Lead (Pb) Contamination in Sediments and the Potential of Gastropods as Bioindicators of Pb in Mangrove Forests, Mojo Village, Pemalang

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Abstract

The Mojo Village mangrove forest in Pemalang has undergone environmental degradation due to land conversion into shrimp farming areas. This land conversion has resulted in increased anthropogenic activities that have the potential to become sources of heavy metal pollution in sediment waters, particularly lead (Pb). This study aimed to analyze Pb concentrations in sediments and gastropods and assess the potential of gastropods as bioindicators of Pb pollution. Sample preparation followed the USEPA 3051 method, and Pb analysis was conducted using Atomic Absorption Spectrophotometry (AAS). The results of the study showed that five species of gastropods from two families found in the mangrove pond area of Mojo VillageareLittoraria melanostoma, Littoraria scabra, Cerithidea cingulata, Cerithidea obtusa, and Cerithidea decollata. Pb concentrations in sediments averaged 11.86 ± 1.24 mg/kg, while in gastropods, the average was 0.43 ± 0.16 mg/kg. The source of Pb is thought to come from anthropogenic activities such as domestic activities and transportation and ship activities in the research area. Although Pb levels in sediments indicate low contamination and no pollution, they may still pose potential biological risks. Cerithidea cingulata and Cerithidea obtusa were categorized as deco-concentrators with the potential to serve as bioindicators of Pb pollution. The study also revealed a very strong correlation between Pb concentrations in sediments and gastropods.

***Keyword:** Bioindicators; Cerithidea cingulata; Cerithidea obtusa; Lead; SQGs*

INTRODUCTION

The mangrove ecosystem is a vital component of coastal regions, providing essential services such as serving as nurseries for marine life, shielding coastlines from erosion, filtering pollutants, and preventing saltwater intrusion. Beyond these ecological functions, mangroves also hold substantial economic value. In Indonesia, including Pemalang Regency, mangrove forests are a prominent feature along the coastlines. Pemalang Regency, located on Java's northern coast, boasts a 76.63 km shoreline. Within this region, Mojo Village is home to an 88.57-hectare mangrove forest, currently managed as an ecotourism site by local residents (Puryono & Suryanti, 2019). However, this mangrove forest faces challenges, including degradation due to land-use changes which can produce pollutants that are harmful to the environment (Muali, 2020).

Heavy metals, particularly lead (Pb), are common pollutants in waste effluents. Elevated Pb levels can enhance toxicity, persistence, and bioaccumulation in marine organisms, including gastropods (Riani *et al*., 2018). Gastropods are macroinvertebrates frequently found in coastal ecosystems. They can serve as bioindicators in aquatic environments due to their ability to accumulate chemical compounds in their tissues (Puryono & Suryanti, 2019).

Currently, data on heavy metal content and the use of gastropods as bioindicators of heavy metals in the mangrove forest of Mojo Village, Pemalang, is still limited and needs further investigation. Previous studies on Pb contamination in sediments in the mangrove forest area have been conducted (Syaifullah *et al*., 2018; Natsir *et al.,* 2019), but have not included the potential of

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gastropods as heavy metal indicators. Therefore, this study aims to provide information on pollution status and the potential of gastropods as bioindicators of Pb in the pond areas of the mangrove forest in Mojo Village, Pemalang.

MATERIAL AND METHODS

The study took place in August 2023 in the pond areas of Mojo Village's mangrove forest, Ulujami District, Pemalang Regency, Central Java. Sampling was conducted at three sites near milkfish ponds (Figure 1), with coordinates recorded via GPS. Locations were selected purposively based on habitat features and gastropod presence. The purposive sampling method was chosen because it aims to collect samples from locations that have the presence of target gastropods and relevant habitat characteristics. This approach is effective in ensuring that the data obtained comes from areas that have a direct relationship to Pb bioaccumulation in gastropods.

Samples collected included water physicochemical parameters, sediments, and gastropods. Water parameters such as temperature, salinity, pH, and dissolved oxygen (DO) were measured in situ using a Water Quality Checker (WQC) AMTAST EC900. Sediment samples were collected in triplicate from each station to a depth of 1 m using polyvinyl chloride (PVC) pipes, then homogenized without stratifying depth layers. Sediment homogenization was performed to obtain the average value of Pb concentration in a location, which can reflect the level of exposure to heavy metals that are potentially available to gastropods. This approach is relevant in bioaccumulation studies because target organisms generally interact with the surface layer of sediment. To prevent oxidation, samples were preserved at 4 °C (Haryati *et al*., 2022). Gastropods were collected by hand sorting within a 1 m² transect (Ulandari *et al*., 2022) and identified through morphological observation using the guides Shells of Queensland and The Great Barrier Reef.

