



ISSN Print: 2664-9926
 ISSN Online: 2664-9934
 NAAS Rating (2025): 4.82
 IJBS 2025; 7(10): 200-203
www.biologyjournal.net
 Received: 07-08-2025
 Accepted: 11-09-2025

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Bioaccumulation of heavy metals in mangrove crabs and human health risk assessment

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DOI: <https://www.doi.org/10.33545/26649926.2025.v7.i10c.789>

Abstract

Mangrove ecosystems serve as nursery habitats for many commercially harvested crustaceans, yet these coastal wetlands also accumulate pollutants carried by tidal and riverine inputs. This research quantified the concentrations of lead (Pb), cadmium (Cd), chromium (Cr), and zinc (Zn) in gill, hepatopancreas, and muscle tissues of the mangrove crab *Scylla serrata* collected from four stations along the Hurghada coastline, Egypt, between June 2023 and March 2024. The health risk to local consumers was evaluated using the Target Hazard Quotient (THQ) and Hazard Index (HI) approach. Metal concentrations varied significantly among tissues, with the hepatopancreas accumulating the highest Pb (23.4 mg/kg dry weight) and Cd (4.71 mg/kg) loads. Station C, located near a small-vessel harbor, recorded the highest overall contamination. THQ values for Pb through muscle consumption exceeded 1.0 at Station C, indicating a potential non-carcinogenic risk. The hazard index combining all four metals reached 2.38 at Station C, well above the safety threshold. These results point to a localized contamination hotspot that warrants monitoring and consumption advisories for subsistence fishers.

Keywords: Bioaccumulation, heavy metals, mangrove crabs, *Scylla serrata*, health risk assessment, target hazard quotient, hepatopancreas, lead contamination, coastal pollution, Red Sea

Introduction

Mangrove-lined coastlines are among the most metal-contaminated marine habitats on the planet, yet they remain critical feeding and breeding grounds for commercially important crustaceans [1]. Heavy metals entering mangrove sediments bind to organic matter and clay particles, creating a long-term reservoir that benthic organisms encounter daily through burrowing and feeding [2]. Crabs are especially prone to metal uptake because they process large volumes of sediment-associated food and respire through gills in direct contact with contaminated water [3].

The Red Sea coast of Egypt has experienced expanding port activities, desalination brine discharge, and coastal construction over the past two decades, all of which introduce metallic pollutants into nearshore waters [4]. Hurghada, one of the region's major tourist cities, hosts a commercial fishing harbor and several boat-repair yards that release antifouling paint residues and fuel spillage into adjacent mangrove stands [5]. Despite this, few published surveys have examined metal burdens in edible crabs from this stretch of coastline.

Risk assessment frameworks recommended by the United States Environmental Protection Agency express non-carcinogenic risk through the target hazard quotient, which compares estimated dietary intake of a metal with its oral reference dose [6]. When THQ exceeds 1.0 for a single metal, or the combined hazard index for multiple metals exceeds 1.0, the exposure scenario is considered unsafe and corrective action is warranted.

This research measured Pb, Cd, Cr, and Zn in three tissue types of *Scylla serrata* from four stations along the Hurghada mangrove belt, and calculated THQ and HI values based on local consumption patterns. The aim was to identify which tissues and which sites pose the greatest risk to human health, so that targeted advisories can be issued [7].

Material and Methods

Material

Adult male *Scylla serrata* (carapace width 9.2–13.8 cm, n = 120) were hand-collected from burrows and baited traps at four stations along a 12 km stretch of the Hurghada mangrove

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coastline. Sampling took place quarterly from June 2023 to March 2024 (30 crabs per season). Station A was upstream of the main harbor, Station B was adjacent to a fish-landing jetty, Station C was directly opposite a boat-repair yard, and Station D was 4 km south of the harbor in a relatively undisturbed mangrove patch. Live crabs were transported on ice to the Aquatic Chemistry Laboratory at the Red Sea University of Marine Biology, Hurghada, within three hours of capture. The research was approved by the Faculty Research Ethics Panel (Ref: RSUM/FREP/2023-027, dated 22 May 2023).

Instrumentation and analytical equipment

Metal concentrations were determined using a PerkinElmer PinAAcle 900T atomic absorption spectrophotometer equipped with a graphite furnace accessory for Cd and Cr, and a flame module for Pb and Zn. Detection limits were 0.002 mg/L for Cd, 0.005 mg/L for Cr, 0.01 mg/L for Pb, and 0.005 mg/L for Zn. Tissue weights were recorded on a Mettler Toledo ME204 analytical balance (readability 0.1 mg). A muffle furnace (Carbolite CWF 1100) was used for dry-ashing at 450°C. All glassware was acid-washed in 10% HNO₃ and rinsed with deionized water prior to use.

