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Heavy Metals Accumulation in Different Models of Aquatic Organisms in Shatt Al-Arab River-Basrah-Iraq

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ABSTRACT

This study assessed heavy-metal contamination and bioaccumulation in the muscle tissues of two aquatic species, greenback mullet (*Planiliza subviridis*) and Jinga shrimp (*Metapenaeus affinis*), and evaluated the potential risks associated with their consumption. Three sites (Alsiba, Alnajibiya, and Almashab) along the Shatt Al-Arab River were studied from December 2020 to November 2021. Concentrations of lead (Pb), cadmium (Cd), copper (Cu), and iron (Fe) were measured using flame atomic absorption spectrophotometry (FAAS). Lead concentrations were lowest during autumn at all sites and highest during summer and winter. Cadmium was not detected (ND) during winter, spring, or autumn at any site and reached its highest concentrations during summer. Copper was not detected during winter at the Alsiba and Alnajibiya sites, whereas the highest copper concentrations were recorded during spring and autumn. The highest iron concentrations were recorded during spring, summer, and autumn, while the lowest occurred during winter. The annual average concentrations of heavy metals in greenback mullet muscle were 981.654, 6.202, 4.153, and 0.175 µg/g dry weight for iron, lead, copper, and cadmium, respectively. In Jinga shrimp tissues, the annual average concentrations were 1470.173, 21.58, 19.06, and 0.22 µg/g dry weight for iron, copper, lead, and cadmium, respectively. Overall, heavy-metal concentrations in Jinga shrimp tissues were higher than those in greenback mullet muscle, indicating a greater contamination burden in the crustacean than in the fish.

INTRODUCTION

Heavy-metal pollution of water bodies is a serious global concern because of its far-reaching effects on living organisms, including disease risks in humans and adverse impacts on aquatic ecosystems and the survival of aquatic biota **(Aly *et al.*, 2020; Suchana *et al.*, 2021; Shahjahan *et al.*, 2022)**. Heavy-metal contamination can reduce biodiversity in aquatic environments and poses substantial risks to public health when toxic metals accumulate in edible aquatic organisms at concentrations above acceptable limits **(Mustafa *et al.*, 2024)**. Fish can accumulate pollutants and other hazardous substances from their surrounding environment, making them useful indicators of contamination in aquatic ecosystems **(Fatima *et al.*, 2020; Sarkar & Islam, 2020)**. Heavy metals are among the most important environmental pollutants because of their persistence and their toxic effects on aquatic organisms, even when some are present at low concentrations **(Parihar *et al.*, 2019)**. Human exposure may occur through polluted drinking water and the consumption of contaminated fish and other aquatic organisms. Following uptake, heavy metals can accumulate in organs and tissues such as the brain, muscle, lungs, liver, and kidneys, potentially leading to serious health effects **(Isangedighi & David, 2019; Kumar *et al.*, 2019; Fu and Xi, 2020)**.

Urbanization and industrialization are major sources of heavy-metal pollution and can have significant effects on aquatic organisms and human health **(Yarur *et al.*, 2019; Ya-jun Hong *et al.*, 2020)**. Although heavy metals occur naturally in the environment, extensive industrial use and the uncontrolled discharge of untreated wastes can substantially increase their concentrations in aquatic ecosystems **(Singare & Dhabarde, 2014; Sarkar *et al.*, 2022)**.

Some heavy metals, including mercury, cadmium, lead, chromium, and arsenic, have no known biological function and can produce acute and chronic toxic effects even at low concentrations. Their non-biodegradable nature also allows them to persist for long periods in aquatic environments **(Al-Hejuje, 2014; Ali & Khan, 2018; Mitra *et al.*, 2022)**. In contrast, essential elements such as copper, iron, and zinc are required in trace amounts but become toxic when present at excessive concentrations **(Kar *et al.*, 2008)**. Heavy metals can enter aquatic animals through the skin and gills and may subsequently accumulate in the liver, muscle, kidneys, and other tissues **(Makedonski *et al.*, 2017; Singh *et al.*, 2020)**.

Heavy metals in water and aquatic organisms may originate from natural sources, such as rock weathering and forest fires, as well as from human activities including sewage discharge, untreated industrial effluents, and agricultural practices. The use of fertilizers, herbicides, and pesticides containing metals such as copper, zinc, and arsenic can increase metal loads in rivers **(Angon *et al.*, 2024)**. Shipping and port activities can also contribute to contamination through fossil-fuel combustion, fuel residues, and emissions containing metals such as mercury and lead **(Briffa *et al.*, 2020; Maciejczyk *et al.*, 2021; Haiping *et al.*, 2022)**.

Crustaceans occupy important positions in aquatic food webs and many are benthic organisms that feed on algae, phytoplankton, small drifting organisms, and detritus. Shrimp are important food sources for humans and aquatic predators and can accumulate heavy metals in their tissues **(Mazlum *et al.*, 2016; Ali *et al.*, 2019; Pandiyan *et al.*, 2020)**. The accumulation of heavy metals in aquatic ecosystems has therefore become an important environmental concern associated with anthropogenic pollution **(Yilmaz *et al.*, 2017)**.

Studies using the same shrimp species, metals, and sampling locations can yield different results because contamination patterns vary with environmental and biological conditions, while adverse human-health effects may arise after long-term consumption of contaminated crustaceans **(Can *et al.*, 2021)**. Increasing attention is consequently being directed toward seafood safety and the maintenance of food quality within acceptable limits. Fish and shrimp are valuable sources of highly digestible protein, vitamins, minerals, and polyunsaturated fatty acids, yet aquatic organisms are also vulnerable to metal contamination in polluted ecosystems **(Diaz *et al.*, 2018)**. **Coffie (2014)**, **Al-Naggar *et al.* (2018)** and **Al-Darraji *et al.* (2023)** reported that environmental heavy-metal levels can increase as a consequence of industrial wastes, agricultural activities, and mining. Previous monitoring of the Shatt Al-Arab system demonstrated that industrial discharges can contribute measurable heavy-metal loads to river water, reinforcing the need to relate tissue accumulation to local anthropogenic inputs **(Al-Darraji *et al.*, 2023)**.

The present study aims to assess heavy-metal concentrations in greenback mullet (*P. subviridis*) and Jinga shrimp (*M. affinis*) as two different aquatic models and to examine their variation in relation to selected physicochemical parameters.