Pb Content Measurement

Sample preparation adhered to the USEPA 3051 method. Samples were dried at 105 °C for 24 hours, then homogenized by grinding with a mortar and pestle. A 2 g portion of each sample was analyzed using an AAS Thermo iCE 3000 series instrument. The analysis followed APHA guidelines, with a detection limit of 0.001 ppm at a wavelength of 283.3 nm (Permata *et al*., 2018).

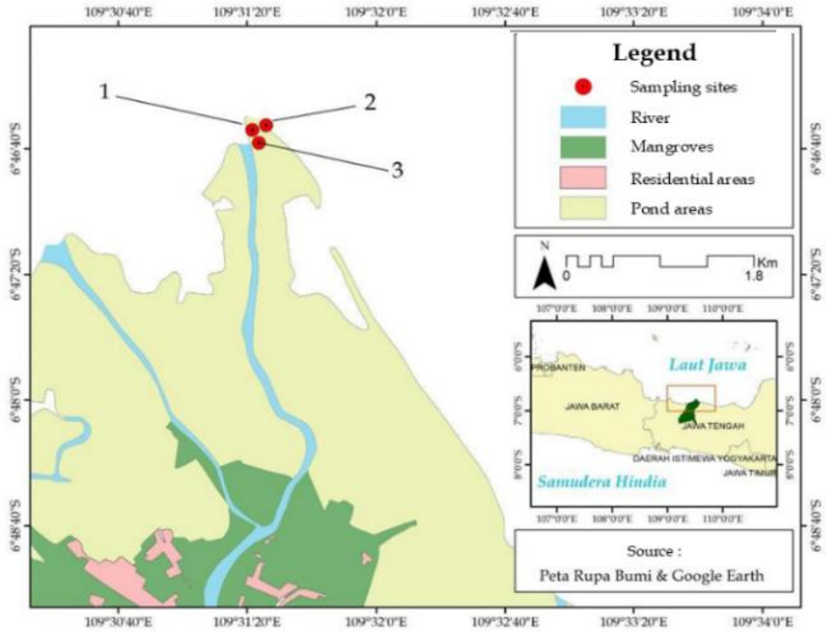

Figure 1. Sampling location in Mangrove Forest, Mojo Village

Contamination Levels and Ecological Risk of Pb

The Pb content in sediments was compared with quality standards from CCME (2002) and ANZECC/ARMCANZ (2000). To assess contamination levels and ecological risk, the Contamination Factor (CF) was calculated. The CF represents the ratio of the measured heavy metal content in sediments to the naturally occurring levels in the environment (Ali *et al*., 2016). The CF calculation is given in Equation 1.

$$CF = Cn/Bn \ldots\ldots\ldots(1)$$

The Contamination Factor (CF) is calculated using Cn, the Pb content in the sample, and Bn, the average natural Pb content (Pb = 20 mg/kg). CF values are categorized into four levels based on the classification by Perumal *et al*. (2021). The CF categories are detailed in Table 1.

The Geo-accumulation Index (I-geo) is a formula used to assess heavy metal contamination in sediments based on natural fluctuation levels (Muller, 1969 *in Petukhov et al*., 2023). I-geo equation is shown in Equation 2.

$$I\text{–}geo = \log_2 (Cn)/(1{,}5\,(Bn)) \ldots\ldots..(2)$$

Geo-accumulation Index (I-geo) is calculated using Cn, which represents the Pb content in the sample, Bn, which represents the average natural Pb content, and a constant of 1.5 to account for variations in Bn due to lithogenic effects. The I-geo index values shown in Table 2.

Sediment Quality Guidelines (SQGs) are formulas used to describe sediment contamination levels by comparing them with appropriate quality guidelines. The SQG equations are shown in Equations 3 and 4.

$$PEL\text{-}Qi = contaminant/PEL \ldots\ldots.(3)$$

$$SQG\text{-}Q = (PEL\text{-}Qi)/n \ldots\ldots..(4)$$

PEL-Qi represents the ratio of the Probable Effect Level (PEL) for each contaminant, where PEL is the concentration at which adverse effects on aquatic biota are likely. SQG-Q is the Sediment Quality Guideline value, and n is the number of heavy metals tested. Interpretation of SQG-Q values follows the criteria established by Zhou *et al.*, 2018 as shown in Table 3.

