

DETERMINATION OF HEAVY METAL CONTENTS IN *Lanceolaria* sp. IN THE CAU RIVER IN NORTHERN VIETNAM

Bui Thi Thu^{1,*}, Nguyen Bich Ngoc¹, Trinh Kim Yen¹

¹*Faculty of Environmental, Hanoi University of Natural Resources and Environment*

*Email: btthu.mt@hunre.edu.vn

ABSTRACT

Heavy metal contamination in aquatic ecosystems poses a significant threat to both environmental health and human populations due to the persistent and toxic nature of these pollutants. This study focuses on the bioaccumulation of heavy metals (Zn, Cu, Pb, Cr, Cd) in *Lanceolaria* sp., a benthic invertebrate and examines the correlation between metal concentrations in the organism and sediments from the Cau River basin in Northern Vietnam. Sampling was conducted at 28 locations along the Cau River. The results indicate that metal accumulation in *Lanceolaria* sp. follows the order Zn > Cu > Pb > Cr > Cd, with average concentrations of 52.932, 19.343, 18.496, 7.549, 4.536 mg/kg dry weight, respectively. Chromium levels exceeded the Hong Kong standard at 10 of the 28 monitoring sites. Strong positive correlations were identified between sediment and organism concentrations for Cu, Pb, Zn and Cd ($r = 0.40$, $p < 0.05$). These findings highlight the potential of *Lanceolaria* sp. as an effective bioindicator for assessing heavy metal pollution in freshwater ecosystems.

Keywords: Accumulation, Cau River, heavy metals, *Lanceolaria* sp., sediments.

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1. INTRODUCTION

Heavy metal pollution in aquatic environments is a growing concern worldwide due to its toxic effects on ecosystems and human health. These metals are persistent in the environment and can accumulate in sediments, leading to long-term contamination of river systems. Moreover, heavy metals can bioaccumulate in aquatic organisms, particularly in benthic species, which are in close contact with sediments. As these metals move through the food chain, they pose a threat to higher organisms, including humans, who consume contaminated fish and mollusks [1, 2, 3]. The potential for bioaccumulation and biomagnification makes the study of heavy metal contamination in river ecosystems a critical area of research, particularly in regions undergoing rapid industrialization like the Cau River basin.

The Cau River basin, one of the most extensive and industrially active regions in

Northern Vietnam, plays a critical role in the socio-economic development of the area. Stretching 288.5 kilometers from its source in Cho Don district, Bac Kan province, the river flows through densely populated provinces such as Thai Nguyen, Bac Giang, Bac Ninh and Hai Duong before merging with the Thai Binh River [4]. This region has seen rapid industrialization, including mining, metallurgy, electroplating, plastic manufacturing, and detergent production. These industries, while contributing to economic growth, have also led to significant environmental challenges, particularly the release of hazardous heavy metals such as copper (Cu), lead (Pb), zinc (Zn), cadmium (Cd), and chromium (Cr) into the river system.

Despite the recognition of heavy metal pollution as a serious environmental issue, there remain significant gaps in knowledge about the extent of contamination in the Cau River, particularly in the sediment and benthic species

that serve as bioindicators of pollution. While various studies have investigated the levels of water-soluble metals in the Cau River, few have focused on the accumulation of metals in benthic organisms, which can provide a more accurate assessment of long - term pollution levels. Sediments act as both a sink and a source of heavy metals, making it essential to understand how these metals accumulate in organisms that live in or near sediments, such as *Lanceolaria* sp., a commonly found bivalve in the Cau River system.

Given the critical role that benthic organisms play in aquatic ecosystems and their potential use as bioindicators [5], this study focuses on determining the concentrations of key heavy metals (Cu, Pb, Zn, Cd and Cr) in the tissues of *Lanceolaria* sp. and assessing the correlation between these concentrations and metal levels in river sediments. The findings of this study will help identify the extent of heavy metal contamination in the Cau River and evaluate the suitability of *Lanceolaria* sp. as a bioindicator species for monitoring pollution.

Previous research has shown that benthic organisms are effective at reflecting the level of heavy metal pollution in their habitats. Studies conducted by Bui Thi Thu *et al.* (2018) [6] and others have demonstrated strong correlations between metal concentrations in sediments and in benthic species, particularly for metals like Cu and Zn. However, the bioaccumulation of other metals, such as Pb and Cd, has been more variable, with some species showing inconsistent accumulation patterns. This variability may be due to differences in the bioavailability of these metals, which is influenced by factors such as pH, redox potential, and organic matter content in sediments.

Despite the progress made in understanding heavy metal accumulation in aquatic ecosystems, there is still a need for more comprehensive studies that link metal concentrations in sediments with bioaccumulation in benthic organisms across different environmental conditions [7]. The current study aims to address this gap by examining the relationship between sediment metal concentrations and bioaccumulation in

Lanceolaria sp., providing valuable data on the environmental health of the Cau River. This research not only contributes to the scientific understanding of heavy metal pollution in riverine ecosystems but also has practical implications for environmental monitoring and management.

2. MATERIALS AND METHODS

2.1. Research subjects

Study objects: Heavy metals: Cu, Pb, Zn, Cd and Cr in *Lanceolaria* sp. were collected along the Cau River.

First sample collection time: May 2019; supplementary assessment sample collection time: May 2022.

