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Nuclear Technique-Based Analysis of Metal Distribution in Mud Snails and Mangrove Sediments

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Abstract

A study is carried out on the concentrations of Major elements (Fe, Mn, Zn, Na and K) present in surface sediments, tissues and shell of mangrove snail gastropod, *Cerithidea Obtusa* from 10 locations throughout west coast Malaysia. In carrying out the analysis, the best and most convenient method being the Instrumental Neutron Activation Analysis (INAA). Samples were obtained, dried, crushed to powdery form and samples prepared for INAA. All the samples for analysis were weighted approximately 150 mg for short irradiation and 200 mg for long irradiation time. As calibration and Quality control procedures, blank samples, standard reference material IAEA-Soil-7, SL-1, SRM 1566b, and SRM 2976 were then irradiated with thermal neutron flux of 4×10^{12} $ncm^{-2}s^{-1}$ at the MINT TRIGA Mark II research reactor operated at 750 kW where a pneumatic transport facility was used.The order of accumulation of major element in surface sediment, tissues and shellwas Fe>Na>K>Mn>Zn, Na>K>Fe>Mn> Zn and Na>K>Fe>Mn>Zn comparatively. The biota sediments accumulation factor (BSAF) varied in range (0.02-10.04) for tissues and (0.01-0.82) for shell.

Keywords: Environmental pollution, Marine mollusc, Neutron activation.

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1. Introduction

Marine pollution has become one of the most pressing environmental challenges of the 21st century, threatening the sustainability of aquatic ecosystems and the safety of seafood resources [1, 2]. Among the various pollutants, trace metals are of particular concern due to their persistence, bioaccumulation potential, and toxicity to aquatic organisms and humans. Anthropogenic activities such as mining, agriculture, and industrial discharges have intensified metal loading into coastal waters, leading to contamination of sediments and the organisms that inhabit them [3-6]. Monitoring the extent of such contamination is therefore essential for both ecological risk assessment and food safety management.

Molluscs represent one of the largest and most ecologically diverse animal phyla, with an estimated 80,000–100,000 species distributed across marine, freshwater, and terrestrial environments [7]. They play a significant role in global food security, providing high-quality protein and essential micronutrients such as calcium, sodium, zinc, and iron. Snails, in particular, are ecologically important as grazers, detritivores, and sensitive bioindicators of environmental change [8, 9]. Their nutritional value, characterized by low fat and high protein content, makes them a valuable dietary resource, especially in regions facing protein shortages [10].

Despite extensive research on the nutritional value of land snails and commercially important bivalves, relatively few studies have addressed the toxicological risks associated with consuming marine snails [11, 12]. This knowledge gap is significant, given that many marine gastropods inhabit estuarine and intertidal zones where metal contamination from human activities is often elevated. *Cerithidea obtusa* (*C. obtusa*), a mud-dwelling gastropod widely distributed along the west coast of Malaysia, is an important seafood commodity and a potential biomonitor due to its sediment-feeding habits and site fidelity. However, data on its metal bioaccumulation patterns and potential health risks to consumers remain scarce.

This study addresses this gap by quantifying the concentrations of Fe, Mn, Zn, Na, and K in the surface sediments, soft tissues, and shells of *C. obtusa* collected from the west coast of Malaysia. The results are evaluated in relation to international permissible limits to assess potential risks to human health. Elemental concentrations were determined using Instrumental Neutron Activation Analysis (INAA), a highly sensitive, non-destructive analytical technique capable of simultaneous multi-element detection with minimal sample preparation. The findings provide new insights into the role of *C. obtusa* as a biomonitor and contribute to understanding the safety of this species as a food source in metal-impacted coastal environments.

2. Experimental

2.1. Study Area and Sampling Procedure

This present study was conducted in mangrove area along river estuaries in the West Coast of Malaysia (~800 km) which are covered from latitude: N 05º 20’ 24.7” to N 01º 15’ 58” and longitude: E 100º24’25.2” to E 103º30’39” as shown in Table 1. The ten Locations of present study are exposed to the different type sources of pollution and mainly due to agriculture, aquaculture, industrial development, tourism, shipping port, hydroelectric power plant and etc. The sampling map and details of the sampling locations are shown on Table 1 and Figure 1.

Table 1.
The description of sampling location.

