

Analysis of lead and cadmium contamination content in meti shells (*Batissa violacea* von Lammarck, 1818) from the La'a River, Petasia Village, Central Sulawesi

*Analisis kandungan cemaran timbal dan kadmium pada kerang meti (*Batissa violacea* von Lammarck, 1818) asal Sungai La'a, Desa Petasia, Sulawesi Tengah*

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ABSTRACT

Background: The meti clam (*Batissa violacea* L. von Lamarck, 1818) is a freshwater bivalve of significant ecological and economic importance, functioning as a natural filter feeder in aquatic ecosystems. However, increasing domestic and anthropogenic activities have contributed to heavy metal contamination in its habitat, posing potential health risks to consumers.

Objective: This study aimed to determine the concentrations of lead (Pb) and cadmium (Cd) in meti clams as a preliminary assessment of environmental quality and food safety in the La'a River.

Methods: A quantitative descriptive design supported by laboratory analysis was employed. Samples were purposively collected from three sites—upstream, residential, and downstream—each consisting of 30 edible clams with a minimum shell length of 4 cm. Following wet digestion, meat and shell samples were analyzed for Pb and Cd using Atomic Absorption Spectrophotometry (AAS).

Result: The highest Pb level in meat was found downstream (0.2495 mg/kg), while the highest Cd level was upstream (0.2133 mg/kg). In shells, the highest Pb and Cd levels were detected in residential areas (34.5528 mg/kg and 3.3753 mg/kg). All metal concentrations in edible tissues were below the BPOM limit (1.0 mg/kg), indicating safety for consumption. However, high accumulation in shells indicates environmental stress.

Conclusion: Meti clams remain safe for consumption, but elevated heavy metals in shells reflect environmental pollution. Continuous monitoring and pollution control are needed, and shells may serve as bioindicators of contamination.

Keywords: *Batissa violacea*, cadmium, clam, heavy metals, lead

ABSTRAK

Kerang meti (*Batissa violacea* L. Von Lamarck, 1818) adalah biota air tawar yang sangat penting bagi masyarakat secara ekonomi dan secara ekologis sebagai filter feeder. Namun, aktivitas domestik dan pencemaran antropogenik menyebabkan pencemaran logam berat di habitat perairan tempat hidupnya, yang mengancam kesehatan konsumen. Oleh karena itu, penelitian ini sangat penting untuk mengetahui tingkat cemaran logam berat pada kerang meti, terutama timbal (Pb) dan kadmium (Cd). Hal ini dilakukan sebagai langkah awal untuk memantau kualitas lingkungan perairan dan keamanan pangan. Desain deskriptif kuantitatif dengan analisis laboratorium digunakan dalam penelitian ini. Metode *purposive sampling* digunakan untuk mengumpulkan sampel kerang meti dari tiga lokasi berbeda di Sungai La'a: hulu, pemukiman, dan hilir. Sebanyak 30 ekor kerang meti konsumsi diambil dari tiap lokasi, dengan panjang cangkang minimal 4 cm. Setelah proses destruksi basah, bagian daging dan cangkang

dipisahkan untuk kemudian diuji kandungan Pb dan Cd menggunakan Spektrofotometri Serapan Atom (SSA) sesuai dengan SNI 01-2974-1992. Hasil penelitian menunjukkan bahwa konsentrasi Pb tertinggi pada kerang ditemukan di hilir sungai (0,2495 mg/kg), sedangkan konsentrasi Cd tertinggi ditemukan di hulu sungai (0,2133 mg/kg). Dalam cangkang, konsentrasi Pb dan Cd tertinggi juga ditemukan dalam jumlah yang bervariasi, mulai dari 34,5528 mg/kg (di permukiman) hingga 3,3753 mg/kg (di permukiman). Semua logam berat dalam daging kerang terletak di bawah batas jumlah maksimum yang ditetapkan oleh BPOM (1,0 mg/kg), sedangkan logam dalam cangkang berada di bawah jumlah batas yang disebutkan di atas. Parameter Pb dan Cd pada daging kernel meti Sungai La'a menunjukkan bahwa masih dapat dikonsumsi, tetapi akumulasi logam berat pada cangkang menunjukkan bahwa ada tekanan pada lingkungan perairan. Untuk memastikan keamanan konsumsi jangka panjang, diperlukan pengawasan rutin kualitas air Sungai La'a dan pengendalian sumber pencemar, terutama di daerah permukiman. Selain itu, penggunaan kerang meti sebagai bioindikator logam berat harus dipertimbangkan dalam program pengawasan kualitas perairan.