2.2. Study area

Lanceolaria sp. were collected along the Cau River, which flows through five provinces in Northern Vietnam: Bac Kan, Thai Nguyen, Bac Giang, Bac Ninh and Hai Duong.

2.3. Methodology

Sediment and benthic samples were collected using specialized sampling equipment. An Ekman bucket (USA manufacturer) was employed, with a sampling area measures 20 cm x 20 cm x 20 cm. The materials used included stainless steel and a polyester sampling cord.

Samples were collected from 28 distinct locations along the Cau River, which flows through the Northern Vietnamese provinces of Bac Kan, Thai Nguyen, Bac Giang, Bac Ninh and Hai Duong. At each location, one sediment sample was taken either from the middle of the river or near the river bank (where the river serves as a provincial boundary), alongside one *Lanceolaria* sp. sample. These samples were composite, consisting of material collected from the surface to a depth of approximately 0 - 20 cm. At each site, three large samples were taken, with each large sample comprising three smaller samples spaced 1 meter apart, which were then combined to form a representative composite sample. The large samples were spaced 2 - 3 meters apart, following the isosceles triangle method. The representative composite sample

was then obtained by mixing the three large samples [8, 9, 10].

After collection, sample was sealed in zip bag, refrigerated and transported to the laboratory. All

samples were handled and preserved in accordance with ISO 5667-15:1999 [11]. Figure 1 illustrates the sampling locations.

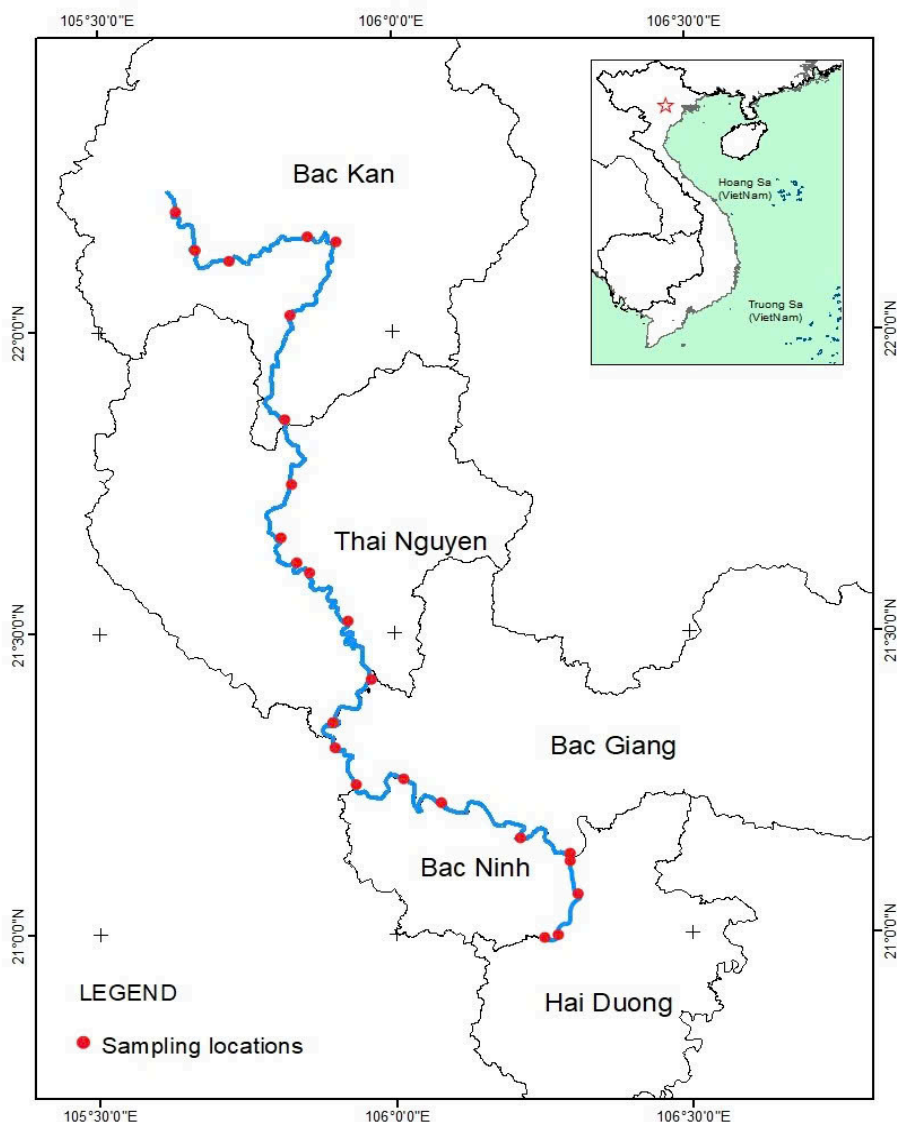


Figure 1. Location of Cau River sediment sampling

Through surveys and sampling, no *Lanceolaria* sp. samples were obtained from the sediment of Cau river in Bac Kan province.

