ORIGINAL ARTICLE

Assessing Heavy Metal Risks in Freshwater Fish from Bernam River: Implications for Human Health

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ABSTRACT

Introduction: This study evaluates the concentration of heavy metals (Pb, Cr, Cu, Cd, Zn) in eight freshwater fish species (*C. apogon, H. macrolepidota, L. fasciatus, M. nigriceps, O. vittatus, P. bulu, P. oxygastriodes,* and *P. schwanenfeldii*) from Bernam River, Malaysia. **Methods:** Heavy metals were assessed using wet digestion and flame atomic absorption spectrometry (FAAS). **Results:** Metal concentrations ranged from 0.03 mg/kg to 15.95 mg/kg. Gills and liver had the highest metal concentrations, while muscles had the lowest. *P. oxygastroides* had the highest Zn concentration (15.35 mg/kg) in its gills, and *P. schwanenfeldii* had the highest Pb concentration (15.95 mg/kg). *L. fasciatus's* liver had the highest Cu concentration (9.55 mg/kg), and *C. apogon's* liver had the highest Cd concentration (1.83 mg/kg). Significant variations in Zn and Cu levels were found among the fish species ($p<0.05$), with no significant differences in Pb and Cd. Non-carcinogenic risk assessments showed HI values <1, indicating negligible health risks from fish consumption. A TR value for Pb $<10^{-4}$ suggests no carcinogenic effects, while a TR value for Cd $>10^{-}$ indicates potential cancer risk from some fish species. **Conclusion:** This study highlights the need for monitoring heavy metal contamination in aquatic ecosystems to protect human health. Effective environmental management, continuous surveillance, and regulatory measures are crucial to ensure the safety of fish consumption from the Bernam River.
Malaysian Journal of Medicine and Health Sciences (2025) 21(s2): 8–17. doi:xxx

Keywords: Heavy Metals, Freshwater Fish, Bioaccumulation, Health Risk Assessment

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INTRODUCTION

Malaysia has been grappling with river pollution since the 1970s, coinciding with forest areas converting to agricultural land and the onset of rapid urbanization (1). The Bernam River, one of the largest water supply sources in Malaysia, serves multiple functions including agricultural, industrial, and residential consumption, as well as transportation and communication for basin residents. Rapid urbanization surrounding the Bernam River basin has led to a shift in land use which in turn will increase the river's susceptibility to pollution from sources like development, agricultural chemicals (pesticides and fertilizers), sand mining, industrial and domestic sewage (2). The continuous release of agricultural chemicals and untreated domestic and industrial waste, often containing heavy metals, into water poses an ongoing environmental problem with the potential to impact river and aquatic ecosystems and adversely affect public health (3).

Heavy metals can occur naturally or be derived from anthropogenic sources. They are necessary for life but can become toxic due to their longevity in the environment, and accumulation in organisms via bioaccumulation (4). The accumulation of heavy metals in organisms can cause physiological and biological toxicity when occurring in high concentrations (5). The most common heavy metals that have high density and are toxic in low quantity are arsenic (As), cadmium (Cd), chromium (Cr), lead (Pb), mercury (Hg), and thallium (TI). These heavy metals get into the water supply through the groundwater, rivers, streams, and lakes where industrial and commercial dispose of their toxic waste (6). This is an environmental concern that has negative repercussions for public health because heavy metals can enter the food chain and be ingested by humans and other living organisms (5). The accumulation of heavy metals in the food chain heightens health risks to humans, resulting in potential carcinogenic and teratogenic effects (7).