Kata kunci: *Batissa violacea*, Kadmium, Kerang, Logam Berat, Timbal (Pb)

INTRODUCTION

Heavy metal pollution in coastal areas is a crucial issue because these substances can accumulate in organisms' tissues and move through the food chain.¹ Metals such as lead (Pb), cadmium (Cd), and mercury (Hg) originate from various human activities, such as vehicle emissions, industry, mining, and domestic waste disposal, which are ultimately carried to coastal areas through surface water flow.²

Batissa violacea L. von Lammarck, 1818 (meti clam), which is often found in the waters of the La'a River, Tompira Village, North Morowali Regency, Central Sulawesi, is a good bioindicator because of its ability to accumulate heavy metals in its body tissue.³ As a filter feeder, this clam uses its gills to filter water and consume food. This filtering mechanism allows the clam to capture organisms, organic debris, and other suspended particles found in the air.⁴ As a result, the mussel also can absorb and ingest hazardous substances, such as lead (Pb), found in particles or in the air. The sedentary nature of the mussel, which settles on the substrate, makes it directly exposed to the conditions of the waters in which it lives, as contaminants are easily recorded in its body tissue. As a result, the mussel serves not only as a source of animal protein for the community but also as a good bioindicator for tracking levels of heavy metal pollution in freshwater.⁵ Globally, various shellfish species such as *Mytilus* and *Perna viridis* have been identified as effective bioindicators of heavy metal pollution, especially Pb, Cd, and Hg.⁶

Apart from being an environmental indicator, mussels also have economic and nutritional value, with protein content ($\pm 13\%$), fat ($\pm 10\%$), and carbohydrates ($\pm 5\%$), as well as bioactive compounds such as peptides and chitosan, which have antimicrobial and antioxidant properties.^{3,7,8} Agricultural and industrial activities around the La'a River have the potential to increase the risk of pollution and indirectly impact the quality of shellfish consumed by the community. Recent research also highlights the importance of determining Cd levels in bivalves as an indicator of pollution and a basis for evaluating food safety risks, particularly for species routinely consumed by coastal communities.⁹

Consumption of bivalves contaminated with heavy metals such as Cd and Pb can trigger toxic effects on the kidneys, central nervous system, and other vital organs, especially if consumed continuously.⁴ In addition, according to the Food and Drug Monitoring Agency (BPOM), the maximum limit for heavy metal contamination in fresh

seafood is 1.0 mg/kg for Pb and Cd.¹⁰ Heavy metals such as lead (Pb), cadmium (Cd), and mercury (Hg) in water can disrupt the food chain, reduce biodiversity, inhibit the reproduction of aquatic organisms, and make water and sediment less clean. Heavy metals can accumulate over time and disrupt the balance of the ecosystem. Heavy metals can also be harmful to higher organisms, including humans.^{11,12}

Tompira Village is one of the villages in Petasia Timur District, North Morowali Regency, which is crossed by the La'a River—the longest river in the regency with a length of around 96.3 km and a River Basin Area (DAS) of 2,875.63 km².^{13,14} Besides serving as a primary water source, this river also serves as an economic pillar for the surrounding community. The residents of Tompira Village are primarily farmers and fishermen, utilizing the river's resources, such as catching shellfish and shrimp, both for household consumption and to sell for additional income.¹⁵

The Petasia Timur District, based on the 2021–2026 Regional Medium-Term Development Plan (RPJMD) of North Morowali Regency, has been designated as a large-scale industrial area based on mining raw materials. In addition to Petasia Timur, Petasia and Petasia Barat districts are also included in this industrial area.¹⁴ Based on public data from <https://momi.minerba.esdm.go.id/public>

