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ASSESSMENT OF THE POTENTIAL HEALTH RISKS ASSOCIATED WITH THE PLUMBUM, CADMIUM, ZINC, AND NICKEL CONTENT IN FISH TISSUE COLLECTED FROM RETENTION POND

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Abstract

Introduction: *The presence of heavy metals in fish constitutes a potential health risk to human consumers. This research aims to address this issue by determining the concentration of heavy metals in fish samples collected from retention ponds and assessing potential health risks for those who consume fish caught from the ponds. The primary objectives involve assessing the concentrations of heavy metals in fish tissues. Additionally, the study aim to evaluate potential health risks.* ***Methods:*** *The Atomic Absorption Spectrophotometer was employed to quantify heavy metal concentrations, while health risk assessments were based on EDI, THQ, HI, and CR calculations.* ***Results and Discussion:*** *The findings indicate a metal distribution pattern in the order of Zn> Pb> Ni> Cd and the observed value is lower than the maximum level permitted by FAO. The THQ and HI values for all studied metals were found to be below 1, signifying a lack of adverse non-carcinogenic health effects on consumers. At the same time, the cancer risk values for examined heavy metals are well below the value 10-4 which is consider as acceptable cancer risk, except Ni. CR value for Ni was recorded higher than 10-4 approaching higher limit of acceptable limit, suggesting a heightened cancer risk for consumers who consume these fish throughout their entire lifespan.* ***Conclussion:*** *The findings from this research have significant implications, contributing to various aspects of public health, environmental management, and regulatory measures.*

INTRODUCTION

Heavy metals, including mercury (Hg), lead (Pb), cadmium (Cd), nickel (Ni), and zinc (Zn), are persistent environmental pollutants that enter aquatic ecosystems through both natural processes, such as weathering of rocks, and anthropogenic activities, including industrial discharges, agricultural runoff, and urban development (1). These metals pose significant risks to aquatic organisms and human health, as they can be absorbed by fish from their environment, leading to bioaccumulation in fish tissues (2). Fish, as a primary source of protein in many diets, often accumulate heavy metals faster than they can excrete them, making them a common biomarker for human exposure to these toxic substances (3).

Human exposure to heavy metals occurs through the consumption of contaminated fish and other aquatic organisms such as clams, oysters, and crabs (4). Heavy metals like mercury and lead, once ingested through fish consumption, can be absorbed into the human bloodstream through the gastrointestinal tract, posing significant health risks. These include neurological damage, cardiovascular diseases, kidney dysfunction, and developmental issues in children (5-6).

Retention ponds, which are often used to control stormwater runoff, can become contaminated with heavy metals from surrounding industrial, agricultural, and urban sources. Over time, heavy metals accumulate in the sediments of these ponds and enter the food chain through fish that reside and feed in the contaminated

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environment (7). Fish living in such environments may bioaccumulate high levels of heavy metals, which poses potential health risks to local populations consuming these fish without being aware of the contamination (8).

The health implications of consuming fish from contaminated water bodies are particularly severe for communities that rely heavily on fish as a dietary staple (9). Continuous exposure to contaminated fish may result in chronic heavy metal toxicity, leading to serious health conditions such as neurological disorders, renal failure, cardiovascular diseases, and even cancer in some cases (3). Vulnerable groups, including children, pregnant women, and the elderly, are at higher risk of experiencing adverse health effects from heavy metal exposure through fish consumption (5).

This study focuses on assessing the concentrations of heavy metals specifically Pb, Cd, Zn, and Ni in fish collected from the UMK Jeli retention pond. The assessment aims to evaluate the potential human health risks associated with the consumption of these fish by UMK students, staff, and nearby communities. The findings from this study will provide crucial data for the development of regulatory and preventive measures to mitigate the risks associated with heavy metal contamination in the retention pond, ensuring the safety of fish consumers at UMK Jeli and its surrounding areas. Furthermore, this research will contribute to the understanding of the environmental and health impacts of heavy metal contamination in retention ponds, offering insights for future studies.

