



Heavy Metal Contamination and Bioaccumulation of Cadmium, Nickel and Lead in Water and Fish Muscles from the Al-Diwaniyah River, Iraq

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ABSTRACT

Freshwater contamination by trace metals is an environmental issue of direct relevance to aquatic organisms and to communities that consume fish. This study examined cadmium (Cd), nickel (Ni), and lead (Pb) in river water and in the muscle of common carp (*Cyprinus carpio*) and *Silurus* spp. collected from the Al-Diwaniyah River, Iraq, during two sampling seasons. In each season, 45 water samples and 45 muscle samples from each fish species were examined. Water samples contained 0.016 ± 0.002 and 0.014 ± 0.004 $\mu\text{g/L}$ Cd in the first and second seasons, respectively. Nickel increased from 0.035 ± 0.010 to 0.074 ± 0.040 $\mu\text{g/L}$, while Pb increased from 0.016 ± 0.010 to 0.061 ± 0.040 $\mu\text{g/L}$. In common carp muscle, Cd declined from 0.29 ± 0.07 to 0.21 ± 0.10 $\mu\text{g/g}$ dry weight, Ni declined from 2.05 ± 0.38 to 0.72 ± 0.18 $\mu\text{g/g}$, and Pb declined from 12.91 ± 1.08 to 2.04 ± 0.73 $\mu\text{g/g}$. In *Silurus* muscle, Cd changed from 0.14 ± 0.07 to 0.15 ± 0.08 $\mu\text{g/g}$ dry weight, Ni increased from 3.95 ± 1.11 to 8.87 ± 4.12 $\mu\text{g/g}$, and Pb remained similar at 6.02 ± 2.41 and 5.90 ± 3.57 $\mu\text{g/g}$. The results indicate that metal accumulation varied according to both species and sampling season. Common carp had the highest Pb concentration during the first season, whereas *Silurus* had the highest Ni concentration during the second season. Continued monitoring of river water, sediments, and edible fish tissues is warranted to clarify temporal changes in metal exposure and their environmental significance (Kumar et al., 2024).

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1. Introduction

Metal contamination remains an important concern in freshwater environments because metals are persistent and can move between water, suspended material, sediments, and aquatic food webs. In contrast to many organic contaminants, metals are not readily broken down by biological processes. Compared to other biological indicators, the advantages of using fish to monitor water pollution lie in the fact that fish can accumulate metals from various sources (Ali et al., 2019; Ebrahimpour et al., 2011). Metals accumulated by fish can indicate long-term average contamination level of a water body (Patra and Akatti, 2020). However, determining the threshold levels for determining metal pollution by using fish is challenging (Patra and Akatti, 2020).

The characteristics of cadmium and lead and their biological effects make them extremely similar. Cadmium is considered more toxic and is invariably accumulated by fish at different levels depending upon several factors (Lee et al., 2021). Similar to cadmium, lead is also considered a toxic metal and fish often bioaccumulate lead at different levels (Ali et al., 2020). Like cadmium and lead, nickel is also a toxic metal but in contrast to them is essential at lower levels in some biological systems. Long term exposure to nickel can result in toxicity and its accumulation in aquatic organisms (Hossain et al., 2022).

Metal uptake is likely to vary between fish species. This is due to a number of factors including the fish's lifestyle, habits, and ecology; the fish's place in the food web (trophic position); the fish's age and physiological condition; how and how much the fish is exposed to water and sediment; and numerous other factors (Ebrahimipour et al., 2011; Kumar et al., 2024). For these reasons, assessment of multiple fish species usually gives more thorough information about the contamination of an aquatic system compared to assessment of a single fish species.

The Al-Diwaniyah River is an important waterway in the Al-Qadisiyah Governorate of Iraq that provides fish and other aquatic organisms. Given the potential role of fish from the Al-Diwaniyah River in the local food supply, it is important to determine the levels of heavy metals in fish to assess the status of water quality, as well as to assess the safety of fish for human consumption (Alhashemi et al., 2012). This study measured the levels of Cd, Ni and Pb in the water of the Al-Diwaniyah River, the muscle of common carp and other large catfish, as well as to determine the changes that occur over the different seasons and the differences that occur between the two species of fish.

2. Materials and Methods

2.1 Study Area

The study was limited to the Al-Diwaniyah River within the Iraqi Governorate of Al-Qadisiyah. Two seasons of sampling were conducted. During each season, river water and various fish species were sampled and prepared for laboratory analysis.

2.2 Fish Sampling

The studies were limited to the common carp (*Cyprinus carpio*) and *Silurus* spp. specimens. For each of the above species, a sample of 45 individuals was taken during each season. Hence, a total of 90 individuals of each of the above species were sampled. Muscle was selected for this study as it is the principal edible part of fish and reflects what is consumed (Ali et al., 2020).