It is known that the administrative area of Tompira Village has been controlled by a number of Mining Business Permits (IUP) for nickel and sand commodities, both those that are already operational and those that are still in the development stage. Along the La'a River, there are four sand and gravel IUPs with a total area of 131.74 hectares, most of which are used to meet the material needs of the ongoing nickel refining smelter infrastructure development. In addition, in the administrative area of Tompira Village there are also three active nickel IUPs with a total area of 7,931 hectares.^{15,16}

The presence of large-scale mining activities around the La'a watershed has the potential to increase pollution loads, including heavy metals such as lead (Pb) and cadmium (Cd), which can accumulate in biotic and abiotic components of the water. However, to date, no scientific studies have specifically examined the levels of these heavy metals in the mussel species from the La'a River. Most previous research in the Morowali region has focused on analyzing heavy metals in water, sediment, or marine biota, rather than in freshwater biota consumed by the community.^{17,18}

Sampling for this study was conducted in September 2024, coinciding with the period when water quality monitoring data for the La'a River were not yet available on the Ministry of Environment and Forestry's (KLHK) Online Water Quality Monitoring (ONLIMO) system. This lack of data indicates limited temporal monitoring in the La'a River area, despite the installation of automated monitoring systems at two stations, Moleono Village and North Morowali 1. Based on ONLIMO data from January–October 2025, water quality for the La'a River varied between light and heavy pollution categories, with a tendency toward moderate pollution in most months. Therefore, sampling in September 2024 was crucial to fill the data gap and provide an initial overview of water quality conditions and potential heavy metal contamination before the next online monitoring period.¹⁹

Therefore, this study was conducted to analyze the levels of heavy metals Pb and Cd in the tissues and shells of mussels from several points in the La'a River as an initial effort to describe the condition of the quality of the water environment in the North Morowali mining industrial area, precisely along the waters of the La'a River, Petasia village.

METHODS

Study design

This research was conducted from September to December 2024. The research consisted of four stages: meti shellfish sampling, sample preparation, heavy metal content analysis, and data analysis. The study used a case study method with purposive sampling locations.

Meti clam sampling was conducted at three locations in the La'a River, Tompira Village, Petasia Timur District, North Morowali Regency, Central Sulawesi. The three locations are: (1) upstream ($2^{\circ}3'29.48''$ S; $121^{\circ}22'8.24''$ E), (2) residential areas around the La'a River ($2^{\circ}4'32.74''$ S; $121^{\circ}23'18.15''$ E), and (3) downstream ($2^{\circ}1'36.79''$ S; $121^{\circ}28'57.71''$ E). The La'a River is the longest river in North Morowali Regency, with a length of ± 96.3 km and a river basin area (DAS) of ± 2875.60 km².

The selection of the three locations was based on interviews with local fishermen, who noted the abundant availability of Petasia village mussels in the area, as well as considerations of their representation of the river ecosystem from upstream to downstream. The study locations are shown in Figure 1.

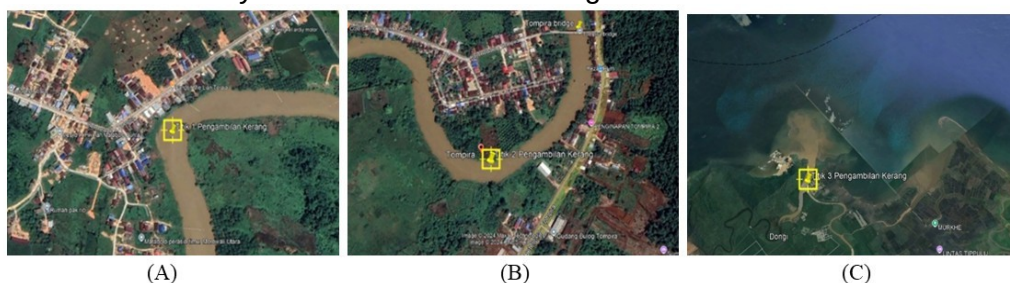


Figure 1. Location of Meti Clam Sampling in the La'a River, Tompira Village: (A) Upstream; (B) Community Settlement; (C) Downstream