Sediment samples were treated for heavy metal analysis following the US EPA (1996) [12]. The samples were air - dried at room temperature, then ground and sieved through a 0.2 mm mesh. A 1.0 gram portion of dry sediment was digested

using 10 mL HNO_3 and 5 mL H_2O_2 30% at 95°C. The heavy metal content in the sediment was calculated using the following formula:

$$X = \frac{C_m \cdot V_s}{m} \cdot K \text{ (mg/kg dry sediment)}$$

In which: X: heavy metals contents (mg/kg dry sediment); C_m : heavy metals concentraion measured on AAS (mg/L); V_s : sample colume (V_s

= 50 mL); m: sample weight (g); K: dry coefficient of sediment.

The *Lanceolaria* sp. samples were kept at refrigerator at 4°C. After species identification, the intestines were removed, weighed and freeze-dried at the Hanoi University of Science and Technology. Wet samples were digested using HNO₃, concentrated HClO₄ and H₂O₂ at 90°C until fully decomposed.

Heavy metal concentrations in both sediment and *Lanceolaria* sp. samples were quantified using a Thermo Fisher M6 AAS at the Environment Laboratory, Hanoi University of Natural Resources and Environment (Vilas 955). For *Lanceolaria* sp., the metal content was calculated as formula:

$$X_k = \frac{C_m \cdot V_s}{m} \text{ (mg/kg dry organism)}$$

Where: X_k : heavy metals content (mg/kg); C_m : metal concentration measured via AAS (mg/L); V_s : volume of the sample solution (mL); m: sample weight (g).

For fresh weight, the conversion was calculated as: $X_t = \frac{X_k}{k}$ (mg/kg fresh organism).

The sediments metals content was compared with Vietnamese standards QCVN

43:2017/BTNMT [13], Canadian Council of Ministers of the Environment (2002) [14] and US EPA (1997) [15].

Heavy metal levels in benthic organisms were compared with QCVN 8-2:2011/BYT [16] for Cd and Pb, and with the Hong Kong Metallic Contamination Regulations for Cr [17, 18].

Data on the correlation between heavy metal content (Cu, Pb, Zn, Cd and Cr) in the *Lanceolaria* sp. samples and in Cau River sediments were analyzed using Origin 9.0 software. Statistical analysis, including ANOVA and least significant difference (LSD) tests, was conducted with a significance level of $\alpha = 0.05$ [19].

3. RESULTS AND DISCUSSION

3.1. Heavy Metal Accumulation in *Lanceolaria* sp.

The concentrations of heavy metals (Zn, Cu, Pb, Cr and Cd) in *Lanceolaria* sp., a species of bivalve, were measured across multiple locations along the Cau River. The research revealed varying levels of metal accumulation, highlighting the species' role as a potential bioindicator of environmental contamination. Table 1 summarizes these concentrations, showing that the metal content in *Lanceolaria* sp. followed the order Zn > Cu > Pb > Cr > Cd.

Table 1. Results of determining the concentration of Cu, Pb, Zn, Cd and Cr in *Corbicula* sp. samples living in Cau River sediment

Place of observation	Heavy metal content in <i>Lanceolaria</i> sp. (mg/kg fresh organisms)				
	Cu	Pb	Zn	Cd	Cr
Thai Nguyen	2.822 ± 0.927	2.198 ± 0.714	9.620 ± 1.306	1.056 ± 0.211	0.029 ± 0.209
Bac Giang	2.451 ± 0.352	2.556 ± 0.667	6.393 ± 1.290	0.364 ± 0.142	1.032 ± 0.150
Bac Ninh	2.250 ± 0.635	2.431 ± 0.597	6.226 ± 1.826	0.526 ± 0.153	1.012 ± 0.170
Hai Duong	2.590 ± 0.549	2.196 ± 0.20	4.562 ± 0.511	0.419 ± 0.050	0.835 ± 0.108
QCVN 8-2:2011/BYT	-	1.5		2.0	

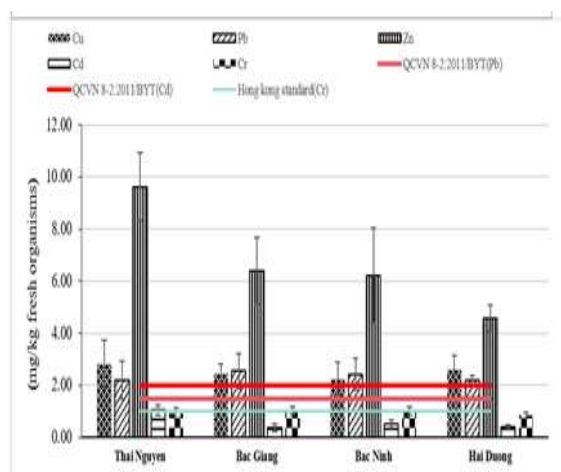


Figure 2. Heavy metals content graph of *Lanceolaria* sp. of Cau River

The findings indicate that the metal content in *Lanceolaria* sp. follows the decreasing order of Zn > Cu > Pb > Cr > Cd. This hierarchy reflects a prevalent trend in benthic organisms, where Zn levels were highest among the metals tested, ranging from 10.986 to 27.270 mg/kg of dry organisms. Zn plays an essential role in biological processes; however, its excessive presence in aquatic systems can disrupt metabolic activities in organisms. Elevated Zn concentrations were particularly prominent at monitoring stations such as Thai Nguyen, indicating potential industrial and urban runoff as a source. Moreover, the consistently high bioaccumulation of Zn suggests that *Lanceolaria* sp. is highly sensitive to Zn contamination, making it a reliable bioindicator of Zn levels in river sediments.