MATERIALS AND METHODS

Study Area

The study was conducted at three sites (Alsiba, Alnajibiya, and Almashab) along the Shatt Al-Arab River (Table 1 & Fig. 1). The Alsiba site is located on the right bank of the Shatt Al-Arab River, opposite the refinery in the Iranian city of Abadan. The Alnajibiya site is located near the Najibiyah thermal power plant. The Almashab site is located on the Karma Ali River, northwest of Basrah, and extends toward Hor Al-Hamar Marsh, approximately 5 km from the Alnajibiya site.

Table 1. Geographical coordinates of the study sites.

Sites	Northern coordinates	Eastern coordinates
Alsiba	N 20° 30’ 14.07”	E 48° 48’ 3.81”
Alnajibiya	N 34° 30’ 18.57”	E 46° 47’ 42.72”
Almashab	N 37° 30’ 50.67”	E 42° 47’ 2.40”

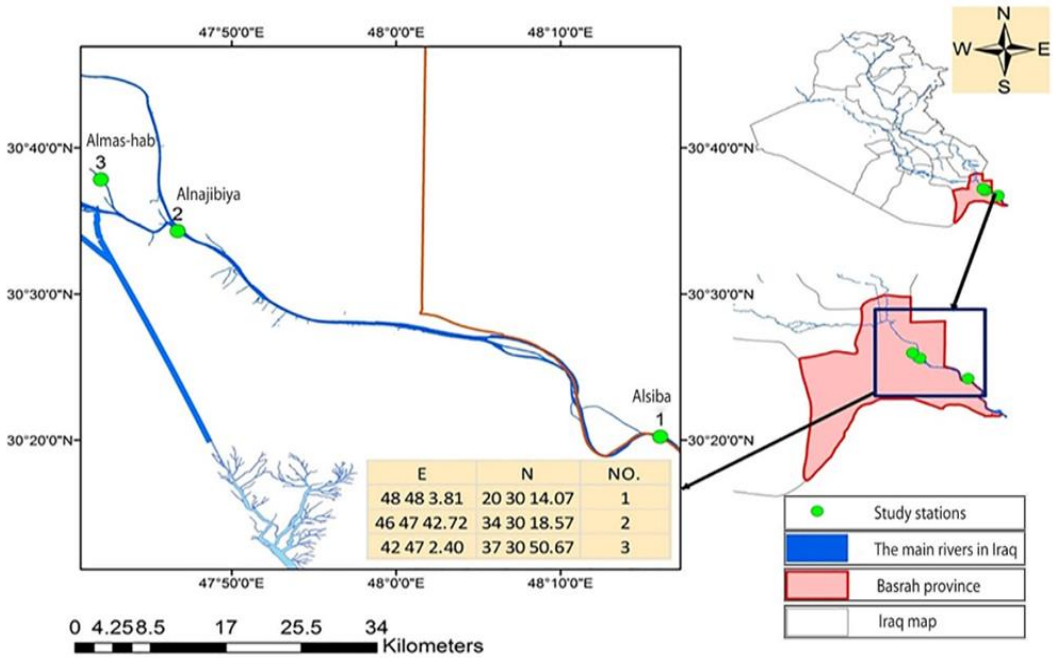


Fig. 1. Map of the Shatt Al-Arab River showing the study stations.

Heavy Metals

Extraction of Heavy Metals from Fish and Shrimp Muscle Tissues

Heavy metals (lead, cadmium, copper, and iron) were extracted from the muscle tissues of the aquatic specimens according to the **ROPME (1982)** method. For each dried and pre-ground fish or shrimp muscle sample, 0.5 g was transferred separately into a 150-mL Pyrex digestion tube. The sample was digested with 2 mL of a concentrated nitric acid (HNO_3) and perchloric acid ($HClO_4$) mixture (1:1; 1 mL of each acid). The tubes were thoroughly shaken and left for 16–24 h. They were then placed in a water bath at 70 °C for 30 min to complete the initial digestion, followed by heating on a hot plate until the mixture became clear. The digest was diluted to a final volume of 25 mL with deionized water and filtered through a 0.45-µm Millipore filter to remove particulate matter. Results were expressed as µg/g dry weight.

The concentrations of lead, cadmium, copper, and iron in the prepared samples were measured using a flame atomic absorption spectrophotometer (FAAS) equipped with an appropriate cathode lamp. The analytical wavelengths used for each element are presented in Table (2).

Table 2. Absorption wavelengths (nm) used for heavy-metal determination.

Heavy metals	lead	cadmium	copper	iron
Wavelengths	217.0	228.8	324.7	248.3

Statistical Analysis

The results were analyzed by analysis of variance (ANOVA) using the Statistical Package for the Social Sciences (SPSS), version 26. Duncan's multiple-range test was applied at a significance level of $p \leq 0.05$.

RESULTS

Seasonal variations in selected physicochemical parameters of the Shatt Al-Arab River, including air and water temperature, pH, salinity, total suspended solids, and dissolved oxygen, are presented in Table (3). The study also determined lead, cadmium, copper, and iron concentrations in the muscle tissues of greenback mullet and Jinga shrimp at the three study sites. A total of 60 fish and 80 shrimp samples were analyzed.

Table 3. Seasonal variation in physicochemical parameters of the Shatt Al-Arab River.

Physicochemical parameters	sites	Seasonal variation per season			
		Winter	Spring	Summer	Autumn
Air Temperature (C◦)	Alsiba	20.50	31.0	43.0	34.0
	Alnajibiya	19.50	30.0	44.50	32.50
	Almashab	17.50	27.50	42.50	31.0
Water Temperature (C◦)	Alsiba	17.75	26.50	36.50	30.25
	Alnajibiya	16.00	25.25	38.00	28.50
	Almashab	14.50	24.0	36.0	27.75
pH	Alsiba	8.23	7.68	8.22	8.19
	Alnajibiya	7.87	7.58	8.18	7.93
	Almashab	7.88	7.36	7.95	8.47
Salinity (ppt)	Alsiba	2.77	3.25	11.1	6.19
	Alnajibiya	2.64	2.82	10.3	5.65
	Almashab	3.29	3.86	10.85	8.76

Total Suspended Solid (T.S.S) mg/L	Alsiba	5.50	7.50	11.55	9.58
	Alnajibiya	3.0	4.50	6.23	8.09
	Almashab	3.75	5.0	10.45	9.19
Dissolved Oxygen (DO) mg/L	Alsiba	9.50	8.10	4.62	6.00
	Alnajibiya	8.70	7.80	4.02	5.60
	Almashab	10.10	7.30	5.19	6.10

Concentrations of Heavy Metals in the Muscle of Greenback Mullet, *P. subviridis*

Lead (Pb)

Fig. (2) shows seasonal variation in lead concentrations in the muscle tissues of greenback mullet. The highest values were recorded during summer at Alsiba, Alnajibiya, and Almashab (8.3, 10.5, and 18.5 µg/g dry weight, respectively), whereas the lowest values were recorded during autumn (0.12, 0.22, and 0.35 µg/g dry weight, respectively). During winter, lead concentrations were 4.469, 6.089, and 15.056 µg/g dry weight at Alsiba, Alnajibiya, and Almashab, respectively. During spring, the corresponding concentrations were 5.23, 3.14, and 2.45 µg/g dry weight. Statistical analysis showed no significant differences among study sites (p = 0.99), whereas differences among seasons were significant (p = 0.00).