Fish, a staple and important protein source in the Malaysian diet, can be particularly vulnerable to the accumulation of heavy metals. Fish is an excellent source of high-quality proteins, vitamins, minerals, and lipids. Proteins are necessary for synthesizing hormones and digestive enzymes, and repairing and maintaining tissues such as muscles, skin, and bones (8). Fish oils are abundant in omega 3, that have healing properties including antioxidant, anti-inflammatory, hypotensive, anti-diabetic, and antihyperlipidemic effects (9). Heavy metals in fish can undermine the health benefits of eating fish and pose a serious threat to human health. The heavy metals accumulated in the water and sediment from a variety of sources, with sediment serving as a more effective repository than the water itself (10). Heavy metals can potentially accumulate in fish due to the direct consumption of water or organisms in the food chain (11). The toxicity of these heavy metals has proven to be a significant hazard, with several adverse health effects. Consumption of fish with excessive levels of trace metals can disrupt the digestive, circulatory, and central nervous systems of humans (12). In accordance with the Malaysian Food Regulation 1985 and WHO/FAO guidelines (1984), stringent permissible limits have been established for heavy metal concentrations in various fish species. These limits are crucial in safeguarding public health and ensuring the safety of consuming fish products. The detailed permissible limits for key heavy metals such as Cd, Cu, Pb, and Zn are as follows: Cd (2 mg/kg, 1.5 mg/kg), Cu (30 mg/kg, 10 mg/kg), Pb (1 mg/kg, 0.1 mg/kg), Zn (100 mg/kg, 150 mg/kg).

Assessing heavy metal concentrations by using fish as an indicator of environmental quality has been extensively studied in various parts of the Malaysia over the last few decades. Salam et al. (13) assessed heavy metal levels in marine fish and seafood from Kedah and Selangor, Malaysia. Their findings suggest that regular consumption of certain species, including Scylla serrata, Fenneropenaeus indicus, and Megalaspis cordyla, poses a high chronic health risk to local consumers. Additionally, Rosli et al., (14) reported the accumulation of heavy metals such as Cd, Cu, Fe, Mn, Pb, and Zn in various fish species collected from the Terengganu coastal area. However, their findings revealed that the concentration levels of heavy metals in the fish samples were lower compared to the standards and those documented in previous studies conducted in various locations. Despite extensive studies on heavy metal concentrations in Malaysian fish, research on heavy metal levels in Bernam River freshwater fish remains limited. Thus, the purpose of this study is: 1) to determine heavy metals concentration of Cd, Cr, Cu, Pb, and Zn in selected organs of freshwater fish (Gills, Liver, and Muscles); 2) to estimate potential health risks due to freshwater fish consumption from the Bernam River.

MATERIALS AND METHODS

Fish collection

A total of 120 fish samples (8 species) were collected from 6 locations as illustrated in Figure 1. All the collected fish samples were sorted into their species, kept in polyethylene bags, and refrigerated at -20°C until analysis in the laboratory. The characteristics of collected fish species are illustrated in Table I. The selected fish species for the analysis were *C. apogon, P. bulu, L. fasciatus, P. oxygastroides, H. macrolepidota, P. schwanenfeldii, O. vittatus,* and *M. nigriceps.* These species were selected based on their ecological relevance, commercial importance, and potential exposure to heavy metal contaminants in the Bernam River.

Heavy metal Analysis

The fish sample digestion method employed in this study followed the procedure outlined by Adeyemi (15). Two grams of oven-dried fish sample, brought to a constant weight, were placed in a 250 mL beaker, and 10 mL of concentrated HNO_3 was added. The mixture was heated at 90 °C until a clear solution was achieved. Subsequently, approximately 5 mL of concentrated HNO_3 was incrementally added to the sample (repeated at least three times), and digestion continued until the volume was reduced to about 1 mL. After cooling, 5 mL of 1% HNO_3 was introduced to the sample, and the resulting solution underwent filtration using 0.45μm Whatman filter paper. The filtrate was then quantitatively transferred to a 100 mL volumetric flask and diluted to the mark with distilled water. The concentration of heavy metals was determined using an atomic absorption spectrophotometer (AAS) AA 800 (Perkin Elmer, Foster City, CA, USA).

