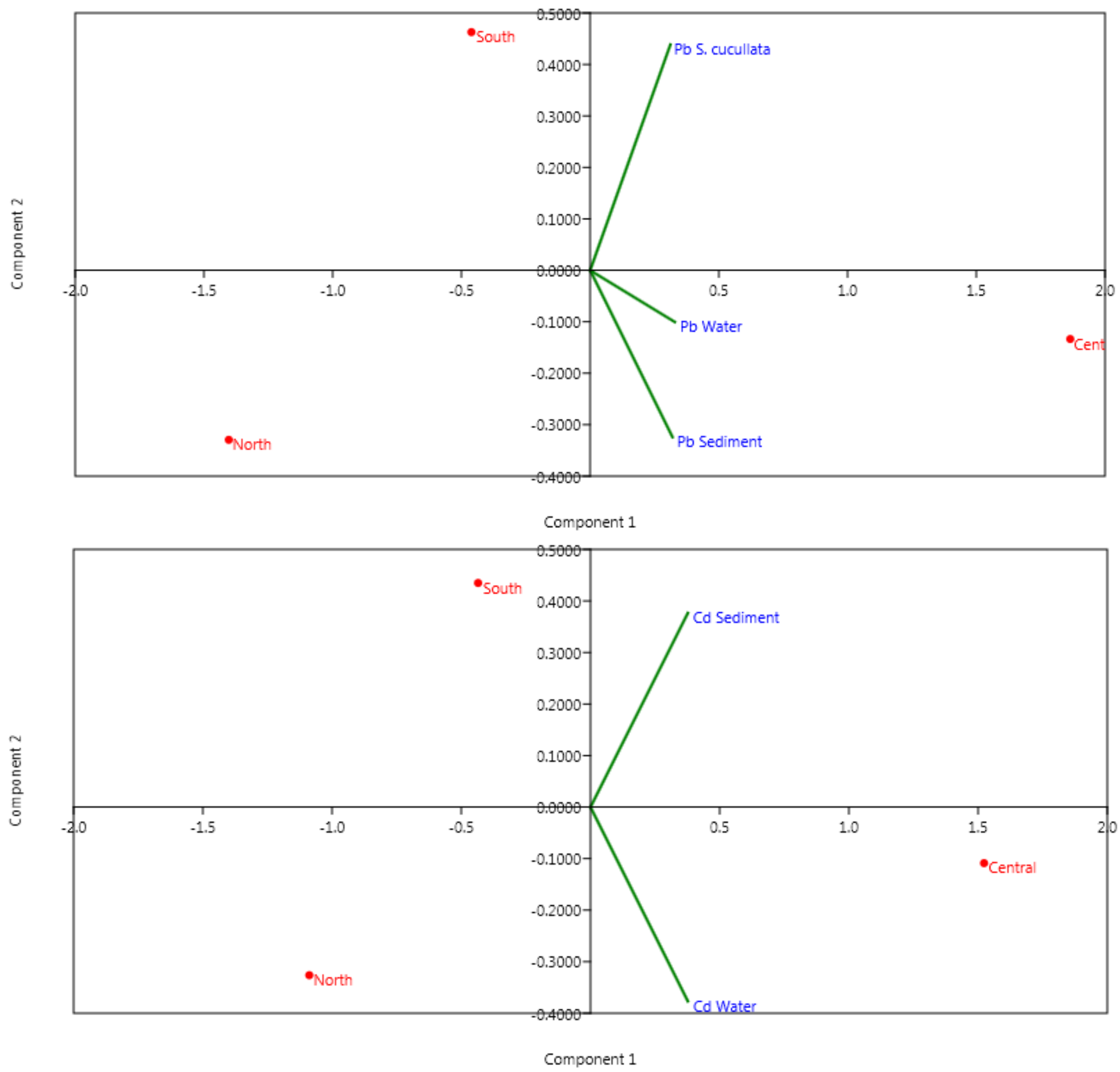

Figure 3. PCA showing the differentiation of heavy metals between parts in the Cunda Strait water of Lhokseumawe City; Top = Pb, Bottom = Cd

Table 9. Correlation coefficient values between PC components and Pb and Cd metal variables between parts in the Cunda Strait water of Lhokseumawe City