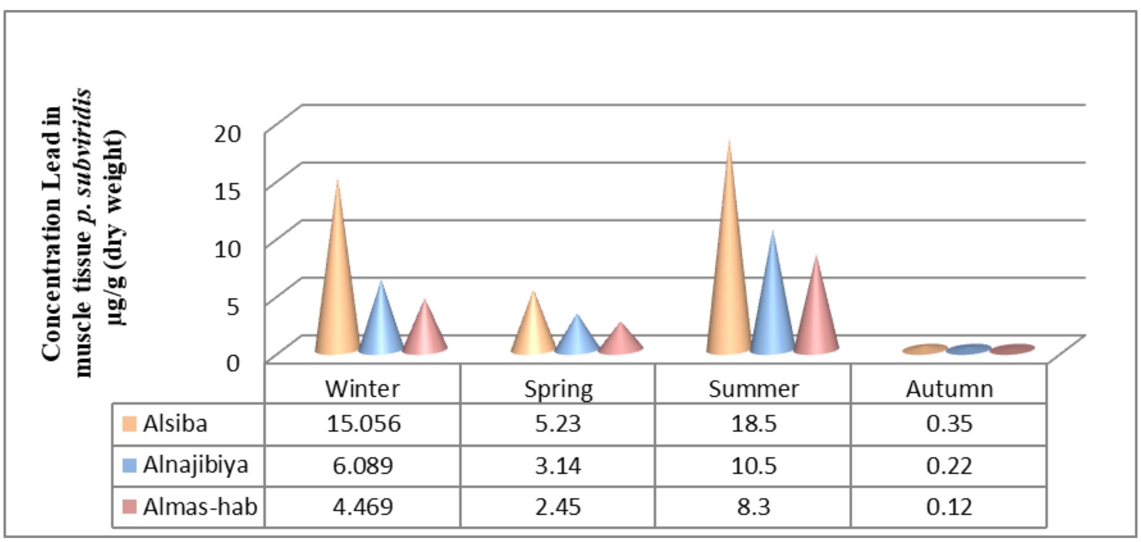


Fig. 2. Seasonal variation in lead concentration in the muscle of greenback mullet, *P. subviridis*, at the study sites.

Cadmium (Cd)

Fig. (3) shows seasonal cadmium concentrations in greenback mullet muscle. The highest values occurred during summer and were 0.8, 0.6, and 0.7 µg/g dry weight at Alsiba, Alnajibiya, and Almashab, respectively. Cadmium was not detected by atomic absorption spectrophotometry during winter, spring, or autumn at any site. Statistical analysis showed no significant differences among study sites (p = 0.99), whereas differences among seasons were significant (p = 0.00).

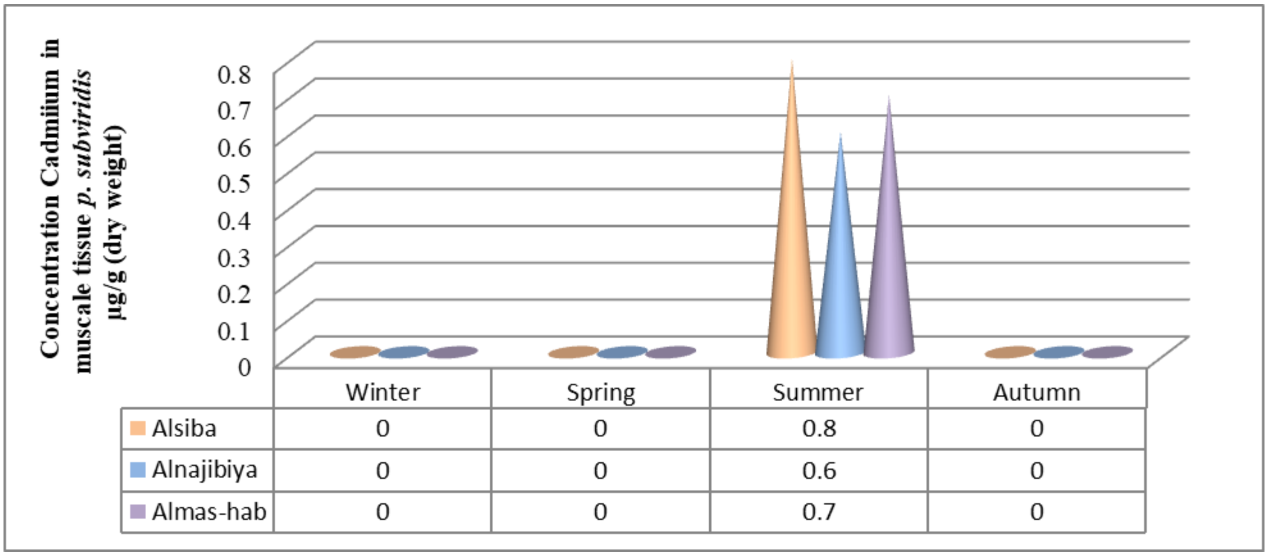
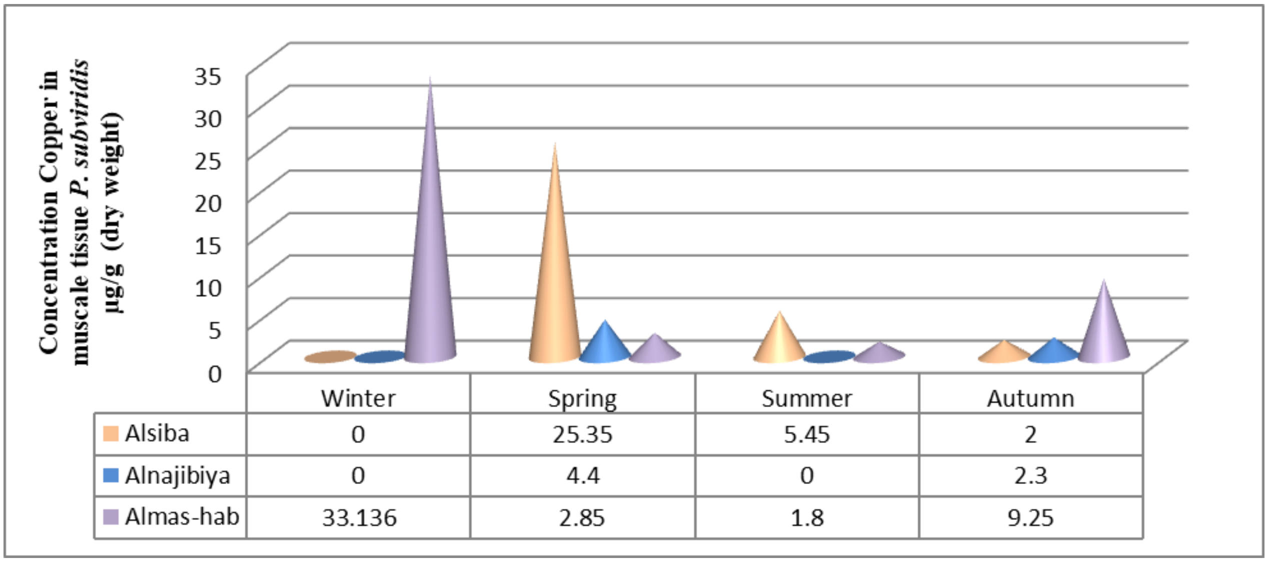