ID	Location Name	GPS Reading	Description of nearby activities
R1	Tok Muda, Kapar, Selangor	N 03º 7’ 30.9” E 101º 20’ 27.7”	1. Residental Area 2. Hydroelectric Power Plant
R2	Sungai Sepang Besar, Selangor	N 02º 56’ 16.9” E 101º 45’ 9.4”	1. Residental Area 2. Intertidal Area
R3	Sungai Pasir Gudang, Johor	E 103º 57’ 26” N 01º 24’ 3.99”	1. Residental Area 2. Shipping Area 3. Intertidal Area
R4	Kuala Gula, Perak	N 04º 55’ 58” E 100º 27’ 33.6”	1. Fishing Village 2. Tourism Spot 3. Fish cage, shrimp pond
R5	Juru, Penang	N 05º 20’ 24.7” E 100º 24’ 25.2”	1. Fishing Village 2. Residental Area 3. Industrial Area
R6	Kampung Panchor, Pantai Remis, Perak	N 04º 31’ 33.4” E 100º 39’ 17.5”	1. Fishing Village 2. Tourism Spot 3. Fishcage,shrimp pond
R7	Sungai Kim Kim, Johor	N 01º 26’ 40.2” E 103º 58’ 14.2”	1. Residental Area 2. Shipping Area 3. Intertidal Area
R8	Lukut, Port Dickson,	N 02º 34’ 49.4”	1. Residental Area

	Negeri Sembilan	E 101° 47' 53.9"	2. Shipping Area 3. Intertidal Area
R9	Pulau Kukup, Johor	N 01° 19' 18.7" E 103° 25' 30.6"	1. Residental Area 2. Shipment Area 3. Fish cage, shrimp pond
R10	Johor Tanjung Pia,	N 01° 15' 58" E 103° 30' 39"	1. Residental Area 2. Shipping Area 3. Tourism spot

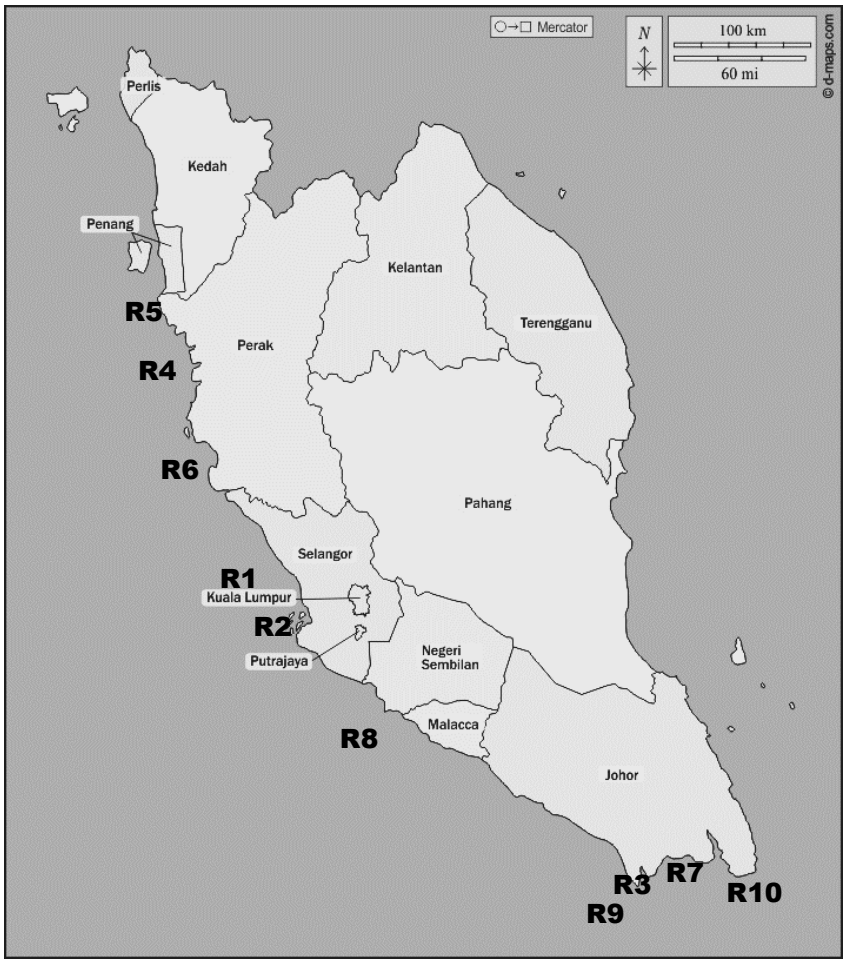

Figure 1.
Location of the surface mangrove sediment sampling stations.

Identification of the species (*C. obtusa*) were followed by the descriptions mentioned [13]. For the present work, 40-50 individual snails with almost similar dimensions (approximately 5.0 cm) were randomly taken from each location. To prevent differences in metal content due to its size or reproductive stage, only the common commercially accepted size of each species were collected [14]. *C. obtusa* were washed off sticking soil with plane water and thawed at room temperature in a clean polythene bag with a label. The soft tissues were then separated from the shell by using crunching the shell carefully without destroy the soft tissues.

To examine the possibility of correlation analysis of snails result with surface sediment, sub surface sediment of mangrove about 500-600 g were collected a depth of 3.0 – 5.0 cm. At each station, four surface sediment samples were collected by scraping the surface layer using a clean plastic spoon. The surface sediments, shell and tissues of each sample were placed in polyethylene plastic bags and they were then kept in an ice box [15, 16]. The surface sediments, shell and tissues each location were dried at 80° C in an oven for at least for 72 hours to constant dry weight to remove moisture content. Dried samples were powdered using glass mortar and spread whit mesh to a particle size of not more than 200 µm and were stored in polyethylene pillboxes [15, 16].