Data source and sampling procedure

Samples used in this study were mussels (*Batissa violacea* (Lamarck, 1818)). At each sampling location, mussels were hand-collected and placed into 3.2 L glass jars. The jars were filled with river water and natural sand from the same location to ensure the mussels could feed during storage and maintain their habitat. The mussels used at each sampling location were randomly selected with a weight of 4–7 grams and a shell length of 5–6 cm. Ten mussels were taken from each sampling location. The selected mussels were then cleaned using water from their natural habitat, washed thoroughly, and the meat was separated from the shell.^{3,8,20} The meat and shell samples were then stored in clean, closed containers until the destruction stage was carried out.

Variables of the study

The variables in this study consisted of heavy metal concentrations of lead (Pb) and cadmium (Cd) in mussel meat and shell samples from different sampling locations (upstream, residential, and downstream areas).

Measurement and instruments

The chemicals used included HNO₃ 65% (Merck), HCl 6 N (Merck), HNO₃ 0.5 N (Merck), HClO₄ 60% (Merck), lead (Pb) master standard solution 1000 mg/L (Certipur), cadmium (Cd) master standard solution 1000 mg/L (Certipur), and milli-Q distilled water. The equipment used included an atomic absorption spectrophotometer (AAS) (Perkin Elmer Analyst 400), an analytical balance (Almega), and laboratory glassware (Iwaki Pyrex). The atomic absorption spectrophotometer was validated using standard solutions, with a coefficient of determination (R^2) > 0.99 for the entire calibration curve, referring to the SNI 01-2974-1992 protocol.^{11,12}

Data collection

This method used two destruction methods, namely dry destruction for meti clam meat samples and wet destruction for meti clam shell samples. Dry digestion was carried out by weighing 20 grams of shellfish meat, then placing it in a porcelain cup and adding 2 mL of HNO₃65%. The mixture was heated gradually on an electric bath until charcoal formed, then dried in a furnace at 500°C for 18 hours. The ash was dissolved in 5 mL of 6 N HCl and reheated until completely dissolved. The resulting solution was diluted with HNO₃0.5 N until it reached a volume of 25 mL, then filtered with Whatman No. 42 filter paper^{21,22}. Wet destruction was carried out by weighing 10 grams of shell samples, which were put into a beaker, then adding 50 mL of water, 10 mL of HNO₃65%, and 6 mL HClO₄60%. The mixture was heated until its volume was reduced to ±10 mL, cooled, then transferred to a 50 mL volumetric flask and diluted with milli-Q distilled water to the mark. The solution was homogenized and filtered before analysis.^{21,23}

Analysis of Heavy Metal Content

The analysis of metal content began with the preparation of standard curves for Pb and Cd solutions. The standard curves were prepared through a multistep dilution process from a stock solution of 1000 mg/L to 100 mg/L, then diluted again to 10 mg/L. From the 10 mg/L solution, a series of standards was prepared with concentrations of 0.2; 0.4; 0.8; 1.6; and 3.2 mg/L for Pb, and 0.2; 0.4; 0.6; 0.8; and 1.0 mg/L for Cd. The absorbance of each standard solution was then measured using an atomic absorption spectrophotometer (AAS) at a wavelength of 217 nm for Pb and 228.8 nm for Cd.²²

The atomic absorption spectrophotometer was validated using standard solutions, with a coefficient of determination (R^2) > 0.99 for the entire calibration curve, referring to the SNI 01-2974-1992 protocol.¹²

After the calibration process, the heavy metal content of Pb and Cd in the shell and meat samples of the mussels was analyzed. The filtrate from the digestion process was used for Pb and Cd analysis. Concentrations were determined based on the regression equation of the standard calibration curve, as follows:^{6,22}

$$Kadar \left(\frac{mg}{kg} \right) = \frac{D - E \times Fp \times V}{w}$$

Information:

D: concentration of sample reading result in SSA (mg/L)

E: blank concentration of reading results in SSA (mg/L)

Fp: Dilution factor

V: Final volume (ml)

W: sample weight (g)

Ethical considerations

State the ethical approval obtained from the relevant ethics committee or institutional review board. Mention the approval number and describe how informed consent and participant confidentiality were maintained (Arial 11, space 1, Justify).