Fig. 3. Seasonal variation in cadmium concentration in the muscle of greenback mullet, *P. subviridis*, at the study sites.

Copper (Cu)

Fig. (4) shows seasonal copper concentrations in the muscle tissues of greenback mullet. The highest value, 11.14 µg/g dry weight, was recorded during winter at Almashab, whereas copper was not detected during winter at Alsiba or Alnajibiya. During spring, concentrations were 10.35, 4.4, and 2.85 µg/g dry weight at Alsiba, Alnajibiya, and Almashab, respectively. During summer, they were 1.8, 1.3, and 5.45 µg/g dry weight, respectively, and during autumn they were 3.0, 2.3, and 7.25 µg/g dry weight, respectively. Statistical analysis showed no significant differences in Cu concentrations among sites (p = 0.44) or seasons (p = 0.74).

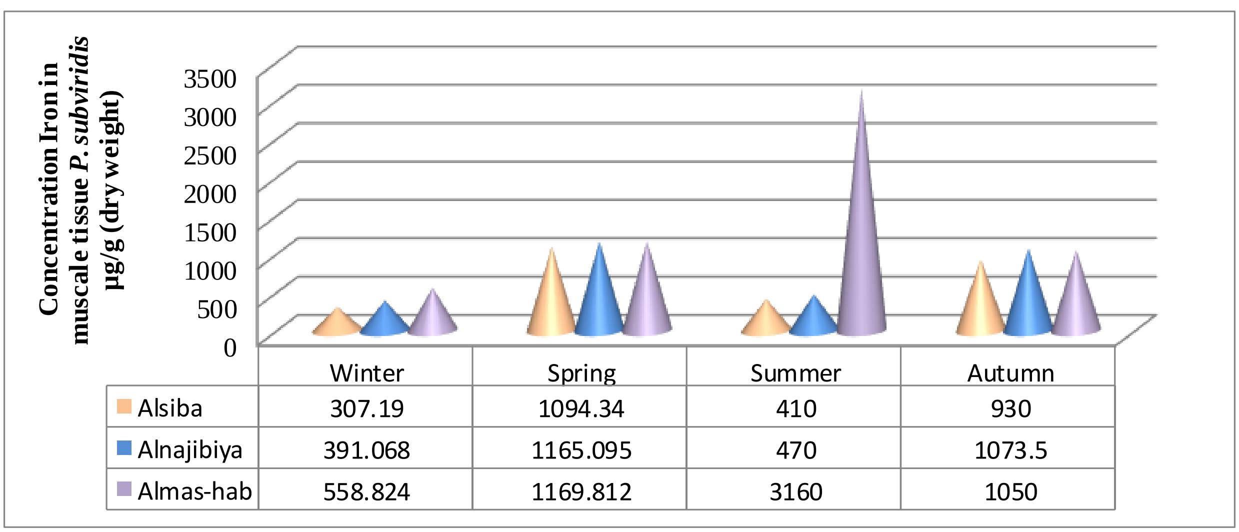


	Winter	Spring	Summer	Autumn
Alsiba	0	25.35	5.45	2
Alnajibiya	0	4.4	0	2.3
Almas-hab	33.136	2.85	1.8	9.25

Fig. 4. Seasonal variation in copper concentration in the muscle of greenback mullet, *P. subviridis*, at the study sites.

Iron (Fe)

Iron concentrations in greenback mullet muscle were considerably higher than those of the other measured metals. The highest value, 3160.0 µg/g dry weight, was recorded at Almashab during summer. During spring, concentrations were 1094.340, 1165.095, and 1169.812 µg/g dry weight at Alsiba, Alnajibiya, and Almashab, respectively; during autumn, they were 930.0, 1073.5, and 1050.0 µg/g dry weight, respectively. During winter, concentrations were 307.190, 391.068, and 558.824 µg/g dry weight, respectively. Statistical analysis showed no significant differences in Fe concentrations among sites (p = 0.29) or seasons (p = 0.54) (Fig. 5).