The analytical procedure employed in this study involved four replicate experiments for all samples to ensure data reliability and reproducibility. Approximately 150 mg of each sample was used for short irradiation and around 200 mg for long irradiation. Certified reference material IAEA-Soil-7 was used as a multi-element comparator for quantification. Calibration and quality control were performed using a series of standards and reference materials, including blank samples, IAEA-Soil-7, SL-1, SRM 1566b, and SRM 2976. The irradiation was conducted using the pneumatic transport facility at the MINT TRIGA Mark II research reactor. The reactor operated at a thermal neutron flux of $3–4 \times 10^{12}$ n cm^{-2}

s^{-1} with a power of 750 kW. For short irradiation, samples were irradiated for 1 minute, followed by cooling periods of 20 minutes and 24 hours, and subsequently counted for 5 and 20 minutes, respectively. For long irradiation, the duration was 6 hours, with cooling periods of 3–4 days and 21–28 days, followed by counting times of 1 hour.

3. Results and Discussions

Analytical results for the certified reference material and measured values of SL-1, SRM 1566b and SRM 2976 of major elements shown in Table 2a and 2b. The recoveries between the measured and certified in INAA method are within the range of acceptable. The recoveries in INAA method for all of the certified reference material are in the range 94 - 138 %.

Table 2(a).
Analysis of the measured concentration of CRM of SL-1 value compared with certified reference materials.

Element	Certified Value	Measured Value	Recovery (%)
Fe	67400±1700	67916±4.6	100.8
Mn	3460±160	3438±1.31	99.4
Zn	223±10	247±0.34	110.6
Na	1700±100	1735±4.2	102.0
K	14500±2100	19737±0.19	136.1

Table 2(b).
Analysis of the measured concentration of CRM of *SRM 1566b and 2976 value compared with certified reference materials.

Element	Certified Value	Measured Value	Recovery (%)
*Fe	205.8±6.8	263.7±4.6	128.1
Mn	33±2	45.7±1.31	138.4
*Zn	1424±46	1339±0.34	93.9
*Na	6887±140	6573±4.2	95.4
*K	6520±90	6294±0.19	96.5

The results obtained for the mean concentration of Fe, Mn, Zn, Na and K in the sediment, tissue and shell samples are presented in Table3(a), 3(b) and 3(c).

Table 3(a).
Mean concentration (mg/kg) of elements in the sediment.

	Location									
	R1	R2	R3	R4	R5	R6	R7	R8	R9	R10
Fe	13972	21874.2	22855.7	26075.5	34579.5	9052.2	28606.9	20098	27073	32429
Mn	92.1243	140.898	113.338	207.104	423.158	140.163	139.844	84.7057	186.13	136.715
Zn	59.7995	85.0827	69.9438	91.8764	348.1	34.1725	81.7714	70.6307	83.0795	72.3486
Na	10945.1	13588.6	15123.1	31667.3	34657.8	6430.94	13472.1	13848.6	21132	27594.5
K	8654.4	12882.3	13346.5	17273.6	17481.5	7113	15561.7	12617.4	15927.2	14937.8

Table 3(b).
Mean concentration (mg/kg) of elements in the soft tissue of *C. obtusa.*

	Location									
	R1	R2	R3	R4	R5	R6	R7	R8	R9	R10
Fe	2229.7	5755.2	1134.5	652.43	4205.2	1517.1	1600.8	1848.8	5934.6	653.19
Mn	580.04	373.21	143.83	737.9	2509.5	466.06	204.36	285.9	485.69	524.16
Zn	600.24	293.5	291.54	207.6	489.38	289.01	327.34	268.05	233.23	256.32
Na	23923	28878	10596	13601	24141	21094	15574	34323	22632	25537
K	10207	10032	8905.7	7774.4	10179	10744	11015	13327	12658	10696

Table 3(c).
Mean concentration (mg/kg) of elements in the shell of *C. obtusa.*

	Location									
	R1	R2	R3	R4	R5	R6	R7	R8	R9	R10
Fe	380.776	286.642	1008.4	394.671	402.83	315.6	416.945	211.748	264.869	209.218
Mn	33.065	11.213	31.257	45.463	234.9	19.811	8.2781	43.118	20.272	15.211
Zn	25.577	8.2611	11.852	4.9456	19.341	2.1155	nd	0.7721	5.0561	nd
Na	6626.7	5989.3	5533.2	5243	6410.4	5257.2	5609.5	3715.4	6754.5	5720
K	1307	833.42	nd	nd	288.24	nd	448.32	255.92	545.67	747.48