Cu concentrations in *Lanceolaria* sp. ranges from 13.987 to 26.287 mg/kg of dry organisms, with the highest concentration found at Thai Nguyen. The bioaccumulation of Cu in *Lanceolaria* sp. shows a similar pattern to Zn, further supporting the species' ability to accumulate metals from its environment. Cu is necessary for many physiological functions, including the formation of hemocyanin, yet elevated concentrations can become toxic, especially when bioavailable in ionic forms. The strong correlation ($r = 0.83$) between Cu levels in sediment and *Lanceolaria* sp. suggests that sediment-bound Cu

is bioavailable and contributes significantly to the metal content in the organism.

Pb content in *Lanceolaria* sp. ranged from 10.986 to 27.270 mg/kg, with the highest levels observed at Bac Giang. Pb accumulation exceeded the regulatory limits at 15 out of 16 monitoring locations, surpassing the QCVN 8-2:2011/BYT [16] by 1.26 to 2.48 times. This widespread Pb contamination raises concerns, particularly as Pb poses severe health risks to both aquatic life and humans due to its non-essential and toxic nature. Pb bioaccumulation in *Lanceolaria* sp. was inversely correlated with sediment Pb levels ($r = -0.65$), suggesting that Pb may be bound to sediment particles and less bioavailable in some regions. This could be due to various environmental factors such as pH, redox potential, or organic matter content that influence the speciation and bioavailability of Pb.

Cd concentrations were relatively lower, ranging from 0.310 to 10.088 mg/kg dry weight (0.04 to 1.472 mg/kg fresh weight), with the highest concentration at Thai Nguyen and the lowest at Bac Giang. Importantly, all Cd levels fell within the permissible limits stipulated by QCVN 8-2:2011/BYT [16] suggesting a less severe contamination scenario for this heavy metal compared to Pb. Nevertheless, Cd remains a potent environmental toxin, capable of causing bioaccumulation and biomagnification through aquatic food webs.

Cr levels were found to range between 0.310 and 10.088 mg/kg, with 10 out of 20 monitoring sites exceeding the permitted limits set by Hong Kong regulations. Cr is particularly concerning due to its potential to exist in its highly toxic hexavalent form, Cr(VI), which poses carcinogenic risks. The highest Cr concentrations were detected at Thai Nguyen, suggesting localized pollution sources, possibly from industrial activities such as tanning, textile processing, or electroplating [4]. Interestingly, the correlation between Cr in sediments and its accumulation in *Lanceolaria* sp. was negative ($r = -0.44$), implying that environmental factors may reduce the bioavailability of Cr.

Cd levels in *Lanceolaria* sp. were relatively low, ranging from 0.310 to 10.088 mg/kg. Despite its toxicity, Cd concentrations remained within acceptable limits as per QCVN 8-2:2011/BYT [16]. The weak correlation between Cd in sediment and its accumulation in *Lanceolaria* sp. ($r = 0.29$) suggests that Cd bioavailability is highly variable, influenced by sediment composition, water chemistry, and the presence of organic materials. These factors could explain the low levels of Cd bioaccumulation, despite its presence in the environment. Similar trends were observed in *Meretrix meretrix*, *Perna viridis* and *Saccostrea* sp., further emphasizing the prevalence of heavy metal pollution in Vietnam's aquatic systems [20, 21]. The comparison underscores the urgent need for stricter regulation and remediation efforts to mitigate the impacts of heavy metal pollution on both ecosystems and public health.

Through the sampling events, there was little change in the concentration of heavy metals accumulated in *Lanceolaria* sp. The concentrations

of heavy metals have increased, but not significantly.

3.2. Correlation Between Metal Content in Sediments and *Lanceolaria* sp.

The relationship between heavy metal content in sediments and in the tissues of *Lanceolaria* sp. was thoroughly explored to understand bioaccumulation patterns. Figures 3a to 3f illustrate the correlations between the concentrations of Cu, Pb, Zn, Cd, and Cr in *Lanceolaria* sp. and in Cau River sediments.

As noted earlier, Cu exhibited a strong positive correlation between its concentrations in sediments and *Lanceolaria* sp. ($r = 0.83$). This correlation indicates that Cu is readily bioavailable and efficiently accumulated by *Lanceolaria* sp. from the sediment. This observation aligns with previous studies that have demonstrated Cu's ability to bind with organic and inorganic matter in sediments, making it more bioavailable for uptake by benthic organisms such as *Lanceolaria* sp.