Determination of Bioindicator Species

The determination of bioindicator species is conducted by calculating the accumulation factor and performing criteria testing. Biota Sediment Accumulation Factor (BSAF) is calculated to assess the ability of gastropods to accumulate heavy metals. The BSAF equation is shown in Equation 5.

$$BSAF = (\text{Heavy metal content in gastropod})/(\text{Heavy metal content in sediment}) \ldots\ldots..(5)$$

Table 1. Contamination Levels Based on CF Values

Value	Category
CF < 1	Low contamination factor
1 ≤ CF < 3	Moderate contamination factor
3 ≤ CF < 6	Considerable contamination factor
CF ≥ 6	Very high contamination factor

Table 2. Pollution Index Based on I-geo Values

Value	Category
I-geo ≤ 0	Practically uncontaminated
0 < I-geo ≤ 1	Uncontaminated to moderate
1 < I-geo ≤ 2	Moderate
2 < I-geo ≤ 3	Moderate to strong moderate
3 < I-geo ≤ 4	Strong
4 < I-geo ≤ 5	Strong to very strong
I-geo > 5	Very strong

Table 3. Interpretation of SQG-Q Values

SQG-Q value	Designation of sediment quality
SQG-Q < 0,1	Unimpacted, lowest potential for observing adverse biological effects
0,1 < SQG-Q < 1	Moderate impact potential for observing adverse biological effects
SQG-Q ≥ 1	Highly impacted potential for observing adverse biological effects

BSAF values are categorized into three levels to describe the ability of organisms to accumulate heavy metals, as detailed in Table 4. The relationship between Pb content in sediments and gastropods in the mangrove forest pond areas of Mojo Village, Pemalang, was analyzed using Pearson correlation testing. Additionally, gastropods were further evaluated as bioindicator species using modified criteria from Zaghloul *et al.,* (2020) in Table 5.

RESULTS AND DISCUSSIONS

Analysis of Pb content in sediments revealed that the average Pb concentration at Station 1 was 11.77 ± 0.05 mg/kg; at Station 2, it was 10.76 ± 0.18 mg/kg; while Station 3 had a concentration of 11.40 ± 1.48 mg/kg. The average Pb content across all stations was 11.31 ± 0.87 mg/kg (Figure 2).

The source of Pb is thought to come from anthropogenic activities of ships such as domestic activities, transportation, and activities. Household wastewater through the use of lead pipes or detergents containing heavy metals can be a source of pollution. Pb metal can also come from electronic waste, batteries, and plastic burning then release Pb into the air and settle in the waters and mangrove sediments. Pb-based anti-rust paint used on fishing boats in the research area, as well as oil spills can be sources of pollution in coastal and mangrove areas.

Stations 1 and 3 showed similar Pb concentrations of 11.77 ± 0.05 mg/kg and 11.40 ± 1.48 mg/kg, respectively. The elevated Pb levels at these stations are likely due to their locations: Station 1 is near a coastal river estuary, which facilitates the input of heavy metals from river flow, while Station 3 is at the Mojo Mangrove Forest Essential Ecosystem Area outlet, a zone frequented by small fishing vessels. Spills from fishing vessels may contribute to Pb levels. In contrast, Station 2, with lower Pb content, benefits from the presence of a mangrove ecosystem known for trapping heavy metals (Zhang *et al*., 2017). Additionally, hydrodynamic factors at Station 2, such as proximity to the sea and estuary, may influence Pb levels through tidal action. Tidal phenomena, waves, and wind can induce bioturbation, resuspension, and erosion, affecting metal concentrations in surface sediments.

Pb in sediments can become a pollutant if concentrations exceed established thresholds. However, in the mangrove aquaculture area of Desa Mojo, Pb levels remain below the limits set by ANZECC/ARMCANZ and CCME. With an average Pb concentration of 11.31 ± 0.87 mg/kg, the sediments in this area are unlikely to adversely affect aquatic biota according to the ANZECC/ARMCANZ and CCME ISGQ and PEL guidelines (Table 6).