nd – not detected

3.1. Sediment

In this study, the concentration of iron (Fe) in sediment samples ranged from 9,052 mg/kg to 34,579 mg/kg, with a mean value of 23,662 ± 7,901 mg/kg. The highest Fe concentration was observed at R5, while the lowest was recorded at R6 (Figure 2a). Overall, the mean Fe concentration obtained in this study was considerably higher than that previously reported for Sg. Janggut, Selangor (9,365 ± 130 mg/kg) [17]. Zinc (Zn) concentrations varied between 34.2 mg/kg and 348.1 mg/kg, yielding a mean of 99.9 ± 89 mg/kg. The highest Zn level occurred at R5, whereas the lowest was detected at R6 (Figure 2b). The mean Zn concentration observed in the present study was lower than those reported for Deep Bay, Hong Kong (240.0 mg/kg) [18] and Guanabara Bay, Brazil (447.5–505.1 mg/kg) [19] as well as for S. Buloh (51.24 ± 39.97 mg/kg) and S. Khatib Bongsu, Singapore (120.23 ± 13.90 mg/kg) [20]. However, it exceeded the value documented for Sg. Janggut, Selangor (21.8 ± 0.41 mg/kg) [17].

Manganese (Mn) concentrations ranged from 84.7 mg/kg to 423.2 mg/kg, with a mean value of 166 ± 98 mg/kg. The maximum Mn concentration was recorded at R5, while the lowest occurred at R8 (Figure 2c). Sodium (Na) concentrations fluctuated between 6,431 mg/kg and 34,658 mg/kg, with an average of 18,846 ± 9,475 mg/kg. The highest Na concentration was observed at R5, and the lowest at R6 (Figure 2d). When compared with other findings, the Na concentrations recorded in this study were within the range reported for sediment cores from Vypin (14,000–45,000 mg/kg; mean 29,300 mg/kg) [21]. Potassium (K) concentrations ranged from 7,113 mg/kg to 17,481 mg/kg, with a mean value of 13,580 ± 3,459 mg/kg. The highest K concentration occurred at R5, while the lowest was recorded at R6 (Figure 2e). These values are comparable to those reported in previous studies, where K concentrations ranged from 2,500 mg/kg to 27,000 mg/kg, with a mean of 12,000 ± 5,240 mg/kg [22].

There was a high variability in metal concentrations at different stations of surface sediments.

In the present study the order of accumulation was Fe>Na>K>Mn>Zn. Fe is the dominant heavy metal. The higher concentrations of Fe in the current study may be due to the nature of the organic compounds of mangrove (clayey substratum) as reported [23, 24]. Higher concentration of Fe might be due to the precipitation of iron as sulphide, which is common in mangrove sediments. Fe and Mn form complexes with organic compounds in the mangrove. Environments (Fe more effectively than Mn) and are thus considerably concentrated in the organic materials. The accumulation of metals varied in sediment was due to their geographical location and also effect by the amounts of sewage and municipal wastes discharged from anthropogenic activities [25]. The regular tidal influx of seawater into mangrove ecosystems contributes to the enrichment of sodium (Na) and potassium (K) in these areas [26]. In mangrove sediments, much of the sodium is bound to clay minerals, particularly montmorillonite, due to their strong fixation capacity. Sodium tends to be present at higher levels than potassium because it bonds more readily to the vacant exchange sites in clay minerals. Although potassium is less strongly fixed, it is a vital nutrient for mangrove species, playing an essential role in carbohydrate synthesis and tissue development. As a result, mangrove plants actively absorb potassium from the sediments, which can lower its concentration relative to sodium. Some of the potassium in these sediments also originates from mangrove litter fall and other vegetative debris, while geological sources include the weathering of potassium-rich minerals such as orthoclase, microcline, and biotite. The comparatively lower potassium content is therefore likely a result of uptake by mangrove vegetation [26]. In contrast, the elevated Zn concentrations observed are likely linked to runoff from nearby agricultural areas. Fertilizers, pesticides, and rodenticides used in farming often contain zinc, which can be transported into mangrove environments through surface water flow and tidal exchange [27].

3.2. Tissue

In this study, Fe concentrations in soft tissues of *C. obtusa* ranged from 652.4 to 5935 mg/kg (mean 2553 ± 2006 mg/kg), with the highest at R2 and lowest at R4 (Figure 2a). The mean Fe level exceeded those reported at Kampung Pasir Puteh (1454 ± 705 mg/kg), Pantai Remis (782 ± 62 mg/kg), and Sg. Sepang Kecil (1111 ± 343 mg/kg) [28]. Zn concentrations varied between 207.6 and 600.2 mg/kg (mean 326 ± 123 mg/kg), highest at R1 and lowest at R4 (Figure 2c), and were generally higher than previous findings from Sg. Janggut (10.3–133.8 mg/kg) [17] Parit Jawa (222 ± 21 mg/kg), Pantai Remis (67.8 ± 1.2 mg/kg), Sg. Sepang Kecil (343 ± 10 mg/kg) [28] and Vellar estuary (15.26–22.50 mg/kg) [29]. Mn ranged from 143.8 to 2510 mg/kg (mean 631 ± 684 mg/kg), with maximum at M5 and minimum at M3 (Figure 2b), exceeding levels reported at Vellar estuary (191.96–242.42 mg/kg) [29] and Anadara rhombea (200–580 mg/kg) [30]. Na ranged between 10,596 and 34,323 mg/kg (mean 22,030 ± 7173 mg/kg), highest in R8 and lowest in R3 (Figure 2d), while K ranged from 7774 to 13,327 mg/kg (mean 10,554 ± 1611 mg/kg), with highest in R8 and lowest in M4 (Figure 2e).