Data analysis

Data analysis was conducted using descriptive methods. The obtained heavy metal data were compared to quality standards referred to in the Food and Drug Monitoring Agency Regulation Number 9 of 2022 concerning Requirements for Heavy Metal Contamination in Processed Foods.²⁴ The resulting data, in the form of Pb and Cd levels from the shells and meat of the mussels, were statistically processed using one-way ANOVA. This analysis was used in this study to determine whether there were statistically significant differences between heavy metal concentrations at all sampling locations. Tukey's test was also performed to examine significant comparisons between each heavy metal.²⁵

RESULTS

Lead (Pb) and Cadmium (Cd) Calibration Curve

A calibration curve is constructed based on the absorbance values of standard solutions measured using an atomic absorption spectrophotometer (AAS). For lead (Pb), the concentration range is 0.2 to 3.2 mg/L. showed a linear relationship with absorbance values between 0.0018 and 0.1457 (Table 1). Meanwhile, for cadmium (Cd), the concentration series of 0.2 to 1.0 mg/L gave absorbance values between 0.0531 and 0.2804 (Table 2).

Table 1. Absorbance of Standard Series of Pb Metal

Sample	Concentration (mg/L)	Absorbance
Blank	0	0.0000
Std 1	0.2	0.0018
Std 2	0.4	0.0089
Std 3	0.8	0.0317
Std 4	1.6	0.0714
Std 5	3.2	0.1457

Table 2. Absorbance of the Standard Series of Cd Metal

Sample	Concentration (mg/L)	Absorbance
Blank	0	0.0000
Std 1	0.2	0.0531
Std 2	0.4	0.1226
Std 3	0.6	0.1785
Std 4	0.8	0.2332
Std 5	1.0	0.2804

From the measurement results, the Pb calibration curve regression equation was obtained: $y = 0.04723x - 0.00554$ ($R^2 = 0.9982$) and Cd: $y = 0.28547x + 0.00191$ ($R^2 = 0.9985$)