Table 2. Result of heavy metal content in Cau River sediment

Place of observation	Heavy metal content (m $\pm$ SD)* (mg/kg dry sediment)				
	Cu	Pb	Zn	Cd	Cr
Bac Kan (n = 6)	31.062 $\pm$ 8.131	44.061 $\pm$ 12.396	47.951 $\pm$ 6.162	0.803 $\pm$ 0.315	57.530 $\pm$ 10.093
Thai Nguyen (n = 5)	53.828 $\pm$ 10.987	70.029 $\pm$ 9.863	316.930 $\pm$ 28.835	3.833 $\pm$ 1.362	106.080 $\pm$ 13.301
Bac Giang (n = 6)	31.654 $\pm$ 5.396	124.750 $\pm$ 15.120	135.440 $\pm$ 22.183	0.878 $\pm$ 0.297	105.480 $\pm$ 10.276
Bac Ninh (n = 6)	40.304 $\pm$ 13.015	150.480 $\pm$ 31.485	124.050 $\pm$ 15.514	0.670 $\pm$ 0.225	101.150 $\pm$ 11.103
Hai Duong (n = 5)	39.793 $\pm$ 9.114	54.167 $\pm$ 28.421	91.329 $\pm$ 21.229	1.345 $\pm$ 0.477	85.277 $\pm$ 3.586
QCVN 43:2017/BTNMT	197	91.3	315	3.5	90
PEC (**)	77.7	396	1532	11.7	159
TEC (**)	28	34.2	159	0.592	56
PEL (***)	197	91.3	315	3.5	90
ISQG (***)	35.7	35	123	0.6	37.3

(*) m: Average value; SD is the standard deviation. (**): Criteria for evaluating heavy metal pollution in sediment according to the total content (mg/kg) of the US EPA, (1997). TEC: Threshold effect concentration; PEC: Probable effect concentration. (***) : Canadian Standards of National Guidance (Sediment Quality Guideline, 2002). ISQG: Thresholds of negative impacts on organisms; PEL: The degree of influence certainly.

Pb, however, displayed an inverse correlation ($r = -0.65$) between its concentrations in sediments and *Lanceolaria* sp. This negative relationship suggests that Pb is not as bioavailable in sediment, possibly due to its strong affinity for particulate matter, which limits its uptake by aquatic organisms. The negative correlation is also reflective of *Lanceolaria* sp.'s potential resistance to Pb accumulation, likely as a result of physiological mechanisms aimed at reducing the uptake of this toxic metal. Similar patterns were observed in studies on other benthic species, such as *Corbicula* sp.

Zn, like Cu, showed a strong positive correlation ($r = 0.75$) between sediment and tissue concentrations. This high degree of correlation indicates that Zn is highly bioavailable to *Lanceolaria* sp. and can be accumulated efficiently from sediment. The strong bioaccumulation of Zn is concerning due to its potential toxic effects when present in excess. Although Zn is essential for many biological processes, elevated concentrations can lead to metabolic disturbances and oxidative stress in aquatic organisms.

Cd exhibited a weak correlation ($r = 0.29$) between its concentrations in sediments and *Lanceolaria* sp. The variability in Cd accumulation suggests that the metal is less bioavailable compared to Cu and Zn, possibly due to its chemical interactions in sediments, which reduce its mobility and uptake by organisms. These

findings are consistent with previous research indicating that Cd bioaccumulation is highly dependent on environmental conditions, such as sediment composition and water chemistry.

Cr showed a negative correlation ($r = -0.44$) between sediment and tissue concentrations, suggesting that Cr is not readily bioavailable to *Lanceolaria* sp. This may be due to Cr's tendency to form stable complexes with organic matter or to be present in less bioavailable forms, such as trivalent Cr(III), in sediments. These findings highlight the need for further investigation into the factors influencing Cr bioavailability and its potential impacts on aquatic ecosystems.

3.3. Implications for Using *Lanceolaria* sp. as a Bioindicator

The use of *Lanceolaria* sp. as a bioindicator for assessing heavy metal contamination in aquatic ecosystems provides valuable insights into environmental monitoring. This study investigated the relationship between the concentrations of Cu, Pb, Zn, Cd and Cr in the flesh tissue of *Lanceolaria* sp. and the corresponding sediments of the Cau River, Northern Vietnam. The results demonstrate the species' potential for monitoring certain heavy metals, such as Cu and Zn, due to their strong correlations with sediment levels. However, variations in the bioavailability and bioaccumulation of other metals, such as Pb and Cr, highlight the complexities of using a single species to assess overall contamination.

Table 3. Relationship between metal concentrations in mussels and sediments in Cau River

Metal	Relationship [Mussels (X)] and sediments (Y)]	The correlation coefficient (*) Pearson (r)	(p-value)
Cu	$Y = 0.221 \cdot X + 11.946$	0.84	0.001
Pb	$Y = -0.049 \cdot X + 19.787$	-0.65	0.03
Zn	$Y = 0.350 \cdot X + 2.008$	0.75	0.007
Cd	$Y = 0.995 \cdot X + 5.846$	0.29	0.39
Cr	$Y = -0.066 \cdot X + 13.403$	-0.44	0.17
Metals	$Y = 0.110 \cdot X + 10.296$	0.40	0.003

(*) Significant correlation $p < 0.05$ (95% confidence level).

Copper (Cu) as a Key Indicator

Copper (Cu) exhibited the highest correlation between sediment and *Lanceolaria* sp. tissue, with a correlation coefficient of $r = 0.83$ ($p < 0.05$). As depicted in figure 3a, the equation $Y = 0.221 \cdot X + 11.946$ describes the close linear relationship between Cu levels in sediment and bioaccumulation in the organism. This strong positive correlation indicates that *Lanceolaria* sp. is an excellent bioindicator for Cu pollution, as the metal's presence in sediments is reflected proportionately in the organism's tissue.