In the present study the order of accumulation was Na> K> Fe>Mn> Zn. Among the five metals tested, Fe, Na and K concentration was the highest in the tissues of *C. obtusa*. Zinc (Zn) concentration was the last elements found to be higher in the mollusk tissue. This could be due to Fe, Na, and K are the essential element which is important role in the metabolic biomolecules activities such as a enzymes, metalloenzymes and respiratory pigments of *C. obtusa* [31, 32]. However, concentration of Zinc (Zn) was still below the compared with permissible limit (667 mg/kg) that set by The Rainbow [33] and Australian Legal Requirements [34] Dry weight 750 mg/kg [28] and higher than permissible limit that set Malaysian Food Act 1983 was 100 mg/kg [35].

3.3. Shell

Overall, the concentrations of Fe, Na, Zn, K, and Mn in the shell of *C. obtusa* were lower than those observed in the sediment and soft tissues of *C. obtusa*. The distribution of these elements is illustrated in Figure 2(a)–2(e). Among them, Na exhibited the highest concentration (6755 mg/kg), while Zn recorded the lowest (0.77 mg/kg). The Fe concentration in the shell ranged from 209 to 1008 mg/kg, with a mean of 389 ± 231 mg/kg. The maximum Fe concentration (1008 mg/kg)

was found at R3, and the minimum (209 mg/kg) at R10 [Figure 2(a)]. The mean Fe level (389 mg/kg) was notably higher than those previously reported at Bako (240 ± 49 mg/kg), Sematan (66 ± 5 mg/kg), and Deralik (52 ± 2 mg/kg) [12].

Manganese concentrations ranged from 8.27 to 235 mg/kg, with a mean of 46.3 ± 67 mg/kg. The highest Mn concentration (235 mg/kg) occurred at R5, while the lowest (8.27 mg/kg) was observed at R7 [Figure 2(b)]. The mean Mn content in this study exceeded that reported for giant clam shells (29.9–65.2 mg/kg) from [36]. Zinc concentrations varied between 0.77 and 25.6 mg/kg, with a mean of 9.74 ± 8.73 mg/kg. The highest Zn value (25.6 mg/kg) was recorded at R1 and the lowest (0.77 mg/kg) at R8 [Figure 2(c)]. The mean Zn concentration (9.74 mg/kg) was comparable or higher than those reported at Pantai Lido (5.96 ± 0.09 mg/kg), Parit Jawa (6.47 ± 0.16 mg/kg), and Sg. Sepang Kecil (3.84 ± 0.77 mg/kg) [28] but lower than at Pantai Remis (67.8 ± 1.2 mg/kg) and close to the range reported for Vellar Estuary mangroves (15.26–22.50 mg/kg) [37].

The concentrations of Na and K in the shell of *C. obtusa* ranged between 3715–6755 mg/kg and 256–1307 mg/kg, with mean values of 5686 ± 878 mg/kg and 632 ± 367 mg/kg, respectively. The highest Na concentration (6755 mg/kg) was observed at R9, whereas the lowest (3715 mg/kg) occurred at R8 [Figure 2(d)]. Similarly, K showed its peak concentration (1307 mg/kg) at R1 and the minimum (256 mg/kg) at R8 [Figure 2(e)].

The distribution and concentration of elements on the shell are related to the chemical mineralogy which includes metals accumulated from the environment. Therefore, metal concentrations in the shells based on the metal concentrations their environments [37]. Among the five metals (Fe, Na, K, Mn and Zn) were analysed, the Na concentration showed highest values compared withother metals. The order of accumulation of the elements in the shell was Na> K> Fe>Mn> Zn.

