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Article

Detection of Some Heavy Metals in Main Drain Fish in Southern Baghdad, Iraq

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Abstract: This study aim to determine the levels of heavy metals including Cadmium, Copper, Lead, Nickel, and Zinc in the gills, liver, and muscles of carpio fish collected from Baghdad Main Drain, and explore how the level of the identified metal varies over the seasons and spatially as a result of environmental changes in order to estimate risks to the health of consumers of the fish species dependent on the drain. This research seeks to analyze trace metal levels in fish caught from Main Drain river in Baghdad –Iraq with emphasis on three sample stations. Carried out bi-monthly collection of fish samples of Cyprinus carpio from October 2023 to January 2024. Metals such as Cadmium, Copper, Lead, Nickel, and Zinc was considered in the analysis, that show location variation based on seasonal climatic changes. Tissues from fish gill, liver, and muscle were dried homogeneous, ground and subjected to acid digestion and the heavy metals was analyzed using Atomic Absorption Spectrophotometer. The gills for Site Sm2 at 170 ppb in winter and liver at Site Sm1 at 353 ppb in autumn. Copper was found to be highest during winter at Site Sm2's gills as 458 ppb and significantly high Lead also at Site Sm2's gills winter being 1507 ppb and Lead at fairly high level present in gills, Liver and muscles. Nickel and Zinc presented dissimilar behavior in the water concentrations and its highest indulgence in gills of Zi were recorded in Site Sm2 during winter with 33 ppb. In this study, it is established that water fish in the Main Drain of Southern Baghdad, especially at Site Sm2 are highly polluted with metals such as Cadmium, Copper, Lead, and Zinc especially in winter. A comparison with other tissues illustrates that gills and liver are more likely to accumulate radioactivity than muscle. High concentrations of lead are equally dangerous to both aquatic life and human beings and therefore calls for constant environ mental check and control.

Keywords: Heavy Metals, Cyprinus Carpio Fish, Season Variation

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1. Introduction

The presence of heavy metals in the aquatic systems is now one of the most pressing Issues of the public health and environment especially in areas where industrial and domestic waste is poorly regulated. Such a system is a threat to life in water bodies in urban areas, for instance, southern Baghdad, Iraq, where raw sewage discharges continue to pollute water sources. Although fish are considered an essential food source for many societies, their offspring can suffer from the accumulation of dangerous heavy metals such as cadmium, copper, lead, nickel and zinc, raising alarming consequences for the people who depend on them for nutrition (Ahmed and Ewees, 2021). It is widely known that heavy metals have penetrated into the environment mainly due to industrialization, inadequate methods of waste management, and agriculture uses. These metals are not biodegradable and can therefore remain in the ecosystem for a long time accumulating in fish and other life forms (Al-Hadidi *et al*., 2023). This concentration not only threatens the aquatic life and other species inhabitant in water but also fatal threats to human beings who consume poisoned fish, especially in areas where they cannot afford to get food variety from other sources (Mansour and Sidky, 2020).

Especially these data are important for the assessment of the risk for heavy metals in fish, consumed by the population, living near the waters contaminated by sewage and for establishing the effective environmental legislation. Consumption of food containing the toxic chemicals results in health complications such as neurological diseases, renal diseases, and various kinds of cancers (Pérez and González, 2020). Furthermore, understanding of the level of contamination and it consequences on the health of the people in the community is crucial in an advocacy for the most at risk groups (Saed and Mohsen, 2022). The WHO highest-level categorisation of challenges, those associated with limited sewage treatment and rising pollution, are also most acute in the southern Baghdad region. Consequently, local fish stocks are exposed to unfavourable conditions that raise the susceptibility for heavy metal intrusion. However, few extensive studies, which look at the existence and concentrations of these metals in fish consumed in the local markets are available (Zabidi and Kamal, 2019).