Statistical Analysis

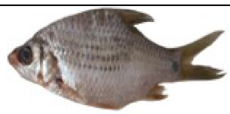
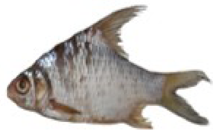
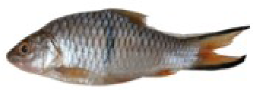
The data was subjected to statistical analysis using SPSS software. Mean and standard deviation calculations were conducted for metal concentrations across various fish species. To address potential issues related to data distribution normality, the Kolmogorov-Smirnov test was employed. Furthermore, the significance of potential differences in elemental content among fish species was assessed using the Kruskal-Wallis non-parametric tests, with p-values below 0.05 considered indicative of significant differences at a confidence level of 95%.

Health risk assessment

Estimated Daily Intake (EDI) of specific heavy metals (Zn,

Fig. 1: Sampling location for freshwater fish for heavy metal analysis

Table I: Characterization of Collected fish species from Bernam River.

Image	Common Name	Scientific Name	Weight (g)	Length (cm)
	Temperas	*Cyclochelichthys apogon*	46.4 ± 2.3	16.0 ± 2.2
	Tengalan	*Puntioplites bulu*	170.2 ± 5.2	23.8 ± 2.5
	Pucuk Pisang	*Labiobarbus fasciatus*	60.7 ± 4.3	18.9 ± 3.1
	Umbut-umbut/ Lalang	*Parachela oxygastroides*	44.3 ± 7.2	18.6 ± 2.5
	Sebarau	*Hampala macrolepidota*	74.0 ± 5.1	19.5 ± 3.2
	Lampam sungai	*Puntius schwanenfeldii*	148.0 ± 4.3	22.6 ± 2.7
	Terbol	*Osteochilus vittatus*	76.8 ± 5.5	18.7 ± 0.8
	Lundu	*Mystus nigriceps*	53.9 ± 6.8	18.7 ± 2.1

Pb, Cu, Cr, and Cd) is calculated using the fish muscles (in wet weight). The determination of EDI is conducted as in Equation 1:

$$EDI = \frac{IRd \times C}{BW} \quad (1)$$

Where IRd = Fish ingestion rate (kg/day) = 0.036 kg, and C = mean of heavy metal concentrations in freshwater fish muscle (mg/kg) in wet weight. The measurement of heavy metal concentration was conducted on a dry weight basis, and a conversion factor of 4.8 was used by converting the dry weight into wet weight (16), BW = Average body weight of an adult Malaysian = 60.0 kg (17).

The Target Hazard Quotient (THQ) and Hazard Index (HI) were employed to assess non-carcinogenic risk (Equation 2 and Equation 3). THQ calculates the risk posed by individual pollutants by comparing exposure levels to reference doses. At the same time, HI estimates the cumulative risk from exposure to multiple contaminants by summing up the individual THQ values. The quantification of THQ and HI can be carried out using an integrated risk analysis equation established by the United States Environmental Protection Agency (USEPA) (18):

$$THQ = \frac{EF \times ED \times IRd \times C}{RfD \times BW \times AT} \times 10^{-3} \quad (2)$$

$$HI = \sum_{i=1}^{n} THQ \quad (3)$$

Where EF is exposure frequency for 365 days per year, ED is exposure to heavy metal contaminants for an average lifetime which is 70 years, and IRd is fish ingestion rate, which is 0.036 kg per adult person per day (15), C is the mean of heavy metal concentrations in freshwater fish muscle with a wet weight of 4.8 conversion factors (Maurya et al., 2019), RfD is the oral reference dose, where the Zn, Pb, Cu, and Cd doses were 0.3, 0.004, 0.04, 0.003, and 0.001 mg/kg/day (17), respectively; BW is 60.0 kg, the average body weight of adult Malaysian; AT is the average time of exposure for non-carcinogens, where 365 days multiply with 70 years of average lifetime exposure (16).