No	Heavy Metals	PC1	PC2
Pb			
1	Pb Water	0.59	-0.18
2	Pb Sediment	0.58	-0.58
3	Pb *S. cucullata*	0.56	0.79
Cd			
4	Cd Water	0.71	-0.71
5	Cd Sediment	0.71	0.71

Table 10. Environmental parameters of the Cunda Strait water of Lhokseumawe City

No	Parameters	South	Central	North	$\bar{x}$
Water					
1	Temperature (°C)	30.20	29.12	30.47	29.66 ± 0.54
2	Transparency (cm)	38.58	57.50	79.00	48.04 ± 9.46
3	Current Velocities ($m.s^{-1}$)	0.16	0.08	0.16	0.12 ± 0.04
4	Salinity (‰)	25.83	25.17	24.67	25.50 ± 0.33
5	pH	7.79	7.54	7.65	7.66 ± 0.12
6	Turbidity (NTU)	862.83	699.38	441.50	1281.10 ± 581.73
7	Dissolved Oxygen ($mg.L^{-1}$)	7.30	5.56	4.79	6.43 ± 0.87
Sediment					
8	Sand (%)	69.17	49.83	88.00	59.50 ± 9.67
9	Silt (%)	23.00	45.00	3.67	34.00 ± 11.00
10	Clay (%)	7.83	5.17	8.33	6.50 ± 1.33
11	N-total (%)	0.08	0.11	0.03	0.10 ± 0.02
12	C-organic (%)	0.49	2.64	0.25	1.57 ± 1.08

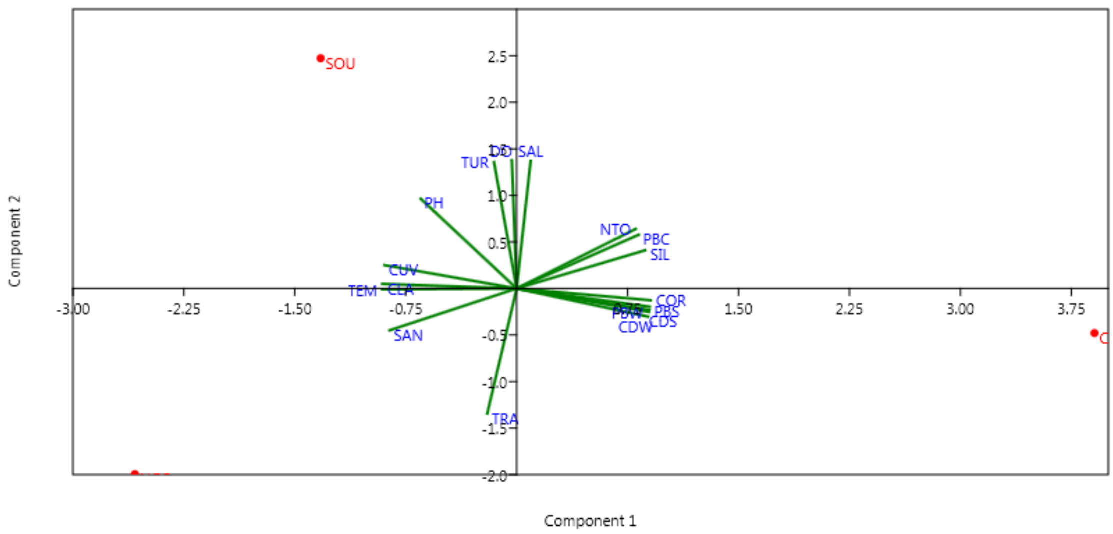

Figure 4. PCA depicting environmental parameters, metal content and sampling section in the Cunda Strait water of Lhokseumawe City; TEM= Temperature; TRA= Transparency; CUV= Current velocities; SAL= Salinity; PH= Power of hydrogen; TUR= Turbidity; DO= Dissolved oxygen; SAN= Sand; SIL= Silt; CLA= Clay; NTO= N-total; COR = C-organic; CDW= Cd water; CDS= Cd sediment; PBW= Pb water; PBS= Pb sediment; PBC= Pb *S. cucullata*; SOU= South; CEN= Central; NOR= North

S. cucullata consumption safety

The average Pb content of *S. cucullata* in Cunda Strait water was found to be 0.198 $mg.kg^{-1}$ when compared to the Pb quality standard set by the National Standardization Agency SNI 7387:2009 and BPOM (2009) which is (<2 $mg.kg^{-1}$). Table 11 shows that the average Pb content of *S. cucullata* in Cunda Strait