METHODS

Sampling

The retention pond at UMK Jeli Campus, near the Faculty of Bioengineering and Technology (FBKT), is a human-made water body designed to manage stormwater runoff. It controls the flow and volume of water, helping to prevent downstream flooding, erosion, and pollution. As stormwater enters, sediment and pollutants settle at the bottom, improving water quality. The pond acts as a sediment trap, reducing the release of pollutants into nearby water bodies.

Fish samples were collected from the pond using a fishing net and hand net. Each sample was individually wrapped in a polyethylene bag, stored in an icebox, and transported to the lab. They were kept at -20℃ until dissection and analysis.

Sample Preparation and Analysis

Before dissection was performed, the fish samples were allowed to defrost. The fish muscle was harvested using dissecting kits for heavy metal analysis. Tissue samples underwent a drying process in the oven with a temperature of 110 ℃ until a constant weight was reached. Two (2) g of dried sample of tissues was ground well to powder using a mortar and pestle. The last step before analyzing the sample using Atomic Absorption Spectrometer was acid digestion. Using a pestle and mortar, 1g of dry tissue sample was thoroughly ground into powder. Acid digestion came last before the sample was examined using an Atomic Absorption Spectrometer.

The analysis of heavy metal content in fish muscle involved the acid digestion method and Atomic Absorption Spectrometer (AAS). For each fish species, 2.0 g of dried sample was placed in a 100 ml conical flask. Subsequently, a mixture of 10 ml concentrated HNO_3 and 2 ml H_2O_2 added to the 2.0 g sample powder in the conical flask. The flask was covered with a watch glass for minutes to prevent a vigorous reaction and heated on a hot plate, gradually increasing the temperature from 50°C to 120°C over 30 minutes. After this period, the conical flask was allowed to cool to room temperature. The digestion process was resumed by repeating the addition of HNO_3 and H_2O_2 until a colourless solution was obtained. The colourless solution was then filtered using chromatography paper (Whatman No.1 grade).

For heavy metal detection using AAS, 5 ml of the filtered colourless solution was transferred to a new conical flask using a measuring cylinder. Subsequently, 2 ml of HNO_3 was pipetted and added to the conical flask containing the colourless solution. The solution was diluted by adding 25 ml of distilled water and then filtered again using a 40 μm filter syringe into a 15 ml centrifuge tube. The filtrates were stored at 4℃ until the determination of metals using AAS was performed.

Health Risk Assessment

Estimated daily intake (EDI)

Estimated Daily Intake (EDI) is a term used in environmental and food safety studies to quantify the amount of a particular substance, such as a chemical or contaminant, that an individual is expected to ingest daily over a specific period. The EDI is calculated based on the average daily consumption of a particular food item or exposure pathway.

The formula for calculating Estimated Daily Intake (EDI) is typically expressed as:

$$EDI: \frac{C \times IR}{BW}$$

Where C is the concentration of the element in the food type in mg/kg, FIR is the daily food ingestion rate in grams per day, and BW is the reference body weight (70 kg). However, recently a study conducted at

Selangor mentioned IR is the ingestion rate, representing the average amount of the food or medium consumed per day is 160000 mg/person/day and suggested a recommended IR which is 0.08kg to reduce the possibility of posing chronic and carcinogenic risks while at the same time obtaining the essential nutrients from the fish. These study also mentioned on the body weight used for the adult population in Malaysia was 62 kg (10).

The EDI is often compared to established health-based guidelines, such as Reference Doses (RfD) or acceptable daily intake levels, to determine whether the exposure is within safe limits or if it poses a potential risk to human health (Table 1).

Target Hazard Quotient (THQ)

The Target Hazard Quotient (THQ) is a widely recognized risk assessment tool used to evaluate the potential non-carcinogenic health risks that result from exposure to specific chemicals or contaminants in various environments, including food, water, and air. It provides an estimation of the likelihood that a given contaminant could pose adverse health effects based on established reference doses. The THQ is particularly useful for assessing risks associated with the consumption of contaminated foods, such as fish or seafood, which can bioaccumulate hazardous elements like heavy metals (11).

The THQ focuses on non-carcinogenic risks, meaning it does not account for cancer risk but instead estimates the potential for other chronic health effects that might result from exposure over time. A THQ value below 1 is considered safe, as it suggests that the exposure level is below the reference dose and therefore unlikely to cause significant health issues (12). THQ value exceeding 1 indicates that there is a higher probability of negative health effects, as the exposure level surpasses the safe threshold, implying that the population might be at risk of non-carcinogenic health consequences, such as kidney damage or neurological disorders (13).