2.3 Water Sampling

Forty-five water samples were collected in each season, for a total of 90 water samples. The samples were prepared for determination of Cd, Ni, and Pb, and the resulting water concentrations are reported in $\mu\text{g/L}$.

2.4 Sample Preparation and Heavy-Metal Analysis

Fish muscle samples were oven-dried until a constant weight was obtained. A 1.0-g portion of each dried sample was weighed and subjected to digestion and dissolution using an acid/ultra-pure-water preparation procedure. Water samples were filtered and prepared for analysis. Cadmium, nickel, and lead were quantified in the prepared samples using atomic absorption spectrophotometry (AAS) (Ali et al., 2020; Hossain et al., 2022).

2.5 Statistical Analysis

Results are expressed as mean $\pm$ standard deviation (SD). Differences between seasons were evaluated by analysis of variance (ANOVA), followed by the least significant difference (LSD) test. Statistical significance was considered at $P < 0.05$. Different superscript letters indicate statistically significant differences between seasonal means within the corresponding comparison.

3. Results

3.1 Heavy Metals in River Water

Metal	First season ($\mu\text{g/L}$), n=45	Second season ($\mu\text{g/L}$), n=45
Cd	0.016 ± 0.002 a	0.014 ± 0.004 a
Ni	0.035 ± 0.010 a	0.074 ± 0.040 b
Pb	0.016 ± 0.010 a	0.061 ± 0.040 b

Cadmium showed only a small seasonal decline, from 0.016 ± 0.002 $\mu\text{g/L}$ in the first season to 0.014 ± 0.004 $\mu\text{g/L}$ in the second. In contrast, Ni increased from 0.035 ± 0.010 to 0.074 ± 0.040 $\mu\text{g/L}$, an increase of about 111%. Lead showed the largest relative change, rising from 0.016 ± 0.010 to 0.061 ± 0.040 $\mu\text{g/L}$, or approximately 281%. Thus, the concentration sequence was $\text{Ni} > \text{Cd} \approx \text{Pb}$ in the first season and $\text{Ni} > \text{Pb} > \text{Cd}$ in the second season.

3.2 Heavy Metals in Common Carp Muscle

Metal	First season ($\mu\text{g/g}$ dry weight), n=45	Second season ($\mu\text{g/g}$ dry weight), n=45
Cd	0.29 ± 0.07 a	0.21 ± 0.10 b
Ni	2.05 ± 0.38 a	0.72 ± 0.18 b
Pb	12.91 ± 1.08 a	2.04 ± 0.73 b

All three measured metals were lower in common carp muscle during the second season. Cadmium declined from 0.29 ± 0.07 to 0.21 ± 0.10 $\mu\text{g/g}$ dry weight, while Ni declined from 2.05 ± 0.38 to 0.72 ± 0.18 $\mu\text{g/g}$. Lead showed the largest absolute concentration, reaching 12.91 ± 1.08 $\mu\text{g/g}$ in the first season before falling to 2.04 ± 0.73 $\mu\text{g/g}$. The ranking remained $\text{Pb} > \text{Ni} > \text{Cd}$ in both seasons.

3.3 Heavy Metals in *Silurus* Muscle

Metal	First season ($\mu\text{g/g}$ dry weight), n=45	Second season ($\mu\text{g/g}$ dry weight), n=45
Cd	0.14 ± 0.07 a	0.15 ± 0.08 a
Ni	3.95 ± 1.11 a	8.87 ± 4.12 b
Pb	6.02 ± 2.41 a	5.90 ± 3.57 a

The *Silurus* results differed from those obtained for common carp. Cadmium changed only slightly between seasons, from 0.14 ± 0.07 to 0.15 ± 0.08 $\mu\text{g/g}$ dry weight. Nickel, however, more than doubled, increasing from 3.95 ± 1.11 to 8.87 ± 4.12 $\mu\text{g/g}$. Lead changed little, with values of 6.02 ± 2.41 and 5.90 ± 3.57 $\mu\text{g/g}$ in the first and second seasons, respectively. The order of accumulation changed from $\text{Pb} > \text{Ni} > \text{Cd}$ in the first season to $\text{Ni} > \text{Pb} > \text{Cd}$ in the second.

4. Discussion

4.1 Metals in River Water

Seasonal variation was evident in the river-water concentrations. Samples taken during the second sampling season showed a slight increase in cadmium and more pronounced increases in Ni and Pb. Changes of this nature occur with shifts in the water quality, quantity and flow, or other inputs to the system. Metal behavior in aquatic systems is highly variable and in constant flux based upon a myriad of interacting physicochemical factors. Concentrations of metals measured in the water column fail to capture the total metal burden in a river system. Concentrations in water, sediment and biota should be examined to fully evaluate metal burden in aquatic systems (Ali et al., 2019).