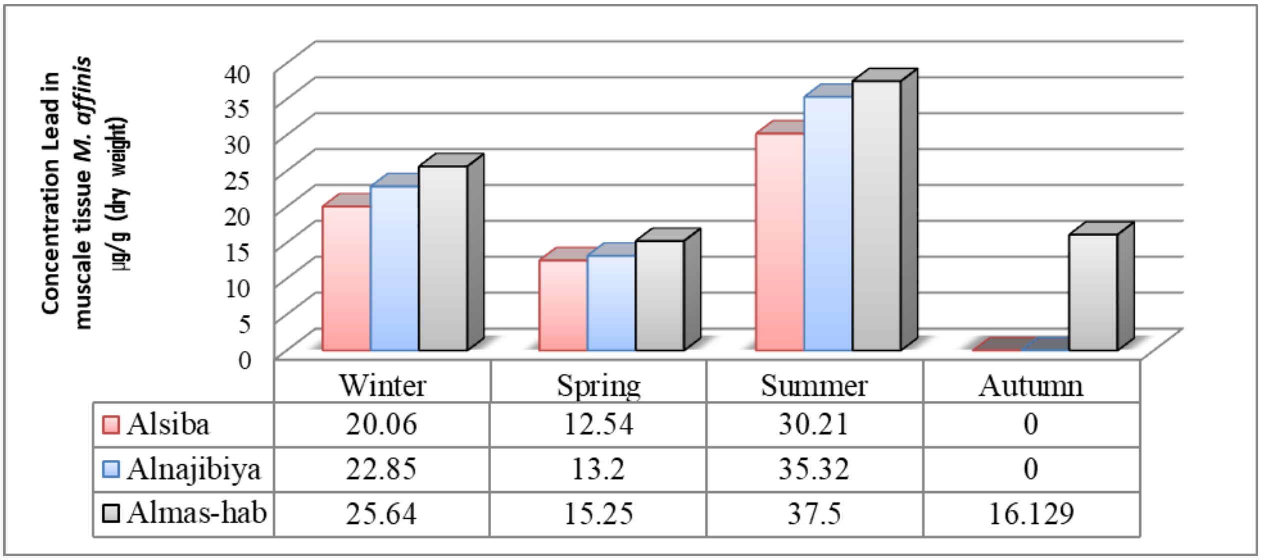
	Winter	Spring	Summer	Autumn
Alsiba	307.19	1094.34	410	930
Alnajibiya	391.068	1165.095	470	1073.5
Almas-hab	558.824	1169.812	3160	1050

Fig. 5. Seasonal variation in iron concentration in the muscle of greenback mullet, *P. subviridis*, at the study sites.

Concentrations of Heavy Metals in the Muscle of Jinga Shrimp, *M. affinis*

Lead (Pb)

Fig. (6) shows seasonal changes in lead concentration in Jinga shrimp muscle. The highest values were recorded during summer at Alsiba, Alnajibiya, and Almashab (30.21, 35.32, and 37.5 µg/g dry weight, respectively). No lead was detected by spectrophotometry during autumn at Alsiba or Alnajibiya. During winter, concentrations were 20.06, 22.85, and 25.64 µg/g dry weight at Alsiba, Alnajibiya, and Almashab, respectively; during spring, they were 15.25, 13.2, and 12.54 µg/g dry weight, respectively. Statistical analysis showed no significant differences among sites ($p = 0.99$), whereas differences in Pb concentrations among seasons were significant ($p = 0.00$).



	Winter	Spring	Summer	Autumn
Alsiba	20.06	12.54	30.21	0
Alnajibiya	22.85	13.2	35.32	0
Almas-hab	25.64	15.25	37.5	16.129

Fig. 6. Seasonal variation in lead concentration in the muscle of Jinga shrimp, *M. affinis*, at the study sites.

Cadmium (Cd)

Fig. (7) shows seasonal cadmium concentrations in Jinga shrimp muscle. The highest concentrations occurred during summer and were 0.8, 0.6, and 0.5 µg/g dry weight at Alsiba, Alnajibiya, and Almashab, respectively. Cadmium was not detected by atomic absorption spectrophotometry during winter or spring at any site, or during autumn at Alsiba and Alnajibiya. Statistical analysis showed no significant differences in Cd concentrations among sites ($p = 0.77$), whereas differences among seasons were significant ($p = 0.00$).

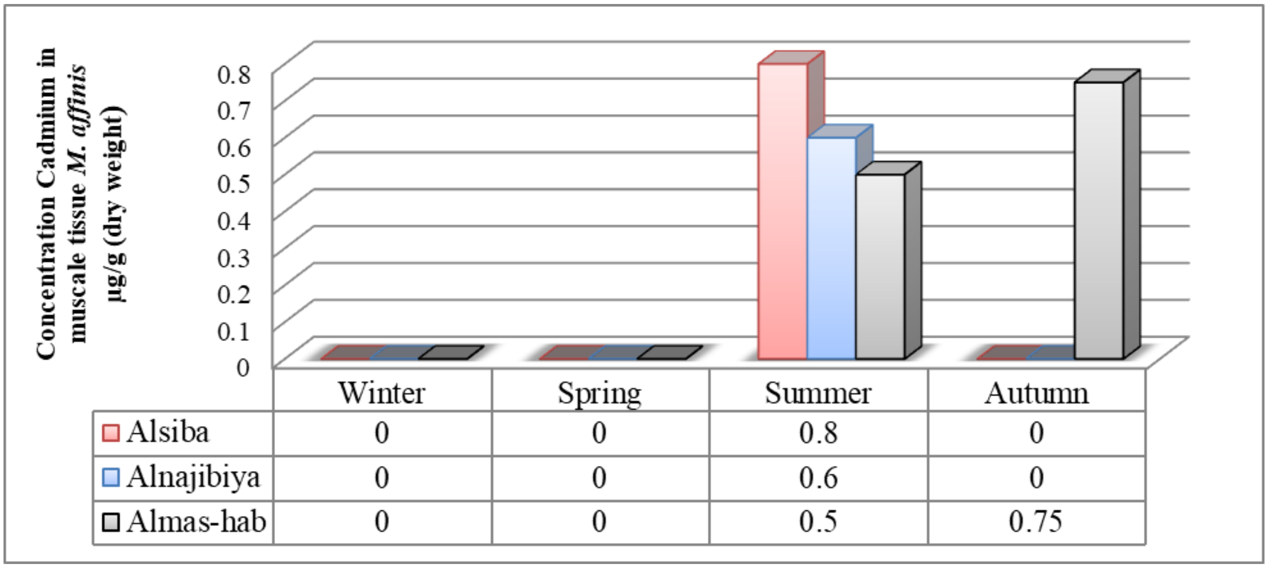


Fig. 7. Seasonal variation in cadmium concentration in the muscle of Jinga shrimp, *M. affinis*, at the study sites.

Copper (Cu)

Fig. (8) shows seasonal copper concentrations in Jinga shrimp muscle. The highest values were recorded during autumn at Alsiba, Alnajibiya, and Almashab (32.85, 28.65, and 30.15 µg/g dry weight, respectively), with relatively small differences among sites. The lowest values were recorded during summer (13.45, 11.25, and 14.1 µg/g dry weight, respectively). During winter, concentrations were 26.23, 13.41, and 28.14 µg/g dry weight, respectively, and during spring they were 14.3, 23.5, and 22.95 µg/g dry weight, respectively. Statistical analysis showed no significant differences in Cu concentrations among sites ($p = 0.88$), whereas differences among seasons were significant ($p = 0.00$).