There are certain moments that are crucial when doing research in this area. Some of these factors are; difficulties in sample collection and analysis, the seasons under which the samples are collected, and the social-economic factors that may hinder community participation. Moreover, the density dependence of heavy metal concentrations and the patterns of ecological interactions and pollution sources also characterise the problem of heavy metals in fish (Hassan and Jebur, 2021). All these issues require the engagement of local authorities, researchers and the community in order to pave the way forward. Effective sewage treatment measures should be put in place, people should be educated on the effects of pollution and resultant health consequences; monitoring of aquatic systems continued as critical measures toward alleviating effects of heavy metal pollution. Also, setting standards on the consumption of fish can go along way enhancing environmental conservation for this can protect the health of the people (Al-Ghazali and Kadhum, 2020). As such, the research seeks to systematically evaluate the heavy metal contents, especially the five aforementioned heavy metals, in the major sewage-infested fishes of southern Baghdad. Therefore, this research aims at availing actionable insights for the proper approach to efficient pollution control, and contain pollutive influence by endeavouring to establish seasonal fluctuations aides in comprehending the contamination impact factors. Finally, the study will help in protecting aquatic life and the health of societies that rely on these important foods.

2. Materials and Methods

2.1 Study Area

The study area of research included the Main Drain (Al-Masab Al-Aam River) in southern Baghdad, a critical irrigation drainage system, is designed to manage agricultural wastewater by preventing contamination of the Tigris and Euphrates rivers (Olson and Speidel, 2024). The current study involve three sites:

- Site 1: Al-Ridwaniyah which located at 20-30 kilometers west of Baghdad, characterized by low water levels and limited vegetation.
- Site 2: Al-Mahmoudiya which Situated 30 kilometers southwest of Baghdad, featuring narrow channels and low vegetation.
- Site 3: Al-Youssoufia which Situated approximately 25 kilometers southwest of Baghdad, this site is significantly affected by industrial and agricultural pollution.

2.2 Sample Collection

Cyprinus carpio fish samples were collected using gill nets, and the weight of the samples ranged between 150 grams and 350 grams. Dissection allows extraction of gill, liver, and muscle tissues for heavy metal analysis (Imam *et al*., 2022).

2.3 Fish sample digestion processes

Samples of fish tissues were first dried and homogenized and then digested with peroxide and nitric acid. The solutions obtained with the described procedure were also filtered and treated for AAS analysis.Atomic Absorption Spectrophotometer (AAS) are used to determine the concentrations of some heavy metals like Cd, Cu, Pb, Ni and Zn. using a mixture of hydrogen peroxide and nitric acid. The resulting solutions were filtered and prepared for analysis with AAS.

2.4 Heavy Metal Analysis

Atomic Absorption Spectrophotometer (AAS) are used for quantifying heavy metals such as Cd, Cu, Pb, Ni, and Zn. Standard calibration curves were prepared from the stock standard solutions of the heavy metal and the concentrations were determined in the fish tissues. This was done in three repetitions to be able to confirm consistency of the results.

3. Results and Discussion

3.1 Effect of location and season on cadmium concentration in gills, liver and muscles of fish

The data in Table 1 demonstrate that Cd concentrations in fish gills augmented up to Site Sm2 in both times of the year: autumn 122 ppb and winter 170 ppb. Site Sm3 revealed detectable levels only in winter at 34 ppb while Site Sm1 recorded B.D.L at any period of the year.

Table 1. Effect of location and season on cadmium concentration in gills of fish

Location	Autumn	Winter	LSD
Sm1	B.D.L.	B.D.L.	0.00 NS
Sm2	122	170	14.90
Sm3	B.D.L.	34	9.53
LSD	19.57	16.45	---

Table 2 shows that liver cadmium levels increased significantly in autumn at site Sm1 (353 ppb) compared to winter (189 ppb). Level values at site Sm2 change unnoticeably from the fall level (270 ppb) to the winter level (279 ppb), while site Sm3 has lower concentrations.

Table 2. Effect of location and season on cadmium concentration in liver of fish

Location	Autumn	Winter	LSD
Sm1	353	189	28.97
Sm2	270	279	11.02 NS
Sm3	163	148	16.37 NS
LSD	22.72	28.66	---

Muscle tissues also had relatively low concentration of Cd compared with liver and gills; in winter Site Sm3 had 20 ppb while all other sites averaged B.D.L or minimal as shown in table 3.