Cu is essential for many physiological processes, including enzyme activity and oxygen transport in aquatic organisms. However, excessive Cu concentrations can lead to oxidative stress, damage to cellular structures, and disruption of metabolic functions. The findings of this study align with previous research, such as Bui Thi Thu *et al.* (2018, 2019) [6, 22], who also reported a high correlation between Cu in *Lanceolaria* sp. and sediment ($r = 0.767$, $p < 0.01$). The ability of *Lanceolaria* sp. to reliably reflect Cu contamination suggests that it can serve as an early warning system for monitoring areas affected by industrial runoff, agricultural inputs, and mining activities, all of which are known to contribute to Cu pollution in rivers.

Lead (Pb) Bioaccumulation Dynamics

In contrast to Cu, lead (Pb) displayed a negative correlation between its concentration in sediments and in *Lanceolaria* sp. tissue. As shown in Figure 3b, the equation $Y = -0.049 \cdot X + 19.786$ and the correlation coefficient $r = -0.65$ ($p < 0.05$) indicate an inverse relationship. This finding suggests that higher levels of Pb in sediment correspond to lower Pb accumulation in *Lanceolaria* sp. tissue, which could be due to several factors affecting Pb's bioavailability.

Lead is a non-essential and highly toxic metal, posing risks to neurological, reproductive, and developmental systems in both aquatic organisms

and humans. Its bioavailability is often influenced by environmental factors such as sediment composition, organic matter and the redox conditions of the aquatic environment, which can sequester Pb in forms that are less bioavailable. The negative correlation observed in this study contrasts with the positive correlations found in other species, such as *Corbicula* sp., which tend to accumulate Pb in proportion to its sediment levels. This difference suggests that *Lanceolaria* sp. may have developed physiological mechanisms to regulate or limit Pb uptake, potentially reducing the risk of Pb toxicity within this species.

Despite the negative correlation, it is important to note that Pb concentrations in *Lanceolaria* sp. still exceeded permissible levels at 15 out of 16 sampling locations, according to the QCVN 8-2:2011/BYT [16]. This widespread Pb contamination raises significant concerns, and while *Lanceolaria* sp. may not be the most sensitive indicator of Pb pollution, the high Pb levels in the sediments themselves warrant immediate attention.

Zinc (Zn) as a Consistent Bioindicator

Zinc (Zn), like Cu, showed a strong positive correlation between its concentration in sediment and in *Lanceolaria* sp. tissue, with a correlation coefficient of $r = 0.75$ ($p < 0.05$), as described by the equation $Y = 0.221 \cdot X + 11.946$ (Figure 3c). Zn is an essential micronutrient, playing a crucial role in protein synthesis, enzyme function, and cellular growth in aquatic organisms. However, excessive Zn concentrations can be toxic, leading to metabolic disturbances and inhibition of growth and reproduction.

The significant correlation between Zn in sediments and *Lanceolaria* sp. tissue reflects the metal's high bioavailability in aquatic environments. Zn is commonly found in industrial waste, agricultural runoff and domestic sewage, which contribute to its presence in river sediments. Given its strong correlation with

sediment levels, *Lanceolaria* sp. can be effectively used as a bioindicator for monitoring Zn contamination in aquatic ecosystems. Similar findings have been reported in studies from other regions, such as Ming *et al.* (2015) [23] research in the Yellow River Delta, China, where strong correlations between Zn in sediment and benthic species were also observed.

Cadmium (Cd) and Inconsistent Accumulation Patterns

The relationship between cadmium (Cd) concentrations in sediment and *Lanceolaria* sp. tissue was weak, with a correlation coefficient of $r = 0.29$ ($p > 0.05$), indicating that Cd bioaccumulation in *Lanceolaria* sp. is not closely related to its sediment levels (Figure 3d). Cd is a highly toxic metal that can cause severe health effects, including kidney damage and skeletal deformities, through chronic exposure. It is often released into the environment through industrial processes such as mining, metal plating and battery manufacturing.

The weak correlation found in this study suggests that Cd's bioavailability in the Cau River may be influenced by other factors, such as its chemical speciation, sediment characteristics, or competition with other metals. Cd may form complexes with organic matter or sulfides in the sediment, reducing its bioavailability for uptake by *Lanceolaria* sp. Previous studies on *Corbicula* sp. also reported inconsistent correlations between Cd in sediment and tissue, as seen in the work of Bui Thi Thu *et al.* (2018) [6], where Cd in *Corbicula* sp. and sediment had a low and inconsistent correlation ($r = 0.134$, $p > 0.05$). This suggests that Cd bioaccumulation patterns may vary significantly between species and environmental conditions, limiting *Lanceolaria* sp.'s utility as a consistent bioindicator for Cd contamination.

Chromium (Cr) Bioavailability Challenges

Chromium (Cr) showed a negative correlation between its concentration in sediments and

Lanceolaria sp. tissue, with a correlation coefficient of $r = -0.44$ ($p > 0.05$), as shown in Figure 3e. This suggests that Cr in the Cau River sediments is not readily bioavailable for uptake by *Lanceolaria* sp., despite its high concentrations in the sediment. Cr is a known carcinogen, particularly in its hexavalent form (Cr(VI)), which poses significant risks to both aquatic life and humans. However, Cr(VI) can be reduced to Cr(III), a less toxic form, in anoxic conditions typically found in river sediments, which may explain the low bioaccumulation observed in this study.