Target cancer risk (TR) was used to estimate the carcinogenic risks over a lifetime of exposure (19). The formula for calculating TR is shown in Equation 4. The carcinogen slope factor (CSF) value for Pb is 0.0085 mg kg-1day-1, and Cd is 6.3 mg kg-1day-1 respectively (20).

$$TR = EDI \times CSF \quad (4)$$

RESULTS

Heavy metal concentration in selected freshwater fish

In this study, the heavy metal concentrations were measured in eight different types of freshwater fish species, (*C. apogon, P. bulu, L. fasciatus, P. oxygastroides, H. macrolepidota, P. schwanenfeldii, O. vittatus,* and *M. nigriceps*). The concentrations of heavy metal were reported in milligrams per kilogram (mg/kg) of dry weight. The study's findings revealed a pattern of heavy metal distribution among the fish organs. In general, the Gills and Liver exhibited the highest concentrations of heavy metals, while the muscles displayed the lowest levels (Table II). The Gills displayed higher concentrations of Zn and Pb, while the Liver showed increased accumulation of Cu. In contrast, Cd did not demonstrate any distinct pattern among the selected freshwater fish species, and notably, Cr was undetectable in all sampled specimens. Analysis of fish in this study reveals that *P. oxygastroides* has the highest Zn concentration in its Gills (11.35 ± 0.09), while *P. schwanenfeldii* shows the lowest Zn concentration in its Muscle (0.90 ± 0.13 mg/kg). Importantly, the Zn concentrations in all eight selected freshwater fish species remained within the permissible limit of 100.00 mg/kg, as set by FAO and WHO (21).

In terms of Pb, the highest concentration was observed in the Gills of *P. schwanenfeldii* (15.95 ± 0.64 mg/kg), whereas the lowest concentration was detected in the Muscle of *O. vittatus* (0.17 ± 0.18 mg/kg). Out of the eight selected freshwater fish species, seven exceeded the permissible limit of 1.50 mg/kg for Pb set by FAO and WHO (22). The concentrations that surpassed this limit were observed in *C. apogon* (Gills - 11.25 ± 0.88 mg/kg), *P. bulu* (Gills - 9.53 ± 1.78 mg/kg, Liver - 4.93 ± 1.26 mg/kg), *L. fasciatus* (Gills - 10.03 ± 0.94 mg/kg), *P. oxygastroides* (Gills - 14.70 ± 2.25 mg/kg), *H. macrolepidota* (Gills - 5.33 ± 1.57 mg/kg), *P. schwanenfeldii* (Gills - 15.95 ± 0.64 mg/kg), and *M. nigriceps* (Gills - 9.33 ± 1.48 mg/kg). Regarding Cu, the Liver of *M. nigriceps* exhibited the highest concentration (9.55 ± 0.12 mg/kg), while the lowest concentration was detected in the Gills of *O. vittatus* (0.12 ± 0.13 mg/kg). An excessive amount of Cu can be harmful to aquatic organisms due to its toxic nature (23). It has the potential to cause Liver and kidney damage, as well as toxicity associated with the breakdown of lipids, iron deficiency, and impairment of membranes (19,20).

Cd is a non-essential element that is introduced into the aquatic ecosystem through various natural and anthropogenic sources. In this investigation, only *C. apogon*, *P. bulu*, and *H. macrolepidota* exhibited the accumulation of Cd in all their organs, whereas the remaining fish species displayed Cd accumulation in specific organs only. The highest concentration of Cd is found in *C. apogon* Liver (Liver: 1.83 ± 0.04 mg/kg). According to Garai et al. (23), the Gills, Liver, and kidney display the highest accumulation of Cd in fish,

Table II: Concentration of heavy metals (mg/kg-dry weight) in fish tissues of selected freshwater fish species in the Bernam River