Table 3. Effect of location and season on cadmium concentration in muscles of fish

Location	Autumn	Winter	LSD
Sm1	7	B.D.L.	5.66
Sm2	B.D.L.	5	4.15
Sm3	B.D.L.	20	5.83
LSD	5.78	7.94	---

According the WHO guidelines, the concentration of cadmium (Cd) in fish tissues should be at 100 ppb for human consumption In this study, Cd concentrations were detected higher especially in gills and liver of fish in Site Sm2. Cd in gills was highest in winter and lowest in autumn averaging 170 ppb and 122 ppb respectively and this level is above the WHO limit hence this study unveils the high levels of environmental pollution and the dangers this poses to consumers. In liver tissues, Cd concentrations at Site Sm1 were 353 ppb in autumn, which is still beyond permisable limits. except one winter season, Cd concentrations were comparatively lower in the beadless muscle and varied between 2 and 20 ppb at Site Sm3 as observed in the above figures; however, it is well below the WHO limit of 25 ppb but contains the record of background contamination. The high cadmium levels in fish gills collected from Site Sm2 signify that there is on-going contamination, probably from agricultural activities or industrial drainage, as observed by Huang et al. (2020).

The absence of detectable Cd at Site Sm1 could be an assertion of a relatively less polluted site Sm than Ss, which is in agreement with Manta *et al*. (2002) that identified a strong relationship implying that inputs from local sources have a major bearing with metal uptake by fish tissues. Also, the current results trend concurs Oudah *et al* (2021), who found high Cd concentrations in the fish tissue from the water influenced by Euphrates River with high levels of urban wastewater and agri–chemical effluents (Oudah *et al*., 2021). Likewise, in Al-Chabaish marsh, a Cd accumulation trend of gills > liver > muscle was observed and the highest level of Cd were recorded at stations influenced by sewage and chemical usage. On the other hand, the study conducted by Al-Naymi *et al*. 2019 focused on the biomagnification of heavy metals within water bodies and fish, cause by industrialization. Two of these works described the effects of environmental pollution on the concentration of heavy metals, and this analysis implies that tissues of fish including gills are vulnerable to metal depositing through water.

Al-Naymi *et al*. also found out that fish landed with hematological and biochemical changes as a result of exposure to fly ash emanating from power plants supporting the notion that liver tissues are greatly affected by environmental pollutants. It is seen that the contrast in the concentration of Cd in liver tissues is steep and it could represent biomagnification and might indicate physiological adaptation or phenomenon stress. Eldin *et al*., (2019) observed similar fluctuations in liver Cd concentration which they attributed to an increase in agricultural effluent during certain time of the year. Site Sm3 resulatives mild pollution and supports prior findings that high heavy metal levels correlate with the environment. The concentration of Cd detected in the muscles of the observed animals is very low and corresponds to the data obtained by Clootridge *et al*. (2015), according to which muscle tissues have low levels of high bioaccumulation of heavy metals. This observation may be suggesting that the liver is able to detoxify the presence of these compounds in Baseline, but there is a cause for worry on the long term exposure impacts on the health of the fishes in the face of similar environmental factors.

3.2 Effect of location and season on Copper concentration in gills, liver and muscles of fish

Cu concentrations were highest at site Sm2 during the winter (458 ppb), indicating a significant seasonal effect, while the other sites showed much lower values as shown in Table 4.

Table 4. Effect of location and season on Copper concentration in gills of fish

Location	Autumn	Winter	LSD
Sm1	167	116	14.67
Sm2	93	458	37.02
Sm3	67	59	8.63 NS
LSD	18.52	33.97	---

High Cu concentrations were apparent at Site Sm1 which equaled 353 ppb autumn in liver tissues. As illustrated in table 5, the averages at Site Sm2 also remain more or less the same (270 ppb autumn, 279 ppb winter).

Table 5. Effect of location and season on Copper concentration in liver of fish

Location	Autumn	Winter	LSD
Sm1	353	189	22.58
Sm2	270	279	10.08 NS
Sm3	163	148	13.98
LSD	27.02	19.87	---

Muscle tissue showed high fluctuations in site Sm1 from 15 ppb in autumn to 85 ppb in winter, while little variation was observed at other specific sites as shown in Table 6.

Table 6. Effect of location and season on Copper concentration in muscles of fish

Location	Autumn	Winter	LSD
Sm1	15	85	7.91
Sm2	60	57	5.37 NS
Sm3	68	67	4.13 NS
LSD	10.54	9.66	---

Regarding Cu, according to WHO, its concentration in fish should not be more than 10 000 ppb. The current analysis showed that Cu levels (e.g., 458 ppb at Site Sm2 in winter) are much lower than this limit but the indication of bioaccumulation especially in liver tissues up to 353 ppb at Site Sm1 can be of a long-term exposure and possibly environmental concern up to 353 ppb at Site Sm1), signals potential chronic exposure and environmental concerns. These current outcomes are similar to those of Eldin *et al*. The seasonal concentrations of Cu were nearly constant in the liver tissues for the reasons explained by the authors of the given paper; the liver serves as a detoxifying organ (Eldin *et al*., 2019).