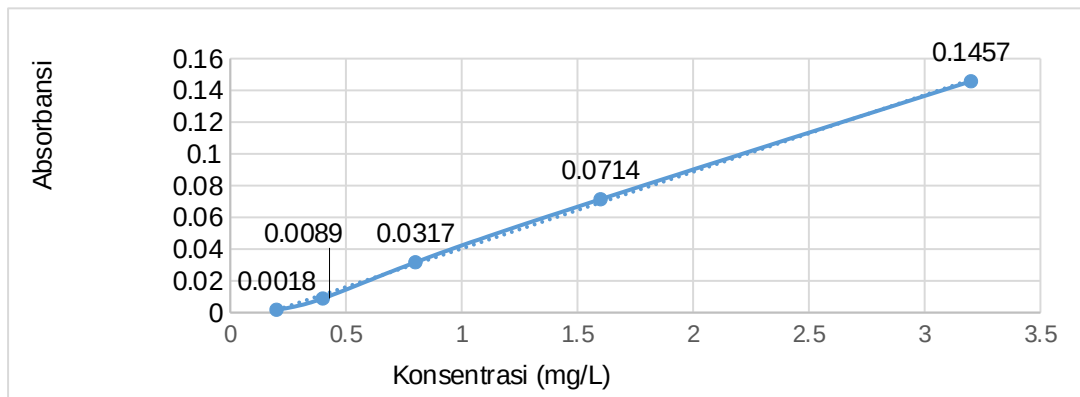


Figure 2. Pb Standard Calibration Curve

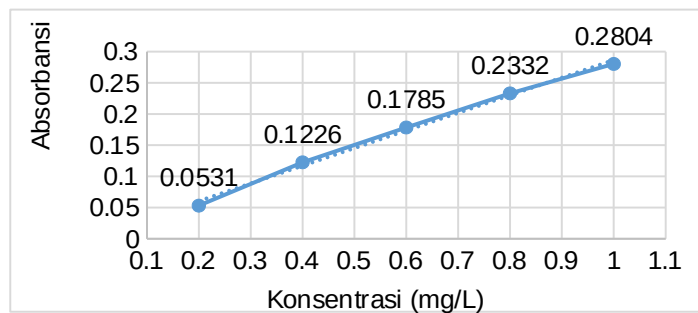


Figure 3. Cd Standard Calibration Curve

Both coefficient of determination (R^2) values indicate that the relationship between concentration and absorbance is very strong and valid according to the Lambert-Beer Law principle. This proves that the AAS method used in this study is feasible and accurate for quantitative analysis of heavy metals in shellfish samples.¹⁴

Heavy Metal Concentrations in the Meat and Shells of Meti Clams

The analysis results of lead (Pb) and cadmium (Cd) levels in mussel meat showed variations between sampling locations. The highest Pb concentration was found at the downstream location (0.2495 mg/kg), followed by the upstream location (0.1216 mg/kg) and residential areas (0.0462 mg/kg). For Cd, the highest levels were recorded at the upstream location (0.2133 mg/kg), followed by residential areas (0.2041 mg/kg) and downstream (0.1866 mg/kg). All values were still below the maximum limit for heavy metal contamination for fresh food according to the Indonesian Food and Drug Authority (BPOM), which is 1.0 mg/kg for Pb and Cd.¹⁵

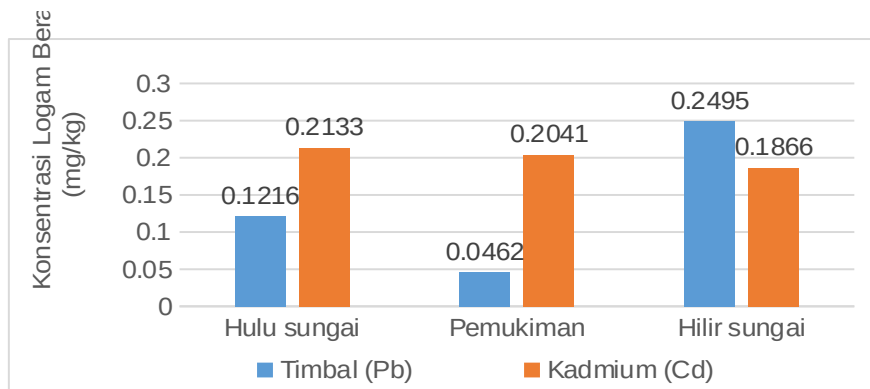


Figure 4. Concentration of Pb and Cd metals in Meti clam meat

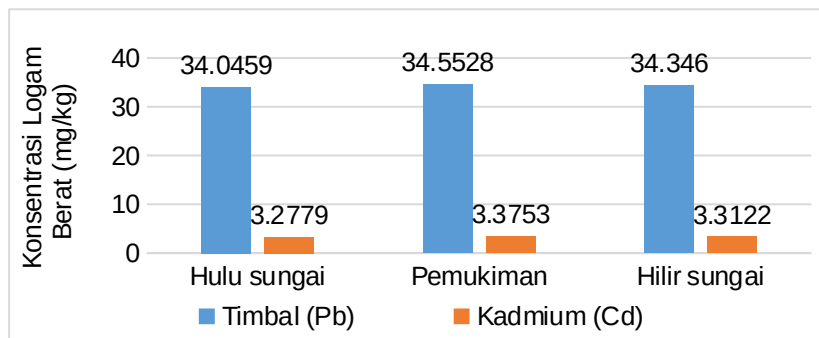


Figure 5. Concentration of Pb and Cd metals in Meti oyster shells

Meanwhile, heavy metal levels in shellfish were much higher. Average Pb concentrations ranged from 34.0459–34.5528 mg/kg, while Cd concentrations ranged from 3.2779–3.3753 mg/kg, indicating that the shells have a greater capacity to accumulate metals than soft tissues (Figure 5).