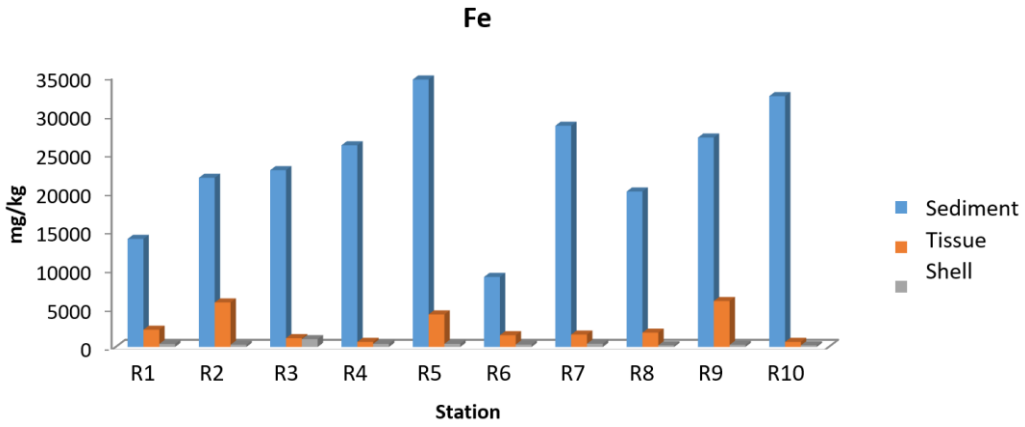

Figure2(a).
Mean concentration (mg/kg) of Fe in sediment, soft tissues and shell of *C. obtusa.*

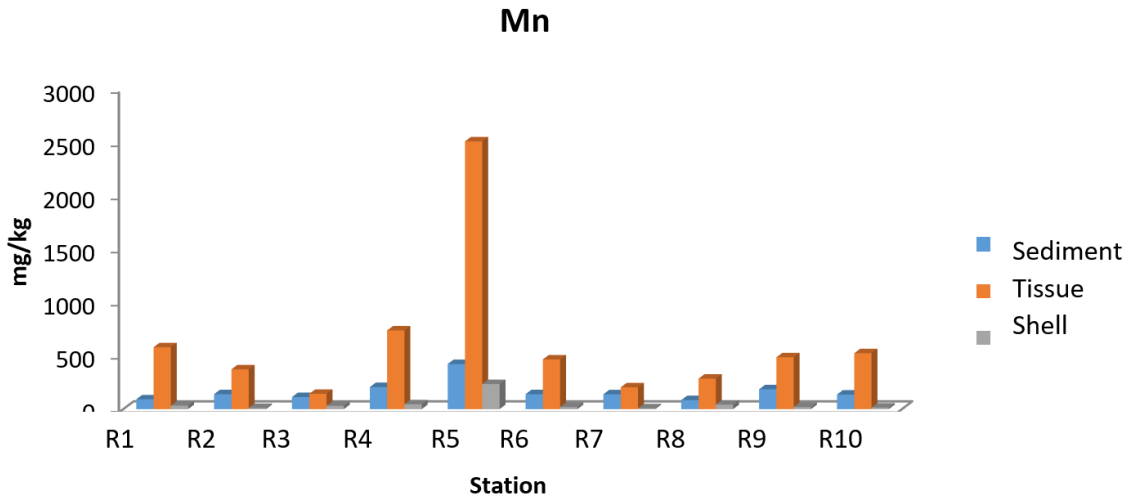

Figure2(b).
Mean concentration (mg/kg) of Mn in sediment, soft tissues and shell of *C. obtusa.*

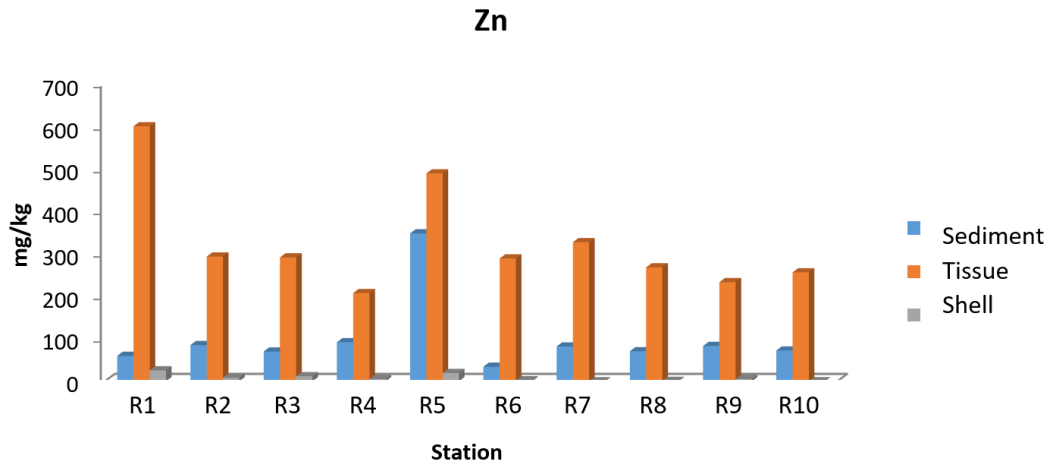

Figure2(c).
Mean concentration (mg/kg) of Zn in sediment, soft tissues and shell of *C. obtusa.*