Methods

Crabs were dissected and gill, hepatopancreas, and muscle tissues were separated, freeze-dried for 48 hours, and ground to a fine powder. Approximately 0.5 g of dried tissue was digested in a mixture of concentrated HNO₃ and HClO₄ (4:1 v/v) on a hot plate at 120°C until a clear solution was obtained [8]. Digests were diluted to 25 mL with deionized water and filtered through Whatman No. 42 paper. Certified reference material (DORM-5, National Research Council Canada) was processed alongside each batch. Metal concentrations were expressed as mg/kg dry weight. Health risk was calculated as $THQ = (Efr \times EDur \times FIR \times C) / (RfD \times BW \times AT \times 10^3)$, where EFr = 365 days, EDur = 30 years, FIR = daily ingestion rate (28 g/day for Egyptian coastal populations), C = metal concentration in muscle tissue, RfD = oral reference dose, BW = 70 kg, and AT = 10,950 days [9]. The hazard index was the sum of individual THQ values.

Quality control and calibration

Recovery rates for the certified reference material DORM-5 were 94.3% for Pb, 97.1% for Cd, 92.8% for Cr, and 98.6% for Zn, all within the acceptable 85–110% range. Calibration curves for each metal were constructed from five-point standard series prepared from Merck CertiPUR single-element standards, with correlation coefficients exceeding 0.998. Every tenth sample was analyzed in duplicate, and relative standard deviations remained below 6.4%. Procedural blanks were included in each digestion batch and returned values below detection limits for all four metals.

Results

Table 1: Mean heavy metal concentrations (mg/kg dry weight) in *Scylla serrata* tissues across four sampling stations

Station	Tissue	Pb	Cd	Cr	Zn
A	Muscle	4.82	0.73	2.14	41.3
A	Hepato.	9.17	2.18	4.63	87.2
A	Gill	6.43	1.42	3.37	63.8
B	Muscle	7.31	1.12	3.48	52.7
B	Hepato.	15.8	3.27	6.91	104.6
B	Gill	10.2	2.04	5.13	78.4
C	Muscle	12.6	1.89	5.27	68.3
C	Hepato.	23.4	4.71	9.82	138.7
C	Gill	17.1	3.38	7.46	97.1
D	Muscle	3.94	0.61	1.87	37.8
D	Hepato.	7.63	1.84	3.94	72.4
D	Gill	5.28	1.17	2.81	54.2

Values are means of quarterly sampling (n = 30 per station per season). Hepato. = hepatopancreas

Metal concentrations followed a consistent tissue ranking across all stations: hepatopancreas > gill > muscle. Station C recorded the highest values for every metal–tissue combination, with hepatopancreas Pb reaching 23.4 mg/kg and Cd at 4.71 mg/kg. Station D, the least disturbed site, had the lowest concentrations overall, though even there, hepatopancreas Pb was nearly double the muscle value.

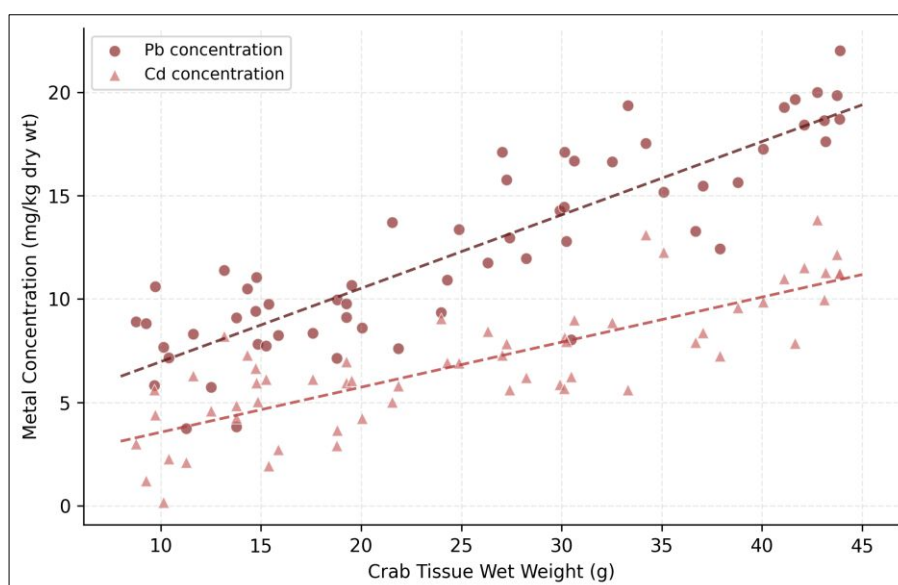


Fig 1: Scatter plot showing the relationship between crab tissue wet weight and concentrations of Pb and Cd, with regression lines indicating positive correlation at all sampling stations