Fish Species	Fish Tissues	Heavy metals				
		Zn	Pb	Cu	Cd	Cr
C. apogon	Gills	8.07	11.25	3.77	0.85	ND
	Liver	5.08	0.42	4.23	1.83	ND
	Muscle	3.12	0.30	2.10	0.60	ND
P. bulu	Gills	4.32	9.53	3.15	0.52	ND
	Liver	2.70	9.53	3.95	1.20	ND
	Muscle	1.80	1.35	1.52	0.12	ND
L. fasciatus	Gills	6.52	10.03	3.95	0.55	ND
	Liver	4.67	1.20	3.78	0.03	ND
	Muscle	2.47	ND	1.03	ND	ND
P. oxygastroides	Gills	11.35	14.70	5.37	0.28	ND
	Liver	8.80	ND	6.92	ND	ND
	Muscle	7.73	0.55	2.45	ND	ND
H. macrolepidota	Gills	7.42	5.33	0.85	0.18	ND
	Liver	5.63	0.47	4.83	1.00	ND
	Muscle	2.28	0.55	0.62	0.02	ND
P. schwanenfeldii	Gills	7.57	15.95	3.15	1.00	ND
	Liver	0.95	ND	2.75	ND	ND
	Muscle	0.90	0.13	0.13	ND	ND
O. vittatus	Gills	3.50	0.38	0.12	0.05	ND
	Liver	2.02	ND	0.88	ND	ND
	Muscle	2.00	0.17	0.38	ND	ND
M. nigriceps	Gills	5.10	9.33	3.30	0.10	ND
	Liver	9.93	ND	9.55	ND	ND
	Muscle	2.28	0.32	0.42	ND	ND

ND* = Heavy metals not detected

with the skin showing the lowest accumulation. The heightened concentration of Cd in the Gills is attributed to their effectiveness in detoxifying Cd.

Comparisons of Heavy Metal Concentrations with Fish Species

A Kruskal-Wallis's analysis was conducted to assess the significant differences in Cd, Cu, Pb, and Zn concentrations among eight different species of fish. The results indicated a statistically significant difference in the concentrations of Zn and Cu ($p < 0.05$) among the various fish species. This suggests that the levels of Zn and Cu vary significantly across the different types of fish under consideration. On the other hand, no significant differences were observed in the concentrations of Cd and Pb ($p > 0.05$) among the eight fish species. This implies that the variations in Cd and Pb concentrations were not statistically significant, indicating a consistent level of these elements across the different types of fish studied. These findings contribute valuable insights into the elemental composition of the selected fish species, emphasizing the importance of understanding and monitoring variations in metal concentrations for environmental and public health considerations.

Health Risk Assessment

Table III shows the EDI, THQ, and HI values due the consumption of each species of freshwater fish. The study reveals EDI values for Zn, Pb, Cu, and Cd were significantly lower and negligible compared to their respective RfD values. The values of THQ of single heavy metal followed in ascending order of Cd < Cu < Zn < Pb < Cr. The THQ values are less than 1 signifies that the level of heavy metal exposure is lower than the reference dose. Therefore, there is no health risk effects are expected from consuming freshwater fish during a lifetime in a surrounding local. Additionally, the Hazard Index (HI), reflecting the combined potential health risk to humans from simultaneous exposure to multiple heavy metals, was also below 1. Consequently, there is no discernible health risk associated with the consumption of fish from the Bernam River.

Table IV presents the target cancer risk values for Pb and Cd due to the consumption of fish from the Bernam River. In this study, the TR values for Pb ranged from 3.3 x 10-6 to 3.3 x 10-5. Based on the TR values from Salam et al. (24), the potential health risk from Pb exposure through the consumption of the selected freshwater fish is negligible, suggesting a safe level of cancer risk. However, for Cd the TR value is 1.1 x 10-2 exceeds the acceptable range (10-3 to 10-4), indicating a potential risk of cancer associated with Cd exposure from the consumption of selected freshwater fish in the Bernam River. The result also suggested that the consumption of *C. apogon* poses the highest risk in this study area.