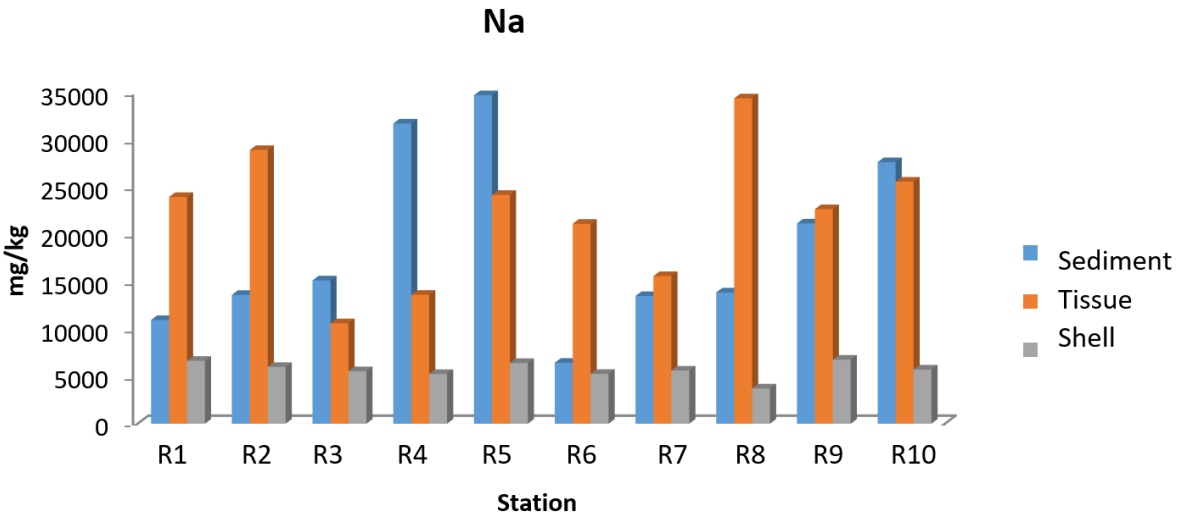

Figure2(d).
Mean concentration (mg/kg) of Na in sediment, soft tissues and shell of *C. obtusa.*

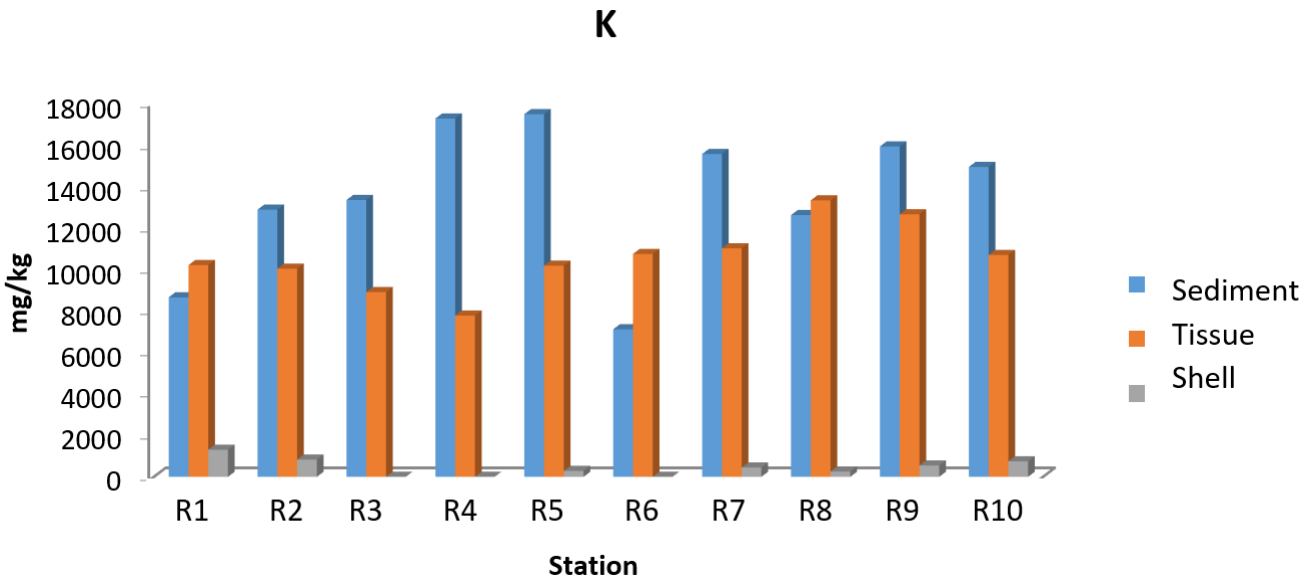

Figure2(e).
Mean concentration (mg/kg) of K in sediment, soft tissues and shell of *C. obtusa.*

In order to estimate the proportion in which metal occurs in the living organism and in associated sediment (BSAF) were calculated for selected metals based on the formula [38]:

$$BSAF = \frac{C_x}{C_s}$$

whereC_x and C_s are the mean concentrations of metal in the different parts of snails (tissues and shell) and in associated sediment respectively. The snail tissues can be classified into macroconcentrator (BSAF > 2), microconcentrators (1<BSAF<2) or deconcentrators (BSAF< 1), as proposed by Dallinger [39].