The negative correlation observed for Cr is consistent with other studies that have found limited bioavailability of Cr in sediments. For instance, Cr often forms insoluble precipitates or complexes with organic matter and clay particles, which can significantly reduce its mobility and uptake by aquatic organisms. This finding suggests that *Lanceolaria* sp. may not be a reliable bioindicator for Cr contamination, as its tissue concentrations do not reflect the sediment levels accurately. However, the presence of elevated Cr concentrations in the sediments themselves remains a concern, particularly given the potential for Cr(VI) contamination from industrial sources.

Overall Heavy Metal Correlation Patterns

Figure 3f provides an overview of the correlation between total heavy metal concentrations (Cu, Pb, Zn, Cd and Cr) in *Lanceolaria* sp. tissue and sediments. The overall correlation coefficient of $r = 0.40$ ($p < 0.05$) suggests a moderate positive relationship, indicating that the bioaccumulation of heavy metals in *Lanceolaria* sp. is influenced by sediment concentrations but is also modulated by other environmental factors.

The varying degrees of correlation for different metals reflect the complexity of heavy metal bioaccumulation in aquatic ecosystems. Metals such as Cu and Zn, which show strong

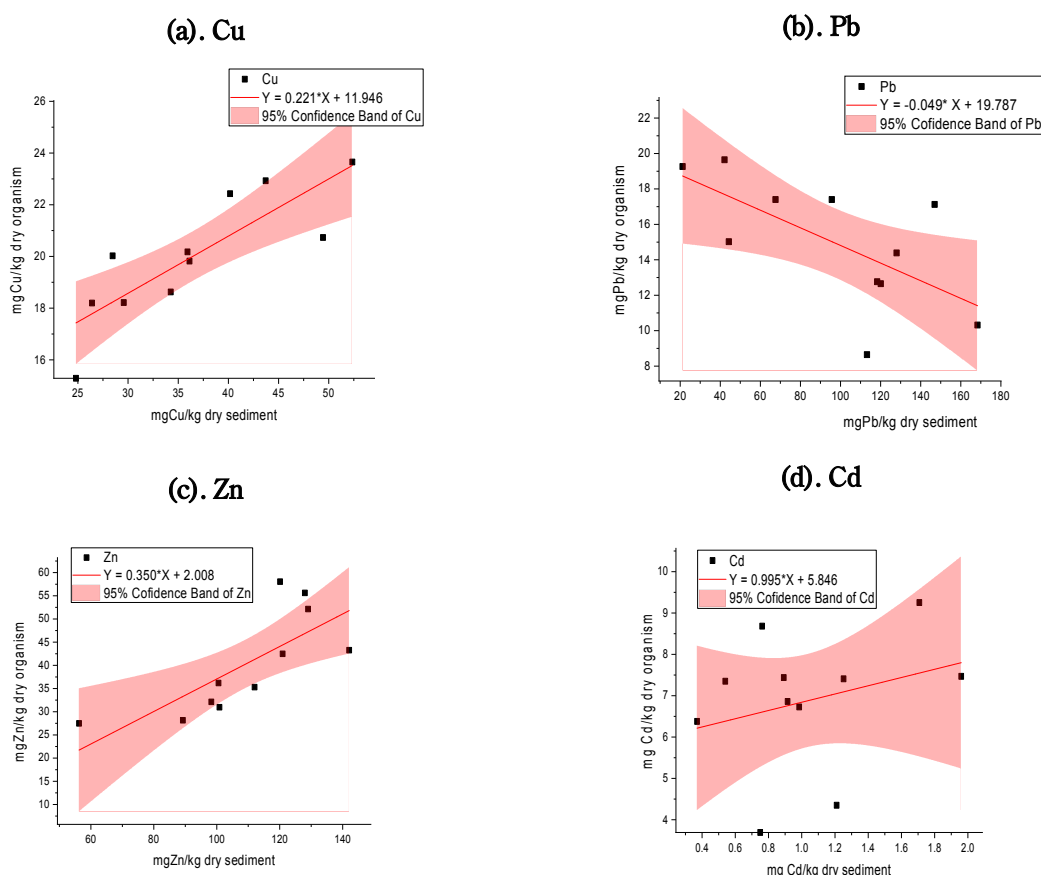
positive correlations, are more readily bioavailable and accumulate consistently in *Lanceolaria* sp., making them reliable indicators of sediment contamination. In contrast, metals such as Pb, Cd, and Cr exhibit weaker or negative correlations, suggesting that their bioavailability and bioaccumulation are influenced by other factors such as sediment chemistry, metal speciation, and the physiological characteristics of the organism.

Implications for Environmental Monitoring

The findings of this study have important implications for using *Lanceolaria* sp. as a bioindicator of heavy metal pollution in aquatic ecosystems. The strong positive correlations observed for Cu and Zn suggest that *Lanceolaria* sp. can be reliably used to monitor contamination levels for these metals in river sediments. This is

particularly valuable for tracking pollution from industrial activities, as Cu and Zn are commonly associated with manufacturing processes, metal plating, and mining operations.