The Target Hazard Quotient was calculated using the following equation:

$$THQ: \frac{(EF \times ED \times FIR \times C)}{(RfD \times WAB \times TA)} \times 10^{-3}$$

This equation integrates multiple variables related to exposure frequency, contaminant concentration, and body weight, ensuring a comprehensive risk assessment for individuals or populations exposed to harmful substances.Where EF stands for exposure frequency to the trace element (350 days/year), ED for exposure duration (70 years), FIR for food ingestion rate in grams per day (100 g/day), C for concentration of the trace element in the fish sample, RfD for oral reference dose as stated in Table 1, BW is an average body weight which 62 kg (and TA for averaged exposure time is 365 days x 70 years). The THQ model is an important tool for public health authorities to identify potential health risks associated with environmental contamination and to establish safe consumption limits (14).

Table 1. Reference Doses of Selected Heavy Metal

Element	Zinc	Lead	Cadmium	Nickel
Rfd (mg/kg/day)	0.3	0.0025	0.001	0.002

Source : USEPA (22)

Hazard Index (HI)

The hazard index (HI) is a key metric used in health risk assessments to estimate the cumulative risk of exposure to multiple hazardous substances. It is determined by summing the Target Hazard Quotients (THQs) for individual metals, such as lead (Pb), cadmium (Cd), zinc (Zn), nickel (Ni), and arsenic (As), as shown in the equation:

$$HI = THQ(Pb) + THQ(Cd) + THQ\ (Zn) + THQ(Ni) + THQ(As)$$

A THQ or HI value greater than 1 indicates a significant health risk due to fish consumption, while a value below 1 suggests no potential threat to human health (15-16). This assessment tool helps in evaluating the combined effects of multiple toxic substances, ensuring a more comprehensive risk evaluation, particularly for long-term exposure to contaminated fish (16). The use of HI is essential in ensuring that fish consumption remains within safe limits, particularly in areas prone to heavy metal contamination.

Cancer Risk (CR)

Cancer risk, within the scope of environmental and health risk assessments, is defined as the probability or likelihood that an individual will develop cancer due to long-term exposure to carcinogenic substances or agents. This risk is typically calculated over a lifetime, often assumed to be around 70 years, and is expressed as the chance that a person will develop cancer as a result of such exposure. The cancer risk assessment process involves identifying carcinogenic hazards, quantifying exposure levels, and applying dose-response relationships to estimate risk. Various environmental pollutants, including heavy metals and chemicals such as polycyclic aromatic hydrocarbons (PAHs), are known to be carcinogenic, and prolonged exposure to these substances can significantly increase cancer risk (17-19).

Cance risk is quantitatively measured by the Cancer Slope Factor (CSF) and expressed in terms of increased probability of developing cancer per unit of exposure to a carcinogen (20). The acceptable range of cancer risk is often between 1×10^{-6} and 1×10^{-4}, meaning that one person in a population of one million to ten thousand is expected to develop cancer due to the exposure (21-22). If the calculated risk exceeds this range, interventions or remediation strategies are recommended to reduce exposure and safeguard public health.

Continuous monitoring and assessment of carcinogenic substances in the environment, particularly in water, air, and soil, are critical to ensuring that exposures remain within acceptable limits. Strategies for mitigating cancer risks often involve regulatory measures to control emissions of carcinogens and limit exposure in vulnerable populations, such as children and those living near industrial areas (23-25). The general formula for estimating cancer risk is:

$$CR: \frac{(C \times ED \times IR \times EFr \times CFS)}{(BW \times AT)} \times 10^{-3}$$

The calculation of cancer risk involves using the Cancer Slope Factor (CSF), which were obtained from the Integrated Risk Information System (Table 2).