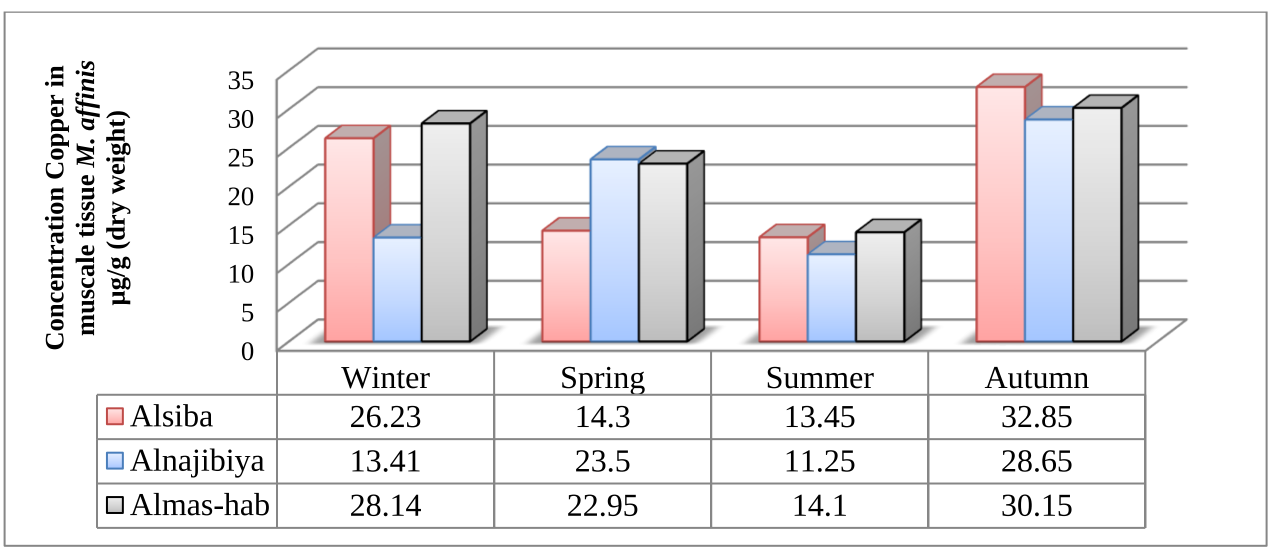
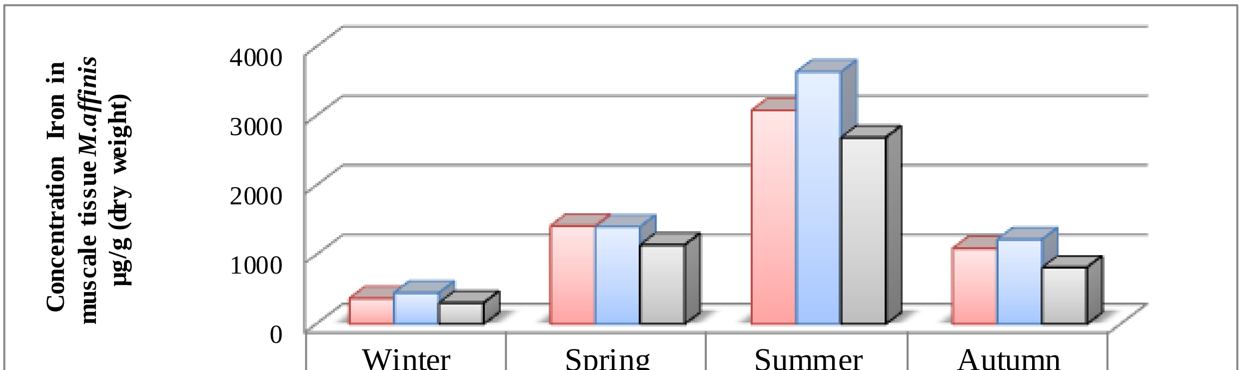


Fig. 8. Seasonal variation in copper concentration in the muscle of Jinga shrimp, *M. affinis*, at the study sites.

Iron (Fe)

Fig. (9) presents iron concentrations in Jinga shrimp muscle. The highest values were recorded during summer (2690.0, 3080.0, and 3640.0 µg/g dry weight in Almashab, Alsiba, and Alnajibiya, respectively), whereas the lowest values occurred during winter (305.011, 370.37, and 449.891 µg/g dry weight in Almashab, Alsiba, and Alnajibiya, respectively). During spring, concentrations were 1419.812, 1405.661, and 1146.227 µg/g dry weight at Alsiba, Alnajibiya, and Almashab, respectively. During autumn, they were 1095.0, 1225.0, and 815.0 µg/g dry weight, respectively. Statistical analysis showed no significant differences among sites (p = 0.87), whereas differences among seasons were significant (p = 0.00).



	Winter	Spring	Summer	Autumn
Alsiba	370.37	1419.812	3080	1095
Alnajibiya	449.891	1405.661	3640	1225
Almas-hab	305.011	1146.227	2690	815

Fig. 9. Seasonal variation in iron concentration in the muscle of Jinga shrimp, *M. affinis*, at the study sites.

DISCUSSION

Marked differences in heavy-metal concentrations were observed in the muscle tissues of greenback mullet and Jinga shrimp across seasons and study sites. These fluctuations may be related to seasonal variation in environmental factors, including temperature, pH, salinity, total suspended solids, and dissolved oxygen, as well as to biological characteristics of the organisms. Differences in metal accumulation among species may also reflect age, sex, maturity, feeding habits, and species-specific capacities to accumulate metals **(Łuczyńska *et al.*, 2018; Ramos-Miras *et al.*, 2019)**.

Environmental factors influence the behavior and bioavailability of metals in aquatic systems. Increasing temperature can enhance solubility and chemical activity, while pH affects metal dissolution and mobility in water **(Phillips & Russo, 1978)**. Higher temperatures can also increase evaporation rates and promote decomposition of organic matter, particularly during summer and autumn **(Moyle & Hussain, 2015)**. Lower pH can increase the solubility and potential toxicity of some metals **(Fang & Lin, 2002)**. Dissolved oxygen is another important abiotic factor in aquatic environments because it is influenced by photosynthesis, respiration, temperature, dissolved salts, and microbial decomposition of organic matter **(Davies & Day, 1998)**.