Table 4. BSAF Value Classification (Krishnan *et al*., 2022)

Value	Designation of sediment quality
BSAF > 1	Macro-concentrator
1 < BSAF < 2	Micro-concentrator
BSAFQ < 1	Deco-concentrator

Table 5. List of Tested Criteria

No.	Designation of sediment quality
1.	Provide measurable response (accumulate pollutants directly from their environment)
2.	Respond in proportion to the degree of contamination or degradation
3.	Common, including distribution within area of question
4.	Ecology and life history well understood
5.	Taxonomically well documented and stable

Table 6. Comparison of Sediment Pb Content to Quality Guidelines

Source	Value	Pb (mg/kg)
Sediment of the mangrove area in Mojo village	Minimum	10,01
	Maksimum	12,96
	Average	11,31
ANZECC/ARMCANZ (2000)	Low	50
	High	220
CCME (2002)	ISGQ*	30,2
	PEL**	112

** Interim Sediment Quality Guidelines; ** Probable Effect Levels*

Pb levels at the research site are within quality guideline limits. However, heavy metals in sediments can still accumulate in organisms that live and forage at the sediment-water interface, as well as in the surrounding sediments and waterbed (Rizkiana *et al*., 2017; Huzariah *et al*., 2022). Comparative analysis shows no significant metal enrichment at the site, as the Pb source is primarily natural rather than anthropogenic. Pb enters aquatic environments through rock weathering and atmospheric particles deposited by rain. Additionally, surface currents from river estuaries influence heavy metal accumulation, with higher current velocities reducing metal accumulation (Ma'rifah *et al*., 2016).

The Contamination Factor (CF) assesses heavy metal contamination in sediments by comparing Pb content in samples to the average natural Pb content (Ali *et al*., 2016). Results, shown in Figure 5, reveal CF values ranging from 0.54 to 0.59, with an average of 0.57 (Figure 3). Station 1 exhibits the highest CF of 0.59, while Station 2 shows the lowest at 0.54. All CF values are below 1, indicating low contamination levels according to Perumal *et al*. (2021). The elevated CF at Station 1, near the Comal River mouth, suggests potential Pb input from river flow. Conversely, the lower CF at Station 2, near the estuary and sea, is likely due to physical factors such as currents and tidal effects causing resuspension. Resuspension disperses particles into the water, which can transport metals and organic molecules into the ecosystem.

The Geoaccumulation Index (I-geo) assesses the degree of heavy metal pollution in sediments (Al-Mur *et al*., 2017). Pb I-geo values range from -1.48 to -1.35, with the highest value at Station 1 (-

1.35) and the lowest at Station 2 (-1.48) (Figure 4). The average I-geo value across all stations is -1.41. These I-geo values suggest that the mangrove shrimp farming area in Desa Mojo is classified as non-polluted (I-geo ≤ 0).

I-geo values are often linked to human activity, with higher activity increasing the risk of Pb pollution. The low I-geo values at the research site are likely due to minimal anthropogenic Pb input. The mangrove ecosystem's ability to accumulate heavy metals also plays a role, influenced by metal bioavailability in sediments and physiological adaptations in mangroves. In aquatic environments, Pb ions tend to form complexes and precipitate onto sediments. Fine sediment particles facilitate the transport of heavy metals from water to sediments. Dissolved Pb ions bind to these fine particles and eventually settle. This is consistent with Lee & Oh (2018) observation that sediments serve as a final repository for contaminants and organic matter. Pb ions in sediments are more stable compared to dissolved ions in water.

In the mangrove shrimp farming area of Desa Mojo, the Sediment Quality Guidelines Quotient (SQG-Q) values range from 0.29 to 0.32, with the highest at Station 1 (0.32) and the lowest at Station 2 (0.29). The average SQG-Q value is 0.30 (Figure 5). The SQG-Q value between 0.1 and 1 indicates a moderate impact, suggesting potential adverse biological effects on aquatic organisms.