Statistical Analysis

Three sets of data on Pb and Cd metal concentrations in the meat and shells of mussels were collected, with three replicates at each sampling location. To determine whether there were differences in metal concentrations between locations, a statistical analysis was performed using a one-way ANOVA test.^{25,26} The results showed that there were significant differences ($p < 0.05$) in the levels of Pb ($p = 0.000$) and Cd ($p = 0.043$) in mussel meat between sampling locations. In contrast, the results of tests on mussel shells showed no significant differences ($p > 0.05$), either for Pb ($p = 0.415$) or Cd ($p = 0.142$).

Statistical analysis results show that variations in metal concentrations in mussel shells across locations are insignificant. This is because mussel shells are naturally an indicator of long-term heavy metal accumulation. The calcium carbonate (CaCO_3) matrix). In shellfish, the proteins will slowly bind metals as the organism grows. This means that changes in pollution levels that occur over a short period of time or in a particular area are not immediately visible in the metal concentrations in shellfish.^{27,28} Several studies have shown that metal concentrations in soft tissues are usually significantly increased compared to shellfish, because soft tissues are more directly exposed to water, food, and soil containing metals (such as Pb and Cd)^{6,29,30} The metal content in shells also tends to be evenly distributed throughout the shell's development,

making it difficult to see differences between locations (the differences between locations are very small).^{27,28,31}

DISCUSSION

Variations in heavy metal levels in mussel meat indicate a significant influence of local environmental conditions. Statistical tests showed that Pb and Cd concentrations in meat tissue varied significantly between locations, indicating variations in pollution along the La'a River. In contrast, metal levels in the shells showed no significant differences, indicating that this section reflects a more uniform, long-term accumulation.

The accumulation of heavy metals in mussels reflects the environmental conditions of the waters along the La'a River, where differences in Pb and Cd levels at each location are closely related to the intensity of human activity. Although this study did not assess the age of individual mussels because the samples came from natural populations, heavy metal accumulation can still be explained by their biological characteristics as benthic organisms and filter feeders that filter suspended particles and organic matter from the water. The results showed that the lowest Pb and Cd levels in shells were found in the upper reaches of the river, at 34.0459 mg/kg and 3.2779 mg/kg, respectively, which is thought to be due to the location being relatively far from direct sources of pollution such as domestic, industrial, and agricultural waste.³² In residential areas, Pb levels increased to 34.5528 mg/kg and Cd to 3.3753 mg/kg, in line with increased household activities, untreated wastewater disposal, and small industrial activities around the river.³³ Meanwhile, downstream, Pb and Cd levels decreased slightly to 34.3460 mg/kg and 3.3122 mg/kg, respectively, which was likely due to natural dilution and mixing of freshwater and seawater, but still showed accumulation due to sedimentation and slowing water flow.³⁴ The difference between heavy metal levels in meat and shells strengthens the ecological interpretation that soft tissues reflect short-term metal exposure related to metabolic activity and current pollution conditions, while shells serve as indicators of long-term accumulation through ionic substitution processes in the calcium carbonate matrix.^{35,36} Thus, although heavy metal levels in the tissues are still below the threshold set by the BPOM, accumulation in the shells indicates the presence of chronic pollution pressure in the waters of the La'a River that requires vigilance through continuous environmental monitoring.

As filter-feeding organisms, mussels actively absorb suspended particles and dissolved substances, including heavy metals, from the aquatic environment in which they live.³⁷⁻³⁹ This active bioaccumulation process causes metal levels in shellfish meat to be more sensitive to fluctuations in pollution at each location.^{21,23} Studies in the Persian Gulf also show patterns of metal accumulation in the soft tissues of bivalves that reflect environmental exposure to oil- and petrochemical-related industrial waste, although without strong statistical differences between locations.⁴⁰

In contrast, shells accumulate metals through a passive adsorption mechanism. The calcium carbonate (CaCO_3) in the shell acts as an absorber of heavy metals through ionic bonds and chemical precipitation.^{39,40} Research states that the inner and outer surfaces of the shell are able to bind Cd and other metals stably, reinforced by natural organic compounds in the shell structure.⁴³ Other studies also confirm that CaCO_3 is very effective in binding Pb through ion exchange reactions and forming insoluble carbonate compounds.⁴⁴ This explains why metal levels in shells tend to be high but the concentrations are similar across locations.