Heavy metals can accumulate in specific tissues of aquatic animals, including the gills, skin, liver, kidneys, and muscle. Such accumulation in fish may represent a risk to consumers **(Gautam *et al.*, 2016)**. Greenback mullet is a detritivorous fish **(Mohamed & Abood, 2019)**, and its feeding habits may facilitate exposure to metals associated with sediments and detrital material. Metals present in water and sediments can also be incorporated into bacteria, worms, phytoplankton, and zooplankton and subsequently transferred to fish through feeding, contributing to bioaccumulation in body tissues **(Nadia *et al.*, 2017)**.

Greenback mullet (*P. subviridis*) exhibited seasonal variation in heavy-metal concentrations in the Shatt Al-Arab River. Iron and lead occurred at the highest concentrations, whereas copper and cadmium were lower. The distribution of metals among tissues may vary, with some metals accumulating in muscle and others concentrating more strongly in the kidneys and liver because of their roles in detoxification and metal metabolism **(Zaghloul *et al.*, 2024)**.

Seasonal variation in lead concentrations across the study sites may be associated with anthropogenic activities, including vehicle emissions, wastewater discharge, agricultural production, refining, mining, and battery manufacturing. The annual average lead concentration in muscle tissue was 6.202 µg/g dry weight, which the study classifies as within the cited permissible limits.

Cadmium was detected in greenback mullet muscle only during summer. The annual average cadmium concentration was 0.175 µg/g dry weight. Elevated metal concentrations in fish tissues may be associated with increased feeding on algae and organic detritus that contain accumulated metals **(Peng *et al.*, 2018)**. Cadmium inputs may also arise from phosphate fertilizers and industrial activities, with subsequent uptake and bioaccumulation in fish muscle. Because cadmium is highly toxic, long-term accumulation in edible fish tissues may pose risks to human health **(Zhang & Reynolds, 2019)**.

Copper concentrations fluctuated among seasons, with an annual average of 4.153 µg/g dry weight. These variations may reflect anthropogenic inputs such as refinery-related oil contamination, paints, and boat fuels, which can introduce variable amounts of copper into the study area.

Iron occurred at substantially higher concentrations than the other measured metals in greenback mullet muscle across all sites and seasons, with an annual average concentration of 981.652 µg/g dry weight. This pattern may reflect the comparatively high iron availability in the Shatt Al-Arab River.

Al-Khafaji and Hussein (2016) reported elevated annual concentrations of lead, cadmium, and copper in the muscle of common carp (*C. carpio*) and zilli tilapia (*T. zillii*) from the Diwaniyah River. **Saleh *et al.* (2018)** reported lead, cadmium, and iron concentrations in the muscles of *Planiliza abu*, *C. carpio*, and *L. vorax* from the Euphrates River in Iraq. **Shaker and Wahab (2020)** described cadmium and copper accumulation in the muscle of *L. vorax*, *Chondrostoma regium*, *Carasobarbus luteus*, and *Planiliza abu* from the Tigris River in Samarra. **Aldoghachi and Altamimi (2021)** also detected lead, cadmium, and copper in the Nile tilapia (*Oreochromis niloticus*) from the Shatt Al-Arab River. **Siregar *et al.* (2020)** reported cadmium and lead concentrations of 175.6 and 256.3 µg/g, respectively, in greenback mullet (*P. subviridis*) from the Donan River, Indonesia.

Based on the standards cited in this manuscript, the measured heavy-metal concentrations in greenback mullet muscle were considered suitable for human consumption when compared with the maximum permissible limits reported by the **World Health Organization (1985)**, **U.S. Federal Environmental Protection Agency (2003)**, **FAO (1985)** and **EPA (1989)**. Iron exceeded the limits cited from **FAO (1985)** and **EPA (1989)**. However, they remained within the limits cited from **WHO (1985)** and **U.S. FEPA (2003)**, as shown in Table (4).

Table 4. Heavy-metal concentrations (µg/g dry weight) in fish muscle in the current study and cited permissible limits for human consumption.

Heavy Metals	**FAO/WHO (1985)**	**EPA (1989)**	**WHO (1985) FEPA (2003)**	Current study (2022)
Lead	50	-	50	6.202
Cadmium	0.2	1.4	5	0.175
Copper	30	54	20	4.153
Iron	100	410	5000	981.652

Table 5. Heavy-metal concentrations in fish muscle tissues in the current study and previous studies.

<table>
<tr><th rowspan="2">Study area</th><th rowspan="2">Type of fish</th><th colspan="4">Heavy metals concentration
µg/g (dry weight)</th><th rowspan="2" colspan="2">Source</th></tr>
<tr><th>lead</th><th>cadmium</th><th>copper</th><th>iron</th></tr>
<tr><td rowspan="2">Diwaniyah River</td><td>C. carpio</td><td>2.90</td><td>1.69</td><td>5.09</td><td>-</td><td rowspan="2" colspan="2">Al-Khafaji and Hussein (2016)</td></tr>
<tr><td>T. zillii</td><td>2.04</td><td>1.23</td><td>2.68</td><td>-</td></tr>
<tr><td rowspan="3">Euphrates River/centr-al Iraq</td><td>Planiliza abu</td><td>0.098</td><td>0.023</td><td>-</td><td>0.271</td><td rowspan="3" colspan="2">Saleh et al. (2018)</td></tr>
<tr><td>C. carpio</td><td>0.087</td><td>0.019</td><td>-</td><td>0.149</td></tr>
<tr><td>L. vorax</td><td>0.963</td><td>0.041</td><td>-</td><td>0.267</td></tr>
<tr><td rowspan="4">Tigris River / Samarra city</td><td>L. vorax</td><td>-</td><td>0.229</td><td>9.482</td><td>-</td><td rowspan="4" colspan="2">Shaker and Wahab (2020)</td></tr>
<tr><td>Chondrostma regium</td><td>-</td><td>0.168</td><td>9.408</td><td>-</td></tr>
<tr><td>Carasobarbus luteus</td><td>-</td><td>0.163</td><td>6.188</td><td>-</td></tr>
<tr><td>P. abu</td><td>-</td><td>0.143</td><td>4.221</td><td>-</td></tr>
<tr><td>Shatt Al-Arab River</td><td>Oreochroms niloticus</td><td>0.03</td><td>0.03</td><td>0.05</td><td>-</td><td colspan="2">Aldoghachi and Altamimi (2021)</td></tr>
<tr><td rowspan="3">Shatt Al-Arab River</td><td rowspan="3">P. subviridis</td><td>0.35-18.5</td><td>0-0.8</td><td>0-10.35</td><td>307-1094</td><td>Alsiba</td><td rowspan="3">Current study (2022)</td></tr>
<tr><td>0.22-10.5</td><td>0-0.6</td><td>0-4.4</td><td>391-1165</td><td>Alnajibiya</td></tr>
<tr><td>0.12-8.3</td><td>0-0.7</td><td>1.8-11.14</td><td>558-1169</td><td>Almashab</td></tr>
</table>