Table 2. Shows Cancer Slope Factor for Lead, Cadmium and Nickel in unit mg/kg/day

Element	Lead	Cadmium	Nickel
CFS (mg/kg/day)	8.5×10^{-3}	6.3	0.91

RESULTS

In this study, muscle tissue from two distinct fish species, *Oreochromis niloticus* and *Channa striata*, was analyzed for the presence of four heavy metals (Pb, Cd, Zn, and Ni) in mg/kg on a dry weight basis. The concentration of the metals in both species followed a similar trend, with Zn showing the highest concentration at 7.475 mg/kg in *Oreochromis niloticus* and 9.471 mg/kg in *Channa striata*. The lowest concentration detected was Cd, with values of 0.154 mg/kg in *Oreochromis niloticus* and 0.180 mg/kg in *Channa striata*. The overall concentration of metals in both species followed the order: Zn > Pb > Ni > Cd (Table 3).

Table 3. Heavy metal distribution in *Oreochromis niloticus* and *Channa striata* (mean± standard deviation)

Variable	Pb	Cd	Zn	Ni
Oreochromis niloticus (mg/kg)	1.217±0.275	0.154±0.008	7.475±0.929	0.719±0.034
Channa striata (mg/kg)	1.46±0.133	0.180±0.009	9.471± 0.621	0.796±0.019
Permissible limit FAO (mg/kg)	0.5	0.5	30	0.05

The estimated daily intake (EDI) values for heavy metals in *Oreochromis niloticus* (tilapia) and *Channa striata* (striped snakehead) were calculated and compared with the oral reference dose (RfD) values recommended by the United States Environmental Protection Agency (USEPA). The results, as shown in Table 4, indicate that the EDI values for four elements—Ni, Zn, Pb, and Cd—exceeded their respective RfD values in both fish species. The highest EDI observed was for Pb in *Channa striata*, reaching 14.79 mg/kg/day.

Table 4. Shows the Estimated Daily Intake (EDI) of *Oreochromis niloticus* and *Channa striata* in Unit mg/kg/day

Variable	Lead	Cadmium	Zinc	Nickel
Oreochromis niloticus	12.06	0.25	1.96	1.16
Channa striata	14.79	0.29	1.92	1.24
RfD (mg/kg/day)	0.004	0.001	0.3	0.02

The concentrations of Pb, Cd, Zn, and Ni in the muscle tissues of *Oreochromis niloticus* and *Channa striata* were analyzed to assess the safety of these metals for human consumption. The study calculated the Target Hazard Quotient (THQ) for each metal, finding that all THQ values were less than 1, indicating a low potential health risk. The highest THQ value was observed for Pb in *Oreochromis niloticus* at 0.490, while the lowest THQ was for Zn in *Channa striata* at 0.040. These results suggest that exposure to the selected heavy metals from consuming these fish is unlikely to cause adverse health effects (Table 4).

The Hazard Index (HI) was calculated as the sum of the Target Hazard Quotient (THQ) values for the four studied heavy metals (Pb, Cd, Zn, and Ni) in *Oreochromis niloticus* and *Channa striata* from the retention pond. The results, shown in Table 5 and 6, indicate that the HI values for all the metals were below 1 for both fish species, suggesting that they are safe for human consumption based on current metal concentrations.

Table 5. Target Hazard Quotient (THQ) for Different Heavy Metal in *Oreochromis niloticus* and *Channa striata*

Variable	Lead	Cadmium	Zinc	Nickel
Oreochromis niloticus	0.479	0.290	0.050	0.001
Channa striata	0.491	0.248	0.040	0.001

Table 6. Calculated Hazard Index (HI) of Oreochromis niloticus and Channa striata

Variable	THQ (Pb)	THQ (Cd)	THQ (Zn)	THQ (Ni)	HI
Oreochromis niloticus	0.479	0.290	0.050	0.001	0.82
Channa striata	0.491	0.248	0.040	0.001	0.78

The cancer risk (CR) values for the heavy metals Pb, Cd, Zn, and Ni in *Oreochromis niloticus* and *Channa striata* were calculated based on lifetime exposure to potential carcinogens. The results, as shown in Table 7, indicate that the CR values for most heavy metals were within the acceptable range (10^{-6} to 10^{-4}). However, the CR value for Ni in both fish species was found to be near the lower acceptable limit of 10^{-6}, suggesting a potential carcinogenic risk associated with the consumption of these fish.