Comparison with research in other regions strengthens the validity of these findings. A study in the Teunom River, Aceh, showed that Hg levels in *Batissa violacea* reached 0.35 mg/kg, although this value is still below the consumption threshold.⁴⁵ In the Calang area,

Pb and Cd levels were found in shellfish that exceeded the SNI threshold, allegedly due to intensive industrial and agricultural activities.²³ These results indicate that heavy metal contamination in shellfish is local in nature and is strongly influenced by the anthropogenic conditions of each region.

The impacts of heavy metal accumulation in shellfish are not only important from an ecological perspective, but also from a public health perspective. Chronic exposure to lead (Pb) has been linked to kidney damage, reduced IQ in children, central nervous system disorders, and reproductive disorders.⁴⁶ Cadmium (Cd), even in small doses, can cause liver damage, bone disorders, and increase the risk of cancer and other degenerative diseases.³⁸ Studies note that heavy metals accumulated through the food chain are a major source of chronic contamination, especially in communities that are highly dependent on aquatic resources.⁴⁷

In terms of regulations, the heavy metal thresholds according to Codex Alimentarius and WHO are stricter than the Indonesian national standards. Codex sets a maximum limit of 0.5 mg/kg for Pb and 0.3 mg/kg for Cd, while the Indonesian Food and Drug Authority (BPOM) sets a threshold of 1.0 mg/kg for both.^{24,46} Therefore, although metal levels in mussel meat from the La'a River are still within national limits, they are approaching international thresholds, particularly for Cd in upstream locations. This serves as an early warning of potential risks if pollution increases.

With these findings, mussels not only serve as a food source but also as a bioindicator of aquatic environments. The varying concentrations of heavy metals in mussel meat can serve as a basis for evaluating ecosystem quality and the effectiveness of waste management in coastal areas. Therefore, it is crucial to conduct regular monitoring and supervision of anthropogenic activities around rivers by the North Morowali Regency Environmental Agency (DLH) in collaboration with universities or accredited laboratories, as well as educate the public about the risks of overconsumption of potentially polluted aquatic biota. This aligns with the guidelines set out in the FAO/WHO Code of Practice for Fish and Fishery Products, which emphasizes the importance of implementing hygiene and monitoring heavy metal contaminants in fishery products to ensure food safety.⁴⁹

This study excels in its analytical approach, comparing heavy metal accumulation in two body parts of the mussel: the soft tissue and the shell. This approach allows for a more comprehensive understanding of heavy metal bioaccumulation behavior in aquatic organisms. Furthermore, sampling at three locations with different environmental characteristics provides a snapshot of the spatial distribution of pollution, making the results relevant for detecting variations in contamination levels.

However, this study has several limitations. One is the limited time span of sampling, which was limited to a single period, thus not fully depicting the temporal dynamics of pollution. In studies of aquatic environmental quality, including heavy metal monitoring, it is recommended to have at least three sampling periods, namely the dry season, transition season, and rainy season.^{48,49} Furthermore, this study only focused on two types of heavy metals, namely Pb and Cd, whereas in reality, waters can be contaminated by various other types of metals.

CONCLUSION

This study shows that the meti clam (*Batissa violacea*) from the La'a River in Petasia village has been exposed to heavy metals lead (Pb) and cadmium (Cd) with varying concentrations between locations. The metal content in the meat tissue is still below the safe consumption threshold according to the BPOM (1.0 mg/kg), while the levels in the shell are higher and reflect long-term accumulation. Differences in metal levels between locations are significant in the meat, but not in the shell, indicating that the meat is more

reflective of active pollution conditions, while the shell acts as a stable accumulation medium. These results confirm the potential of *B. violacea* as a bioindicator of heavy metal pollution in the La'a River and serve as an important basis for environmental monitoring, industrial waste management, and public education regarding health risks from heavy metal exposure.

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