However, the weak or negative correlations for Pb, Cd and Cr highlight the limitations of using *Lanceolaria* sp. as a universal bioindicator for all heavy metals. The bioavailability of these metals is influenced by complex environmental factors, and their accumulation in *Lanceolaria* sp. may not accurately reflect sediment contamination levels. Therefore, environmental monitoring programs should consider using multiple bioindicator species to obtain a more comprehensive assessment of heavy metal pollution, particularly for metals like Pb and Cr that exhibit variable bioaccumulation patterns.



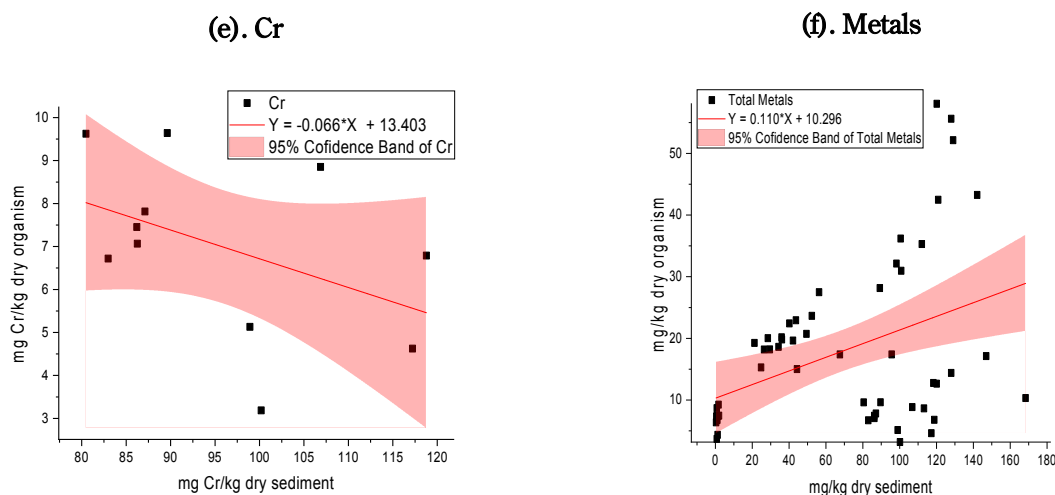


Figure 3. Graph of the relationship between heavy metals in the *Lanceolaria* sp. and Cau River sediment

Comparison research results with studies at some other locations are presented in table 4 as follows:

Comparing the research results with studies at a number of other locations, it shows that there is a close and positive correlation between the metals Cu and Cd in the *Lanceolaria* sp., *Corbiculidae* sp., and the sediments of Cau River in North Vietnam. There are similarities with the

results of research determining relationships in sediments of some rivers in the Central and Northern regions of Vietnam. This shows that there are similarities between the author's research results and some other author's. Research results show that it is initially possible to use axoplasmosis as an indicator organism to monitor heavy metal pollution in sediments in the Cau River in Northern Vietnam.

Table 4. Comparison of research results with other studies

Relationship of heavy metal content in <i>Lanceolaria</i> sp. and river sediments	This research	Other research	
	Cau River, Vietnam	<i>Corbiculidae</i> sp. Estuary of central Vietnam	<i>Corbiculidae</i> sp. at the door of Cu De River, Da Nang city, Vietnam
Cu	$Y = 0.221 \cdot X + 11.946$ (n = 22) $r = 0.84$; $p = 0.001$	$Y = 0.738 \cdot X + 0.103$ (n = 30) $r = 0.67$; $p < 0.01$ [21]	$Y = 0.700 \cdot X + 0.148$ (n = 8) $r = 0.71$; $p = 0.019$ [24]
Cd	$Y = 1.103 \cdot X + 2.693$ (n = 22) $r = 0.77$; $p < 0.01$	$Y = 0.042 \cdot X + 0.047$ (n=30) $r = 0.81$; $p < 0.01$ [21]	
Cr	$Y = -0.066 \cdot X + 13.403$ (n = 22) $r = -0.44$; $p > 0.05$	$Y = -0.151 \cdot X + 1.033$ (n= 30) $r = -0.49$; $p > 0.05$ [21]	

4. CONCLUSION

This study quantified heavy metal concentrations in *Lanceolaria* sp. from the Cau River, revealing a decreasing order of

accumulation as follows: $Zn > Cu > Pb > Cr > Cd$. The average Zn concentration was 52.932 mg/kg dry weight (6.875 mg/kg fresh weight), Cu was 19.343 mg/kg dry weight (2.504 mg/kg fresh weight), and Pb was 18.496 mg/kg dry weight

(2.375 mg/kg fresh weight). For Cr and Cd, the average concentrations were 7.549 mg/kg and 4.536 mg/kg dry weight, respectively. Chromium exceeded the Hong Kong standards at 10 of 28 monitoring sites and Pb levels frequently surpassed QCVN 8-2:2011/BYT limits in *Lanceolaria* sp.

The study established significant positive correlations between the concentrations of Cu, Pb, Zn and Cd in *Lanceolaria* sp. and corresponding sediment samples ($r > 0.5$, $p < 0.05$). Particularly, Cu and Zn exhibited strong correlations with sediment, confirming their bioavailability and accumulation in the organism. These findings align with existing studies, underscoring the utility of *Lanceolaria* sp. as a bioindicator for heavy metal pollution in aquatic ecosystems, particularly for Cu and Zn contamination.

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