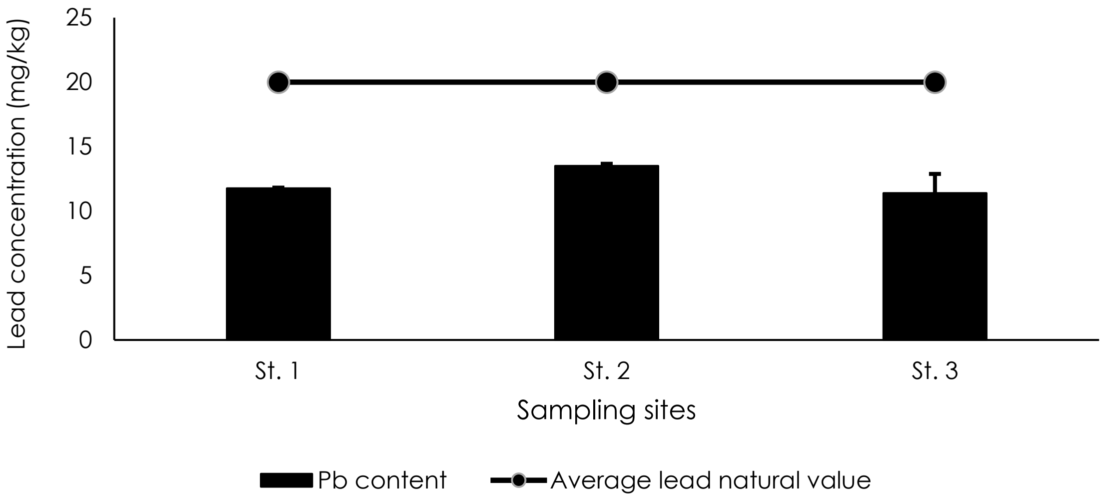

Figure 2. Lead contet in sampling sites

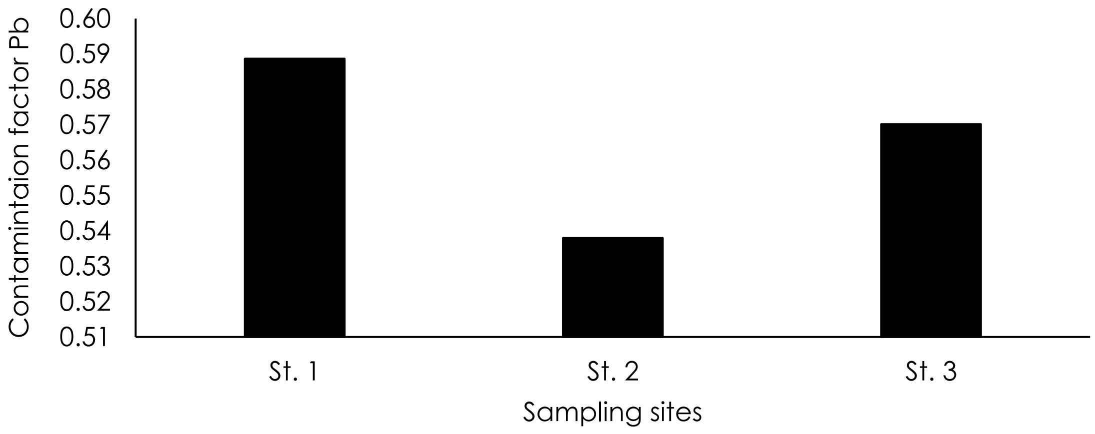

Figure 3. Lead contamination factor in research in sampling sites

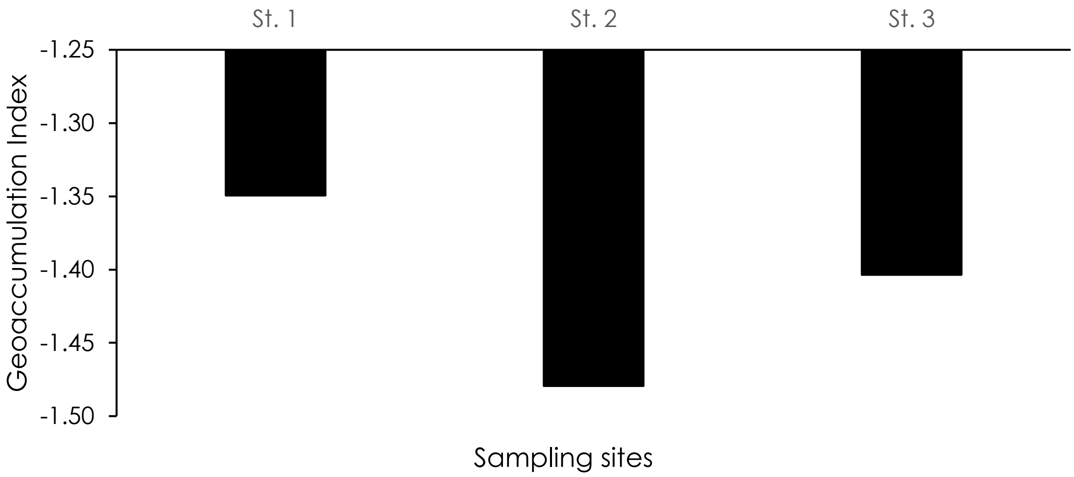

Figure 4. Lead geoaccumulation index in sampling sites

Pb concentrations at the research site were also compared with the Probable Effect Level (PEL) and Threshold Effect Level (TEL) values to evaluate potential biological effects (Figure 6). The Pb concentration in the mangrove shrimp farming area, 11.31 ± 0.87 mg/kg, is below both the PEL (112 mg/kg) and TEL (30.6 mg/kg) values. Pb concentrations below these thresholds do not cause adverse biological effects. Exceeding PEL and TEL levels could disrupt gastropod reproductive systems and have teratogenic effects. The Biota Sediment Accumulation Factor (BSAF) is used to assess the ability of organisms to accumulate chemicals from their environment. BSAF values are utilized for biomonitoring purposes. The BSAF calculations for both species indicate values less than 1, categorizing them as deco-concentrators (Table 7). Deco-concentrators are organisms with a lower capacity for chemical accumulation.

The BSAF value is influenced by the concentration of heavy metals in sediments. Muslim et al. (2023) report a positive correlation between heavy metal concentrations in gastropods and Pb levels in sediments. Additionally, Hoefnagel & Verberk (2017) found that body size affects gastropod metabolism, potentially enhancing accumulation ability. Low BSAF values may also result from the bioaccumulation capacity of gastropods, which depends on environmental and biological factors. Environmental factors, such as organic carbon, pH, dissolved oxygen, temperature, salinity, and sediment size, affect metal solubility. Biological factors, including age, sex, size, feeding habits, and reproductive status, influence each species' ability to accumulate chemicals (Putri *et al*., 2022).