Crustaceans occupy a basal position in many aquatic food chains and provide an important food source for fish and other aquatic organisms; therefore, metals accumulated in crustacean tissues may be transferred trophically. Jinga shrimp (*M. affinis*) exhibited seasonal variation in heavy-metal concentrations in the Shatt Al-Arab River and generally contained higher metal concentrations than greenback mullet muscle. Iron and lead occurred at the highest levels, followed by copper and cadmium. The reported annual average concentrations in Jinga shrimp were 1470.173 µg/g for iron, 21.58 µg/g for copper, 19.06 µg/g for lead, and 0.22 µg/g for cadmium. Differences in metal accumulation in crustaceans may reflect their trophic position, feeding habits, and direct exposure to contaminated sediments and water. The diet of *M. affinis* includes zooplankton, worms, and organic matter, which may account for 72–100% of stomach contents **(Su & Liao, 1984)**. Metal concentrations in surrounding water can also influence accumulation in aquatic organisms **(Al-Timari *et al.*, 2005)**. Additional variation may be associated with environmental contamination levels rather than biomass alone **(Taylor & Maher, 2003)**, sampling site, body part **(Kanakaraju *et al.*, 2008)**, and growth rate **(Zubcov *et al.*, 2012)**. Binding to metallothionein, a protein involved in the sequestration and detoxification of several metals, may also contribute to variation **(Klassen *et al.*, 1999; Sajwan *et al.*, 2008; Joksimovic *et al.*, 2011)**. **Sharifi *et al.* (2017)** reported iron and copper concentrations of 1.23 and 2.99 mg/kg, respectively, in the muscle of *Penaeus semisulcatus* from the Bahri-Kan coastal waters of Khuzestan Province, Iran.

Aytekin *et al.* (2019) reported lead, cadmium, copper, and iron concentrations of 39.935, 7.22, 27.13, and 19.973 µg/g dry weight, respectively, in *P. semisulcatus* muscle from the Yumurtalik coast of the Gulf of Iskenderun, Turkey. **Aldoghachi and Altamimi (2021)**, in a study conducted in the Shatt Al-Arab River near the Al-Najibiyah power plant, reported lead, cadmium, and copper concentrations of 0.18, 0.01, and 0.44 mg/kg, respectively, in *M. affinis*. Assessment of the same river system has also documented lead, cadmium, and copper in both water resources and the tissues of Nile tilapia and *M. affinis*, supporting the use of edible aquatic organisms as indicators of local metal contamination **(Aldoghachi & Altamimi, 2021)**.

Differences between the present results and previous studies may reflect species-specific ecology and habitat preferences, seasonal variation in biological activity and productivity, accumulation of metals in the environment, sampling location, environmental conditions, and differences in the sources and types of metal contamination.

Lead and cadmium are non-essential metals, and their occurrence at elevated concentrations in water and aquatic-organism tissues may indicate environmental contamination. Important sources include sewage and industrial wastewater discharged directly into water bodies. Vehicle emissions associated with leaded fuel have also been identified as potential sources of lead and cadmium contamination **(Fafioye *et al.*, 2002)**. Their presence in tissues may additionally reflect the capacity of aquatic organisms to bioaccumulate metals during long-term exposure through water and food **(Topouoglu *et al.*, 2002; Zhang & Wang, 2007)**.

Copper and iron are essential elements that play important roles in cellular metabolism, growth, and survival; consequently, comparatively high tissue concentrations may partly reflect physiological requirements **(Javaheri Baboli & Velayatzadeh, 2013)**. Increased copper concentrations in the aquatic environment may be reflected in aquatic-organism tissues. Potential anthropogenic sources of copper and iron include industrial wastewater, copper sulfate (CuSO4) used in metal-plating processes, anti-corrosion paints used on vessels, and effluents from paper, textile, chemical, pharmaceutical, and plastics industries **(Goldberg, 1975; Mitra & Chowdhury, 1993; Mitra *et al.*, 2011)**.

Aquatic organisms can acquire iron directly from the surrounding water through the gills or indirectly through food, which may contribute to its relatively high tissue concentration **(Soegianto, 2008)**. Continuous dietary intake can lead to iron accumulation when uptake exceeds excretion **(Kargin, 1996)**. Acute iron poisoning is comparatively uncommon but may be associated with hepatic toxicity **(Tenenbein, 2001)**. Physiologically, iron is an essential dietary element that contributes to homeostasis through its association with proteins and enzymes and, as a component of hemoglobin, plays a central role in oxygen transport **(Valko *et al.*, 2005)**.

When the current heavy-metal concentrations were compared with the values cited from the Food and Agriculture Organization/World Health Organization (FAO/WHO) and the European Union (EU) **(Nabavi *et al.*, 2012)**, lead, copper, and iron concentrations in Jinga shrimp muscle were higher than some of the listed reference values, whereas cadmium was lower (Table 6). The manuscript nevertheless classifies the measured concentrations in the edible muscle of Jinga shrimp as within permissible levels for human consumption.

Table 6. Heavy-metal concentrations (µg/g dry weight) in shrimp muscle in the current study and cited permissible levels for human consumption.

Heavy metals	**FAO (1992)**	**TFC (2011)**	**(FAO/WHO) (2011) and (EU))2008(**	Current study **(2022)**
Lead	0.5	0.3	2	19.06
Cadmium	0.5	0.05	1	0.22
Copper	30	20	20	21.58
Iron	-	-	-	1470.173

CONCLUSION

The Shatt Al-Arab River is continuously exposed to pollutants from multiple untreated effluent sources, including heavy metals. In greenback mullet muscle, iron concentrations were high and exceeded some of the cited permissible limits, whereas lead, cadmium, and copper did not exceed the limits cited in the manuscript. In Jinga shrimp muscle, iron, lead, and copper occurred at comparatively high concentrations, while cadmium occurred at lower levels. The annual average concentrations of iron, lead, copper, and cadmium were higher in Jinga shrimp than in greenback mullet. Heavy-metal concentrations in both fish and shrimp also varied seasonally. Continued monitoring and assessment of pollution are therefore recommended to support the safety and sustainability of aquatic organisms used for human consumption.

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