Table 2: Target hazard quotient (THQ) and hazard index (HI) for muscle tissue consumption at each station

Station	THQ Pb	THQ Cd	THQ Cr	THQ Zn	HI
A	0.47	0.28	0.18	0.11	1.04
B	0.71	0.43	0.29	0.14	1.57
C	1.22	0.73	0.44	0.18	2.57
D	0.38	0.24	0.16	0.10	0.88

THQ > 1.0 and HI > 1.0 are shown in bold context. RfD values: Pb = 0.004, Cd = 0.001, Cr = 1.5, Zn = 0.3 mg/kg/day

THQ for Pb exceeded 1.0 at Station C (1.22), while the combined HI surpassed 1.0 at Stations A (1.04), B (1.57), and C (2.57). Station D was the only site where HI remained

below the safety threshold (0.88). Cd contributed the second-largest share to overall risk at every station.

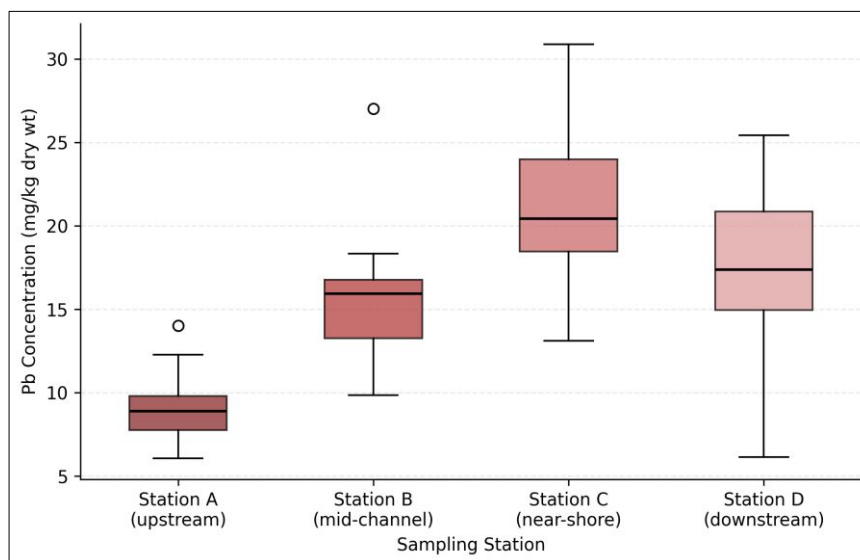


Fig 2: Box plot of Pb concentrations (mg/kg dry weight) in crab muscle tissue across four sampling stations, showing elevated median and spread at Station C

Discussion

The hepatopancreas consistently accumulated the highest metal loads, which aligns with its known role as the main organ for metal detoxification and storage in decapod crustaceans [10]. Metallothionein proteins in hepatopancreatic cells bind divalent cations and sequester them in lysosomal granules, effectively concentrating metals far above ambient water levels [11]. For consumers who eat the whole crab including the "mustard" or hepatopancreatic tissue metal exposure could be substantially higher than estimates based on muscle alone.

Station C's proximity to a boat-repair yard almost certainly explains its elevated contamination. Antifouling paints contain copper and zinc compounds, and scraping operations release particulate metal directly into adjacent waters [12]. Lead may originate from leaded fuel residues in older vessel engines, a source that persists in parts of the developing world despite global phase-out efforts [4].

The hazard index exceeding 1.0 at three of four stations is concerning but should be interpreted alongside actual consumption patterns. Our calculation assumed daily intake of 28 g of crab muscle, which may overestimate exposure for occasional consumers but could underestimate it for subsistence fishers who eat crabs several times per week [13]. A more detailed dietary survey would refine these estimates.

Conclusion

This research documented elevated heavy metal concentrations in mangrove crabs from the Hurghada coastline, with the hepatopancreas serving as the primary

accumulation organ. Station C, near a boat-repair yard, represented a contamination hotspot where Pb-related health risk through muscle consumption alone exceeded safe thresholds. The combined hazard index also surpassed 1.0 at two additional stations. These results call for targeted consumption advisories, particularly for subsistence fishers who rely on crabs as a protein source. Regular monitoring of both sediment and biota metal levels, combined with stricter regulation of boat-maintenance waste disposal, would help protect both ecosystem health and human well-being along this coastline.

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