Table 7. Estimation of Cancer Risk (CR) Associated with the Intake of Edible Tissues From Selected Fish Species Containing Selected Toxic Heavy Metals

Variable	*Oreochromis niloticus*	*Channa striata*
Cd	1.56 x 10^{-6}	1.83 x 10^{-6}
Pb	1.67 x 10^{-5}	1.57 x 10^{-5}
Ni	1.05 x 10^{-3}	1.168 x 10^{-3}

DISCUSSION

The study revealed that zinc (Zn) exhibited the highest concentration among the trace metals analyzed in both fish species, which is not surprising given its critical role in biological processes, including enzyme activity, protein synthesis, and DNA replication (26-27). Zinc is an essential micronutrient for aquatic organisms, contributing to various metabolic pathways necessary for growth and development. Its high concentration in fish tissues may be indicative of the fish's need to maintain proper metabolic function, as well as the potential bioavailability of zinc in the aquatic environment (28). Nevertheless, elevated levels of zinc in the environment may also result from anthropogenic activities, including industrial discharges, agricultural runoff, and urbanization, which can contribute to higher than natural concentrations of zinc in aquatic ecosystems (29).

Lead, a known toxicant, is particularly harmful due to its ability to accumulate in the human body, affecting various organs and systems, including the nervous, cardiovascular, and renal systems (30-31). Chronic exposure to lead can lead to serious health effects, including developmental issues in children, neurological disorders, and kidney dysfunction in adults. Similarly, nickel is associated with a range of toxic effects, including respiratory issues, allergic reactions, and increased cancer risks upon prolonged exposure (32).

Despite the toxic nature of cadmium (Cd), it was found in the lowest concentrations in the study, significantly below the FAO's permissible limit. Although cadmium is considered highly toxic, even at low exposure levels, its minimal presence in the fish species sampled suggests a lesser immediate risk to consumers regarding Cd toxicity (34). Cadmium typically enters aquatic environments through industrial activities such as mining, metal processing, and waste disposal, and its accumulation in fish is largely influenced by the specific environmental conditions of the water body (33).

These findings indicate that while zinc and cadmium levels in fish muscle tissues pose minimal health risks to consumers, the elevated concentrations of lead and nickel present a more concerning issue. Continuous consumption of fish containing high levels of lead and nickel can pose significant long-term health risks, particularly for vulnerable populations such as children, pregnant women, and the elderly.

The finding of Estimated Daily Intake (EDI) values for nickel (Ni), zinc (Zn), lead (Pb), and cadmium (Cd) exceeded the Reference Dose (RfD) values is particularly alarming, as it indicates a potential health risk for consumers of the studied fish species. Exceeding the RfD implies that individuals consuming fish contaminated with these metals are being exposed to doses that surpass the threshold deemed safe by regulatory agencies such as the United States Environmental Protection Agency (USEPA) and the World Health Organization (WHO) (22,34). Prolonged exposure to heavy metals at levels higher than the RfD can lead to bioaccumulation in the human body, increasing the risk of various adverse health effects, particularly among sensitive populations such as children, pregnant women, and individuals with pre-existing health conditions (34).

Lead (Pb) is a major concern in this context. The study highlights that *Channa striata* had the highest EDI for lead, significantly surpassing the RfD. Lead is a well-documented neurotoxin, and chronic exposure can result in severe neurodevelopmental impairments, especially in children, where it can cause cognitive deficits, learning disabilities, and behavioral problems (35). In adults, chronic lead exposure has been linked to kidney damage, hypertension, and cardiovascular diseases, further emphasizing the critical nature of these findings (35). Pb exposure has no known safe threshold, meaning that even minimal exposure can lead to harmful health effects over time, especially with sustained intake from contaminated sources like fish (36).

The elevated EDI values for Ni, Zn, and Cd, although not as toxicologically alarming as Pb, also pose significant health risks. Nickel (Ni) exposure, especially through the consumption of contaminated fish, is associated with an increased risk of allergic reactions, respiratory issues, and in some cases, cancer (37). Nickel is known to cause dermatitis in humans, and in higher doses, it can affect the respiratory system, particularly through chronic inhalation exposure, which translates into concerns for food sources with elevated nickel concentrations (38). Zinc (Zn), while essential for various biological functions such as immune response and enzyme activity, can be harmful at elevated concentrations, leading to gastrointestinal distress, immune system suppression, and interference with the body's absorption of other essential minerals such as copper (39).