Gastropods are organisms commonly associated with mangrove ecosystems, supporting their ecological functions. In the mangrove shrimp farming area of Desa Mojo, five gastropod species from two families were observed: *Littoraria melanostoma, Littoraria scabra, Cerithidea cingulata, Cerithidea obtusa*, and *Cerithidea decollata*. The results study showed that only gastropods *Cerithidea cingulata* and *Cerithidea obtusa* had Pb content in their body tissues, while the other three species were not detected to contain Pb metal in their bodies. *Cerithidea cingulata* and *Cerithidea obtusa* can be used as bioindicators of Pb contamination as indicated by the presence of Pb content in their body tissues. Several studies have used *Cerithidea cingulata* and *Cerithidea obtusa* as indicators of Pb contamination (Ranjan and Babu, 2016; Yap and Al-Mutairi, 2023). This second species can also accumulate Pb higher than other species, so it can be used as an indicator of Pb contamination.

Cerithidea cingulata was the most abundant gastropod species, commonly found in sediment due to its preference for muddy substrates and deposit-feeding behavior (Hassan *et al*., 2021). Conversely, Li*ttoraria scabra* was the least abundant, typically found attached to mangrove roots above the water surface to avoid submersion during high tides (Lalita, 2016). Littoraria gastropods are herbivorous animals whose food consists of microalgae, macrophyte sheets, algae filaments, and mangrove tissue (Alfaro, 2007). The difference in eating habits can be a factor causing the absence (undetection) of Pb content in *Littoraria melanostoma* and *Littoraria scabra*. Pb metal was also not detected in gastropods of the *Cerithidea decollata* species found in the tributary of the Comal Rivers located south of the aquaculture area (Station 3). The water current in the tributary is indicated to transport Pb in the water column to the sea. The prevalence of *Cerithidea cingulata* in the submerged mangrove areas is likely due to its adaptation to these conditions.