The variation in Cu at Site Sm2 in winter may be caused by increased runoff as evidenced by Figueiredo *et al*., who attributed high Cu concentrations in the fish tissues to seasonal runoff Figueiredo *et al*. (2019). The high Cu concentrations in the liver tissues could be attributed to chronic exposure and bio-accumulation agrees with Rahman *et al*. (2021). The constancy of Cu levels in Site Sm2 indicates that continual influences are promoting copper deposition, and these flows should be studied with respect to pollution at these sites. The current results showed an increased Cu concentration at Site Sm2 in winter (458 ppb) and high Cu levels in the liver at Site Sm1 (353 ppb) in Autumn. These findings are in concordance with Al-Tamimi and Al- Azawi,(2015); which established histological changes in the liver and gills of Cyprinus carpio following chronic exposure to sub-lethal copper concentration.

Al-Tamimi *et al*. (2015) revealed that copper toxicity caused degeneration and necrosis of hepatocytes resulting in chronic toxicity to liver similar to the current study finding in liver of fish at Site Sm1. The raise of Cu concentration in muscle at Site Sm1 shows that the accumulation of metals in organisms in the aquatic environment is multifaceted. This was consistent with trends observed by Amin *et al*., 2012 perhaps due to changes in fish diet during certain seasons or due to other environmental factors affecting bioavailability.

3.3 Effect of location and season on Lead concentration in gills, liver and muscles of fish

The results of Pb concentrations grouped in the Table 7 have indicated that the extremely high amount detected in Site Sm2 in winter was 1507 ppb while in Site Sm1, it was 597 ppb and indeed high.

Table 7. Effect of location and season on Lead concentration in gills of fish

Location	Autumn	Winter	LSD
Sm1	95	597	75.91
Sm2	383	1507	103.67
Sm3	467	392	60.55
LSD	59.02	126.74	---

Liver tissue lead concentrations varied and were highest in winter at Site Sm2 (360 ppb), while other stations remained compatible with the control value (see Table 8).

Table 8. Effect of location and season on Lead concentration in liver of fish

Location	Autumn	Winter	LSD
Sm1	133	114	18.54 NS
Sm2	170	360	35.71
Sm3	97	63	20.46
LSD	25.85	56.22	---

Maximum concentrations of Pb in the muscles tissues were found notably in Site Sm1 in winter at 114 ppb and of Site Sm3 in winter at 369 ppb therefore revealing contaminated area see Table 9.

Table 9. Effect of location and season on Lead concentration in muscles of fish

Location	Autumn	Winter	LSD
Sm1	B.D.L.	114	19.64
Sm2	114	72	15.02
Sm3	93	369	45.57
LSD	12.86	38.62	---

For Pb, the WHO co-safe limit for Pb in fish is 300 ppb. This present study identified high levels of Pb in fish gills and significantly at Site Sm2, reaching winter levels of 1507 ppb and 597 ppb at Site Sm1, which greatly surmounted WHO recommended limits.

Likewise for the liver, the concentration of Pb in the positive case was 360 ppb at Site Sm2 in winter; the Pb levels are above the safe consumption limits suggesting high contamination. Achieved lead concentrations in fish gills were very high: at Site Sm2– 1507 ppb in winter indicating high environmental pollution.

The results support Khan *et al*. (2022) who pointed out that Pb is one of the greatest threats to water quality in urban water sources due to industrial influence. Khan *et al*. (2022) also pointed out effects of lead to aquatic system, which you also found about the importance of urgent measures in those regions. This is in agreement with the observations by Oudah *et al*. (2020), who also found high Pb concentrations in fish at Al-Chabaish marsh sites with higher anthropogenic encroachment and raw sewage effluent input. The observed notable change at Site Sm2 is consistent with studies that show that residue of Pb in the fish tissues depended on chronic exposure to polluted water sources (Eldin *et al*., 2019).