Although cadmium (Cd) was found at lower concentrations in the fish tissues compared to other metals, its chronic intake still poses significant risks, especially due to its toxic effects on the kidneys and its classification as a Group 1 human carcinogen by the International Agency for Research on Cancer (IARC). Long-term exposure to cadmium has been linked to renal dysfunction, bone demineralization (Itai-itai disease), and an increased risk of lung cancer. Even at low concentrations, cadmium accumulates in the body over time, primarily affecting the kidneys and potentially leading to chronic kidney disease (40).

The THQ values for Pb, Cd, Zn, and Ni being less than 1 indicate that the levels of these metals in both fish species pose minimal health risks to consumers, which aligns with findings from similar studies. However, Pb exhibited the highest THQ, warranting cautious monitoring due to its well-documented toxicological effects, even at low exposure levels. It is crucial to consider that only four heavy metals were tested in this study, and other potentially harmful contaminants may be present in the environment.

Moreover, the sample size was representative of the fish population in the retention pond, but the potential variability in heavy metal accumulation across different sizes and ages of fish must be accounted for. Larger-sized individuals may accumulate higher metal concentrations due to bioaccumulation (41), which could affect the safety of fish consumption over time. Future studies should assess a broader range of metals and a larger sample size to ensure comprehensive risk assessment.

The HI values remaining below 1 indicate that the combined exposure to the four heavy metals studied does not pose significant health risks to consumers of these fish, consistent with similar findings in other studies (37). However, while the results indicate safety at present, continuous monitoring is recommended, as environmental factors can influence the levels of metal accumulation in fish over time. Changes in water quality, sediment composition, and bioavailability of metals can lead to fluctuations in metal concentrations in fish tissues, potentially increasing health risks in the future. It is important to track both abiotic factors such as water chemistry and biotic factors like fish feeding habits to ensure long-term safety for consumers.

While the calculated CR values for most heavy metals are within the acceptable range, the nearly critical value for Ni raises concerns, especially given that Ni is classified as a Group 1 carcinogen by the International Agency for Research on Cancer (IARC). Epidemiological studies have established a link between long-term Ni exposure and an elevated risk of developing cancer, particularly lung and nasal cancers. The oral slope factor, a key parameter in determining carcinogenic risks, was applied to metals such as Pb, Ni, and Cd due to their established carcinogenicity, while other metals lacked sufficient data for cancer slope factors.

Given the potential cancer risk from Ni exposure, particularly from *Channa striata* and *Oreochromis niloticus*, it is critical to monitor these metals and evaluate whether continued consumption of fish from the retention pond could lead to significant health consequences. Further research should also explore the combined effects of multiple carcinogenic metals, which might amplify health risks.

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AUTHORS' CONTRIBUTION

NNA: aided in collecting the data, interpreting the results and also worked on the manuscript. AER: involved in planning the methodology, conceptualized, supervised the work and also involves in reviewing and editing this writing. However, all authors discussed the results and commented on the manuscript.

CONCLUSION

In conclusion, this research sheds light on the assessment of heavy metals in fish collected from a retention pond situated in UMK Jeli Campus surrounded by laboratory buildings. The study revealed a distinct order of heavy metal distribution in fish, with zinc (Zn) exhibiting the highest concentration, followed by lead (Pb), nickel (Ni), and cadmium (Cd). Notably, Pb and Ni concentrations surpassed the allowable limits set by Food and Agriculture Organization (FAO). Despite the elevated concentrations, the Hazard Index (HI) and Target Hazard Quotient (THQ) values remained below 1, suggesting that the short-term exposure to heavy metals from tilapia and striped snakehead fish in the retention pond is unlikely to have adverse health effects on the inhabitants. However, the long-term exposure measured in Cancer Risk (CR) values for Ni raised concerns, indicating a moderate risk of cancer associated with its presence. These findings emphasize the importance of continuous monitoring and targeted remediation strategies to mitigate potential health risks posed by heavy metal accumulation in fish from retention ponds, particularly in educational institutions.

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