The values of BSAF are shown in Table 4. Based on the values calculated, the tissues of snails from most of sample stations can be classified as macroconcentrator for Mn and Zn. On the other hand, soft tissues of *C. obtusa* were deconcentrators for Fe. The snail shell can be classified as adeconcentrators for all the elements in this study due to value of BSAF < 1. The results of BSAF (macroconcentrators) for Mn and Zn indicates that the tissues of C.obtusa can be used as good biomonitors.

Table 4.
Biota sediment accumulation factors in the tissue and shell of *C.obtusa*.

	Fe		Mn		Zn		Na		K	
	Tissue	**Shell**	**Tissue**	**Shell**	**Tissue**	**Shell**	**Tissue**	**Shell**	**Tissue**	**Shell**
R1	0.16	0.03	6.30	0.36	10.04	0.43	2.19	0.61	1.18	0.15
R2	0.26	0.01	2.65	0.08	3.45	0.10	2.13	0.44	0.78	0.06
R3	0.05	0.04	1.27	0.28	4.17	0.17	0.70	0.37	0.67	-
R4	0.03	0.02	3.56	0.22	2.26	0.05	0.43	0.17	0.45	-
R5	0.12	0.01	5.93	0.56	1.41	0.06	0.70	0.18	0.58	0.02
R6	0.17	0.03	3.33	0.14	8.46	0.06	3.28	0.82	1.51	-
R7	0.06	0.01	1.46	0.06	4.00	-	1.16	0.42	0.71	0.03
R8	0.09	0.01	3.38	0.51	3.80	0.01	2.48	0.27	1.06	0.02
R9	0.22	0.01	2.61	0.11	2.81	0.06	1.07	0.32	0.79	0.03
R10	0.02	0.01	3.83	0.11	3.54	-	0.93	0.21	0.72	0.05

Pearson's correlation coefficient between Fe, Mn, Zn, Na and K levels in the sediment, tissues and shell of *C.obtusa* were shown in Table 5. The Pearson's correlation coefficient showed there are linear relationships among the elements. Mn and Zn were found to have relatively higher positive correlation coefficients (for Mn, r = 0.943 between sediments and tissues; r = 0.900 between sediments and shell, r = 0.963 between shell and tissues). Meanwhile for Zn, r = 0.403 between sediments and tissues; r = 0.434 between sediments and shell, r = 0.864 between shell and tissues). On the other hand, Fe, Na and K mostly showed negative Pearson's correlation between sediments, tissues and shell of *C.obtusa*. These results showed that shell and tissues of *C.obtusa* have different mechanisms of metal accumulation in their body compared with sediments. The present study also showed strong relations of Zn and Mn with environment therefore, precautions are needed to be taken in order to obviate the metal pollution in future. Otherwise, these pollutions can be hazardous for *C.obtusa* and finally to human health.

Table 5.
Correlation between element concentrations in surface mangrove, tissue and shell of *C.obtusa*.

Fe

	Sediment	Tissue	Shell
Sediment	1		
Tissues	0.139	1	
Shell	-0.014	-0.263	1

Mn

	Sediment	Tissue	Shell
Sediment	1		
Tissues	0.943**	1	
Shell	0.900**	0.963**	1

Zn

	Sediment	**Tissue**	**Shell**
Sediment	1		
Tissues	0.403	1	
Shell	0.434	0.864**	1

Na

	Sediment	**Tissue**	**Shell**
Sediment	1		
Tissues	-0.108	1	
Shell	0.209	-0.206	1

K

	Sediment	**Tissue**	**Shell**
Sediment	1		
Tissues	-0.142	1	
Shell	-0.222	0.189	1

Note: **. Correlation is significant at the 0.01 level (2-tailed).

4. Conclusion

The present study demonstrated distinct variations in metal accumulation among the sediments, soft tissues, and shells of *C. obtusa*. These differences are likely attributed to the biological roles of the tissues and shells in the uptake, regulation, and storage of metals. Notably, the concentrations of Mn and Zn in the soft tissues were significantly higher than those in the surrounding sediments, suggesting active bioaccumulation processes. The elevated levels of these metals indicate that

the soft tissues of *C. obtusa* act as macro-concentrators and can serve as reliable indicators of trace metal contamination in mangrove ecosystems. Overall, the findings of this study provide valuable baseline information for future ecotoxicological assessments and environmental monitoring programs. They further support the potential of *C. obtusa* as an effective biomonitor and bioindicator species for evaluating heavy metal pollution in coastal and estuarine environments. Continuous monitoring using this species could contribute to a better understanding of spatial and temporal trends of metal contamination, thereby aiding in the management and conservation of mangrove habitats.

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