Increased deposition of Ni and Pb in the river during the second sampling season could have been caused by changes in water flow and quantity, and/or increased suspended solids, sediment resuspension and/or discharges from agricultural activities or other human activities. More work would be needed to definitively evaluate the cause. This could include additional sampling and analyses to characterize sediments and/or other potential polluting materials (Hossain et al., 2022).

In aquatic systems, the bioavailability and accumulation of metals to fish and other aquatic organisms are largely influenced by the physical and chemical characteristics of the metal and the water, sediment and biotic (organic) environment. It has been well documented that fish and other aquatic organisms bio-accumulate and bio-magnify metals from their surrounding environment (Kumar et al. 2024).

4.2 Metal Accumulation in Common Carp

Common carp showed a pronounced Pb concentration during the first season, with a mean of 12.91 ± 1.08 $\mu\text{g/g}$ dry weight. This was substantially greater than the corresponding Cd and Ni concentrations. During the second season, Pb declined to 2.04 ± 0.73 $\mu\text{g/g}$. Changes in environmental exposure may have contributed to this difference, although tissue concentrations

cannot be explained solely by the contemporaneous concentration in the water. Metals can remain associated with sediments and can also reach fish through dietary exposure (Ebrahimpour et al., 2011).

The overall pattern is consistent with the established observation that freshwater fish can accumulate metals from their environment and food. Earlier work on freshwater fish, including *Cyprinus carpio*, also demonstrated interspecific differences in metal accumulation (Alhashemi et al., 2012). The relatively high first-season Pb value in the present study is therefore an important finding for environmental and food-safety surveillance. Direct comparison with regulatory limits should, however, take account of the fact that the present fish concentrations are reported on a dry-weight basis, whereas some food regulations are expressed on a wet-weight basis.

4.3 Metal Accumulation in *Silurus*

Silurus displayed a different seasonal profile from common carp. The most conspicuous change was observed for Ni, which increased from 3.95 ± 1.11 µg/g dry weight in the first season to 8.87 ± 4.12 µg/g in the second. Nickel consequently became the dominant measured metal in *Silurus* during the second season. This may reflect greater exposure or retention of Ni during that sampling period, although the available data do not allow the precise mechanism to be established (Alhashemi et al., 2012).

Differences in feeding strategy, habitat preference, trophic position, physiology, uptake, and elimination can all contribute to species-specific accumulation patterns (Ali et al., 2020). In comparison, Pb concentrations in *Silurus* were relatively stable across the two seasons, changing from 6.02 ± 2.41 to 5.90 ± 3.57 µg/g dry weight.

4.4 Comparison of the Two Fish Species

Regarding the comparison of the two species, it appears that accumulation was metal-specific and not uniform. In the case of lead, in the first season, the common carp had higher levels of lead than *Silurus* (12.91 ± 1.08 versus 6.02 ± 2.41 $\mu\text{g/g}$ dry weight). In the second season, nickel was higher in *Silurus* (8.87 ± 4.12 $\mu\text{g/g}$) compared to common carp (0.72 ± 0.18 $\mu\text{g/g}$) (Alhashemi et al., 2012; Ebrahimpour et al., 2011).

It can be assumed that the two fish taxa do not respond in the same way to seasonal variations in metal content. For example, differences in habitat usage, feeding ecology, and metabolic rate affect the time period over which a fish retains certain metals. Hence, metal content in a fish does not necessarily mean that the fish is polluted and the results of the study should not be interpreted to imply so.

5. Environmental and Human Health Concerns

Presence of the metals in edible fish muscle can potentially threaten human health as fish can be a route of metal transfer to humans. Lead can accumulate in organs and tissues and is toxic even at low levels (JECFA, 2023). Cadmium is also toxic due to its potential for bioaccumulation. Generally, from an ecological perspective, the metals in fish should not be present (Ali & Khan, 2018). From the results of the study, it can be postulated that common carp and *Silurus* should be continuously monitored.

Nevertheless, the current study should be viewed as preliminary. A full health risk assessment would require more information, especially body weight and the amount and frequency of fish consumption (Hossain et al., 2022). Such information would allow for a more quantitative dietary risk assessment.

6. Conclusion

The presence of cadmium, nickel and lead in water samples of Al-Diwaniyah river and in muscle tissues of common carp and *Silurus* spp. was confirmed. Metal levels in water and fish tissue were variable by season. Water samples from the second season showed a decrease in Cd and increases in Ni and Pb. In common carp, Pb levels were the highest for the sampling period, and in *Silurus*, Ni levels were the highest for the second sampling period.

Overall, the patterns of metal accumulation in fish are variable, and no general patterns of metal accumulation were observed. Extending this line of research in combination with sediment and fish tissue sampling may help define sources, long term trends and transport of metals in the river (Ali et al., 2019).

7. References

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