However, the accumulation of the heavy metals in the liver shows that there is an adaptive mechanism, which opens questions on future effects of the fish health as well as an increased biomagnification effect in food chains. The present research established high Pb concentrations at Site Sm2 during the winter (1507 ppm) which was associated with severe pollution. As well, Al-Tamimi *et al* (2015) noted histological changes in all fish organs and tissues that were affected by sub-lethal concentrations of chromium, which is another heavy metal.1507 ppb in winter, and 597 ppb at Site Sm1, far exceeding WHO limits. In a similar manner, Al-Tamimi *et al*. (2015) observed that fish exposed to sub-lethal concentration of chromium – another heavy metal –, histological damage was evident in the tissues of fish. In both investigations, the content was established that the pollution with heavy metals provokes the death of aquatic organisms and destruction in their tissues and organs, including liver and gills.

3.4 Effect of location and season on Nickel concentration in gills, liver and muscles of fish

For gill tissue, Ni concentration followed decreasing trend in winter from site to site and also in each site from autumn to winter as presented in the Table 10 in which Sm1 have recorded 68ppb in autumn and decreased to 36ppb in winter.

Table 10. Effect of location and season on Nickel concentration in gills of fish

Location	Autumn	Winter	LSD
Sm1	68	36	11.08
Sm2	32	25	7.47 NS
Sm3	60	57	5.06 NS
LSD	9.64	9.12	---

Ni concentrations in liver tissue were found to be highly variable, and site Sm1 showed a dramatic increase from 130 ppb in fall to 384 ppb in winter, suggesting that fish may assimilate metals seasonally, as shown in Table 11.

Table 11. Effect of location and season on Nickel concentration in liver of fish

Location	Autumn	Winter	LSD
Sm1	130	384	26.78
Sm2	253	32	19.56
Sm3	20	271	24.08
LSD	31.07	27.93	---

Muscle Ni concentrations were relatively constant in Sm1 and Sm2 accumulated in the fall and winter periods. Thus, site Sm3 showed an increase in winter to 82 ppb, as shown in Table 12.

Table 12. Effect of location and season on Nickel concentration in muscles of fish

Location	Autumn	Winter	LSD
Sm1	31	29	2.61 NS
Sm2	18	20	2.09 NS
Sm3	24	82	7.52
LSD	5.94	14.67	---

The limit set by the WHO for Nickel (Ni) is 500 ppb in fish. In the current work, Ni levels in gills at Site Sm1 were measured at 68 ppb in autumn and dropped to 36 ppb in winter and thus below the standard limit. However, liver Ni concentrations at Site Sm1 enhanced significantly from 130 ppb in autumn to 384 ppb in winter, near the WHO limit, suggesting Ni bioaccumulation in different seasons. Ni concentration at Site Sm2 was found highest in autumn and lowest in winter. The overall mean values of Muscle Ni concentrations were significantly low, and the maximum concentration of 82 ppb in Site Sm3 in winter. The accumulation of Ni in liver at Site Sm1, also points to localized contamination and long-term threat to the environment and human health. This variation in Ni concentration during winter may be due to variation in environmental conditions that influence bioavailability as was noted by Raizada and Joe (2019). These results indicate that there could be anthropogenic influences regarding pollution and its effects on the environment, so additional analysis of sources of pollution and their impacts needs to be conducted.

The change in Ni concentration depicting marked increase in the liver tissue of Gujarati female is a matter of concern, as indicated by previous research staking relation to new environmental or dietary factors (Raizada & Joe, 2019). Knowledge on behavior of Ni in water bodies is therefore important in preventing further contamination.

In comparison to other studies conducted in Iraq, Ali *et al.* (2011) studied organic pollution in the Tigris and Diyala rivers and observed the effects on fish species and benthic invertebrates associated with high-particle organic matter resulting from urban activities. This is consistent with the suspected sources of pollution mentioned in our current study. Which supports the presence of heavy metals in aquatic life.

While Issa *et al.* (2020) analyzed the accumulation of nickel in sediments and attributed high levels of trace metals to industrial pollution in the Tigris River, they emphasized the effects of human pollution affecting aquatic organisms and ecosystems.

The high value observed at Site Sm3 in muscle encourages suspicions of localized contamination which is supported by evidence from other studies that have shown that fish muscle is capable of accumulating metals such as Ni at a slower rate (Amin *et al*., 2012). Thus, these findings point to the need for locality appropriate evaluation of variation in concentration of heavy metals in fish tissues for proper conservation.

3.5 Effect of location and season on Zinc concentration in gills, liver and muscles of fish

Zn concentration was also significantly different between sites with the highest average site Sm2 recorded at 33 ppb in winter as shown in Table 13.