Tabel 7. Gastropods BSAF Values

Species	BSAF value	Category
Cerithidea cingulata	0,05	*Deco-concentrator*
Cerithidea obtusa	0,02	*Deco-concentrator*

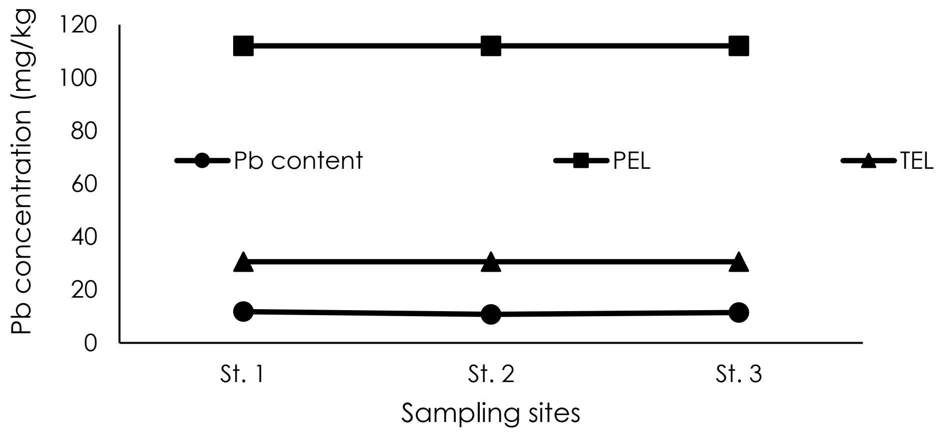

Figure 5. Comparison of Pb concentartions with PEL and TEL values

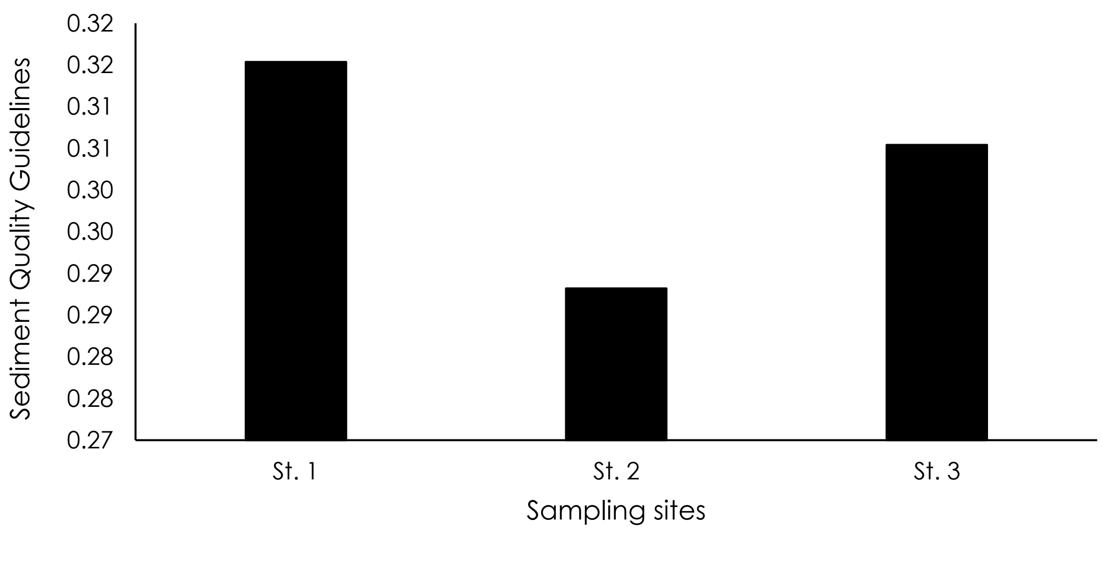

Figure 6. SGQ index for each site

Gastropods were most abundant at Station 1, likely due to its pH of 6.21, which is closest to the optimal level, and its highest mangrove density at 1900 individuals/ha (Haryati *et al*., 2024). The dense mangrove coverage increases organic matter from decomposed litter, boosting gastropod food resources and their overall abundance. Gastropod presence was notably lower at Stations 2 and 3, likely due to reduced organic matter in the substrate. Station 3, with the highest dissolved oxygen (DO) level of 14.90 mg/L, supports this observation, as high DO levels often correlate with lower organic content (Supriyanti *et al*., 2017). Organic matter is essential for benthic organisms like gastropods; thus, areas with more organic material generally support greater gastropod diversity (Dharmawan *et al*., 2016).

In the mangrove area of Mojo village, five gastropod species were identified. *Cerithidea cingulata* and *Cerithidea obtusa* emerged as effective bioindicators for heavy metal contamination. Testing showed these species contained Pb at 0.57 ± 0.05 mg/kg and 0.28 ± 0.06 mg/kg, respectively, and were classified as deco-concentrators, indicating their lower Pb accumulation ability (Table 7). Their effectiveness as bioindicators is due to their sedentary nature, long lifespan, and responsiveness to pollutants. As deposit feeders, they accumulate Pb from sediments through the food chain (Artalina and Takarina, 2018), with higher bioaccumulation compared to crustaceans and fish.