Table 11. Total variance and component matrix of environmental interactions with metal levels in the Cunda Strait water of Lhokseumawe City

Component	Initial Eigenvalues			Extraction Sums of Squared Loadings			Rotation Sums of Squared Loadings		
	Total	% of Variance	Cumu lative (%)	Total	% of Variance	Cumu lative (%)	Total	% of Variance	Cumu lative (%)
Total variance explained									
1	11.84	69.63	69.63	11.84	69.63	69.63	11.84	69.62	69.62
2	5.16	30.37	100.00	5.16	30.37	100.00	5.17	30.38	100.00

Parameter	Component Matrix		Rotated Component Matrix	
	PC1	PC2	PC1	PC2
TEM	-1.000	-0.007	-1.000	-0.021
CLA	-0.999	0.036	-1.000	0.02
COR	0.996	-0.092	0.997	-0.078
PBS	0.990	-0.143	0.992	-0.128
CDS	0.986	-0.168	0.988	-0.168
CUV	-0.983	0.182	-0.986	0.168
PBW	0.983	-0.182	0.986	-0.168
CDW	0.976	-0.219	0.979	-0.205
SIL	0.955	0.298	0.950	0.312
SAN	-0.945	-0.326	-0.940	-0.340
PBC	0.908	0.420	0.902	0.433

Table 12. Results of measurements of Pb levels in *S. cucullata* Cunda Strait

Location	Wet Weight	Pb Concentration (mg.kg^{-1})	Quality Standards
Station I	1.016	0.219	(2 mg.g^{-1}) POM No.03725/B/SK/1989
Station II	1.013	0.148	
Station III	1.014	0.347	
Station IV	1.013	0.281	
Station V	1.014	0	
Average	1.014	0.199	

water of Lhokseumawe City as a whole ranges from 0-0.346 mg.kg^{-1}, with the lowest and highest observed at Stations V and III, respectively.

The high Pb content at Station III was due to the nature of *S. cucullata* which were filter-feeder organisms that could be dangerous for consumption after accumulating toxic substances. However, Station III has the lowest *S. cucullata* density of 0.80 ind.m^{-2}, as shown in Table 12. This is because the environmental conditions in the area are less supportive of growth. Furthermore, community also rarely searches for *S. cucullata* at Station III because the area is difficult to reach and the substrate is muddy.

Consumption Safety Limit (PTWI) in S. cucullata

The maximum safety limit of *S. cucullata* consumption from Cunda Strait water containing heavy metals is based on PTWI (Provisional Tolerable Weekly Intake) FAO/WHO (2004). PTWI for Pb metal is 0.25 mg.kg^{-1} per week or equivalent to 1.750 g.kg^{-1} per week for an adult body weight (70 kg). In this research, the average Pb content in the Cunda Strait water was 0.198 mg.kg^{-1} wet weight (Table 12). Therefore, adult fish weighing 70 kg will reach the PTWI value after consuming *S. cucullata* 8.8 kg per week (1.75: 0.198) to remain within a safe limit. This showed that *S. cucullata* Cunda Strait water of Lhokseumawe City could still be consumed within the specified limit.

Conclusion

Heavy metals content in *S. cucullata* in the Cunda Strait water was 0.198 mg.kg^{-1} and 0.0 mg.kg^{-1} for Pb and Cd, respectively. These values were still below the quality standards set by the Directorate General of POM, Indonesia Ministry of Health POM No. 03725/B/SK/1989 (<2 mg.kg^{-1}). Therefore, Pb and Cd content was considered safe for consumption by adults weighing 70 kg, where the maximum safe limit was 8.8 kg/week. Despite the significant result, the level of Pb and Cd contamination in water and sediments should considered. Based on the analysis, Pb in water and sediments showed an increasing trend, although the specific results for water did not explicitly state that the content exceeded the quality standards. This suggested the potential for pollution that should be considered, particularly regarding the similarity in Pb levels between observation stations. The relationship between the levels of Pb and Cd as well as water and sediment showed a positive pattern, suggesting potential pollution sources. This showed the need for sustainable management of pollution sources to maintain water quality and food safety by focusing on regular monitoring of heavy metals in water, sediments, and *S. cucullata.*

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