Table 13. Effect of location and season on Zinc concentration in gills of fish

Location	Autumn	Winter	LSD
Sm1	16	13	3.06 NS
Sm2	19	33	5.77
Sm3	31	29	2.49 NS
LSD	5.22	5.96	---

Tissues sampled from the liver exhibited the highest concentrations with the highest mean values recorded at Site Sm3 (31 ppb in autumn and 33 ppb in winter) suggesting a probable chronic exposure as shown in Table 14.

Table 14. Effect of location and season on Zinc concentration in liver of fish

Location	Autumn	Winter	LSD
Sm1	21	10	4.69
Sm2	21	30	5.02
Sm3	31	33	2.89 NS
LSD	4.97	6.27	---

Zinc concentrations in the muscles were relatively low and did not significantly differ between sites or season as presented in Table 15.

Table 15. Effect of location and season on Zinc concentration in muscles of fish

Location	Autumn	Winter	LSD
Sm1	6	8	2.08 NS
Sm2	8	4	2.91
Sm3	4	7	2.77
LSD	3.29	3.35	---

For Zinc there is no guideline proposed by WHO for maximum limits in fish to be consumed by humans in spite of being an essential trace nutrient; toxicity levels are generally above 10,000 ppb.In the present study, Zn concentration of gill is low: Site Sm2 is 33 ppb in winter, liver tissue has very low concentration and maximum value of 33 ppb is in Site Sm3 in winter. the present study, Zn levels in gills were low, with Site Sm2 peaking at 33 ppb in winter, and liver tissues similarly showing low concentrations, with the highest being 33 ppb at Site Sm3 in winter. These levels are far below the toxic level, hence the Zn concentrations in the current study are not toxic. Muscle tissues' Zn concentrations were even lower, reaching maximum value of 8 ppb in winter at site Sm1.

While Zn concentrations were found to be comparatively low, there is clear evidence of a sharply increased concentration of the material in the immediate vicinity of Site Sm2, which could mean that there are local sources of contamination here, despite the generally low levels observed, and that monitoring is necessary to detect increases in the levels of Zn over time. The observed variations of Zn levels in soil solution at Site Sm2, which increased in winter, might be explained by the greater availability of Zn as a result of runoff. This is in agreement with literature review outcomes showing that Zn remains a widely found polluter of the agriculture regions (Eldin *et al*., 2019). Ongoing evaluation is key to determining more generalized environmental effects and measures to take towards addressing such effects.

The current study used differences in Zn particularly at Site Sm2, Zn was most influential during winter with 33 ppb. These observations are in conformity with Al-Naymi *et al* (2019) who showed that fish biochemical alterations were associated with metal contamination from pollutants like fly ash. The two papers also show metal accumulation in fish tissues such as Zn and which in turn causes a possibility of physiological stress. Zn at relatively stable in liver tissues across seasons that might suggest an active accumulation and defence mechanism to tissue toxicity from exposure to its ambient environment in agreement with Amin *et al*. (2012). They underscore the need for future research regarding the effects of accumulation of heavy metals on metabolism and well-being of the sampled fish.

These data of Zn distribution in muscles also contribute to the understanding of the process of bioaccumulation of heavy metals. This implies that, although Zn is a micro-nutrient that is vital in fish dietary, concentrations observed may not be life-threatening to fish species. The results conform to previous efficacy estimates that pointed to significantly poor bioaccumulation rates of Zinc in muscular tissues compared with other tissues (Clootridge *et al*., 2015).

4. Conclusion

1. High degrees of heavy metal loading were evident in all of the sites under study but more so in Site Sm2 where Cadmium, Copper, Lead and Zinc content in fish tissues were the highest.
2. Both the cadmium and zinc concentrations were statistically significant depending on the season where metal concentrations were generally higher during the winter, and particularly for the elements Cu and Pb.
3. The most polluted Site Sm2's resulted the most likely due to agricultural or industrial outlets or inflows/Site Sm1 remained largely or completely free from Cd showing it to be a cleaner site.
4. Metals detected in gill lower in moisture content and higher in metals than liver and muscle tissues indicating that organs that are involved in detoxification and filter contaminants within fish are most affected.
5. The high level of concentration of heavy metals, especially lead, poses potential risks to human health as well as aquatic life through the consumption of contaminated fish. This confirms the urgent need to continue monitoring and combating pollution in the affected areas.

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