Previous studies also used these gastropods as Pb indicators. The *concentration of Pb in Cerithidea obtusa collected from Malaysia was 0.90–13.4 mg/kg* (Yap and Al-Mutairi, 2023) and *in India Cerithidea cingulata 0.94 ± 0.28* and *Cerithidea obusta 0.89 ± 0.13* (Ranjan *et al*., 2016). *This shows that the Pb concentration values found in Cerithidea obusta and Cerithidea cingulata in the mangroves of Mojo Village are lower than in Malaysia and India. Cerithidea cingulata* and *Cerithidea obtusa* effectively reflect Pb pollution levels. Pb contamination impacts these species by reducing population density (Ranjan *et al*., 2016) and causing morphological changes. Specifically, *Cerithidea cingulata* shows smaller sizes in contaminated areas and *Cerithidea obtusa* exhibits decreased weight and shell dimensions.

The correlation analysis shows a very strong relationship (r = 0.966) between Pb concentrations in sediments and gastropods. Sugiyono (2016) indicates that an r-value between 0.80 and 1.00 signifies a very strong correlation, demonstrating a direct and significant link between Pb levels in sediments and gastropods. This strong correlation likely arises from gastropods absorbing Pb through their diet. Heavy metals accumulate in gastropods via the food chain, with Pb settling in sediments before biota uptake (Priawandiputra *et al*., 2020). The bioaccumulation process involves Pb binding with organic material in sediments and being absorbed into gastropods (Nasution and Siska, 2011). Higher Pb concentrations in sediments result in greater Pb accumulation in gastropods, which can increase toxicity and negatively impact their growth (Ma'arifa *et al*., 2016).

Salinity can be used as a determining factor in the dispersal of mangrove gastropods. Gastropods are adaptable to a wide range of environmental conditions, such as extreme salinities (Ariyanto et al., 2018). The results study showed that the salinity in the Mojo Village Mangrove Area is 29–30 ppt and suitable for gastropod life. High salinity can increase the mobility of Pb in sediment pore water, conversely at low salinity Pb metal will be more easily bound to sediment particles and organic matter. Organic matter in mangrove sediments such as humic acid and fulvate stability can be affected by salinity. High salinity in sediment pore water can increase the bioavailability and toxicity of Pb which increases the risk of Pb adsorption to gastropods.

Cerithidea cingulata and *Cerithidea obtusa* are detritivores that often dig and consume sediment particles while searching for food. Pb metal adsorbed on sediment or dissolved in pore water can enter the digestive system of gastropods through ingestion. After being swallowed, Pb can be absorbed in the intestine and enter the hemolymph, then accumulate in certain tissues such as gills, hepatopancreas, or other soft tissues. If Pb is dissolved in water due to release from sediment or other pollution sources, gastropods can absorb it directly through the gills or body surface. This process generally occurs through passive diffusion or active transport across the gill epithelial cell membrane. After Pb enters the body, gastropods can store this heavy metal in a less toxic complex form, for example by binding it to metallothionein proteins or precipitating it in mineral granules in hepatopancreas cells. Some Pb can also be excreted through excretory glands or the release of epithelial cells containing heavy metals.

CONCLUSION

Human activities around the mangrove shrimp farming area in Desa Mojo, Pemalang, may contribute to Pb contamination in the waters. Pb levels in sediments indicate low contamination and no pollution, but they may still pose biological risks to aquatic organisms. Among the local gastropods, *Cerithidea cingulata* and *Cerithidea obtusa* emerge as key players in this environmental narrative. Their ability to accumulate Pb makes them vital indicators of contamination. The data reveals a strikingly strong correlation between Pb levels in the sediments and the gastropods, suggesting a clear connection between sediment contamination and the bioaccumulation in these species. This relationship underscores the potential for even low levels of Pb to affect the health of the aquatic environment, weaving a complex story of contamination and its impact on local biota. This study provides an overview of Pb concentrations in sediments and gastropods of *Cerithidea cingulata* and *Cerithidea obtusa*, so that it can be used as a basis for policy makers in monitoring environmental health and management of mangrove areas, especially in Mojo Village, Pemalang.

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