DISCUSSION

Heavy metals play a crucial role in the metabolic activity of fish within the limits approved by international standards. However, their toxicity becomes a concern when heavy metal concentrations exceed the approved limits. As heavy metals are non-biodegradable and persistent, they tend to accumulate in stream sediments, posing a risk to aquatic life, including fish (25). The analysis of heavy metals in fish is of utmost importance due to their potential as sources of pollution and their uptake by fish through various pathways, including absorption through their skin and Gills, as well as through the consumption of contaminated food (25). Zn is a vital micronutrient essential for the human body in small quantities. It can potentially enhance the immune system and promote growth in infants and children (16). In all eight species studied, Zn exhibited the highest accumulation among heavy metals in comparison to

Table III: Estimated Daily Intake (EDI) and Non-Carcinogenic Risk of Fish Consumption

Fish Species	Heavy Metals	C mg/kg	RfD	EDI	THQ	HI
			mg/kg/day			
C. apogon	Zn	14.96	0.3	9.0×10^{-3}	3.0×10^{-5}	0.022
	Pb	1.44	0.004	8.7×10^{-4}	2.5×10^{-4}	
	Cu	10.08	0.04	6.0×10^{-3}	1.5×10^{-4}	
	Cd	2.88	0.001	1.7×10^{-3}	1.7×10^{-3}	
H. macrolepidota	Zn	10.96	0.3	6.6×10^{-3}	2.2×10^{-5}	0.0005
	Pb	2.64	0.004	1.6×10^{-3}	4.5×10^{-4}	
	Cu	2.96	0.04	1.8×10^{-3}	4.4×10^{-5}	
L. fasciatus	Zn	11.84	0.3	7.1×10^{-3}	2.4×10^{-5}	0.0001
	Cu	4.96	0.04	3.0×10^{-3}	7.4×10^{-5}	
M. nigriceps	Zn	10.96	0.3	6.6×10^{-3}	2.2×10^{-5}	0.0003
	Pb	1.52	0.004	9.1×10^{-3}	2.6×10^{-4}	
	Cu	2.00	0.04	1.2×10^{-3}	3.0×10^{-5}	
O. vittatus	Zn	9.60	0.3	5.8×10^{-3}	1.9×10^{-5}	0.0002
	Pb	0.80	0.004	4.8×10^{-4}	1.4×10^{-4}	
	Cu	1.84	0.04	1.1×10^{-3}	2.8×10^{-5}	
P. bulu	Zn	8.64	0.3	5.2×10^{-3}	1.7×10^{-5}	0.0016
	Pb	6.48	0.004	3.9×10^{-3}	1.1×10^{-3}	
	Cu	7.28	0.04	4.4×10^{-3}	1.1×10^{-4}	
	Cd	0.56	0.001	3.4×10^{-4}	3.4×10^{-4}	
P. oxygastriodes	Zn	37.12	0.3	2.2×10^{-2}	7.4×10^{-5}	0.0008
	Pb	2.64	0.004	1.6×10^{-3}	4.5×10^{-4}	
	Cu	11.76	0.04	7.1×10^{-3}	1.8×10^{-4}	
	Cd	0.08	0.001	4.8×10^{-5}	4.8×10^{-5}	
P. schwanenfeldii	Zn	4.32	0.3	2.6×10^{-3}	8.6×10^{-6}	0.0001
	Pb	0.64	0.004	3.8×10^{-4}	1.1×10^{-4}	
	Cu	0.64	0.04	3.8×10^{-4}	9.6×10^{-6}	

Table IV: Target Cancer Risk of Heavy Metals Due to the Consumption of Fish from the Bernam River.

Fish Species	Pb	Cd
C. apogon	7.3×10^{-6}	1.1×10^{-2}
H. macrolepidota	1.3×10^{-5}	-
L. fasciatus	-	-
M. nigriceps	7.8×10^{-6}	-
O. vittatus	4.1×10^{-6}	-
P. bulu	3.3×10^{-5}	2.1×10^{-3}
P. oxygastriodes	1.3×10^{-5}	3.0×10^{-4}

other metals. This is due to the fact that Zn is an essential mineral in fish, actively involved in numerous metabolic processes. Insufficient Zn levels can lead to various conditions including reduced appetite, slowed growth, and impaired immune function (26).

Pb is categorized as a non-essential element and can pose significant toxicity risks when consumed in quantities exceeding the recommended doses established by the Food and Agriculture Organization (FAO) and the World Health Organization (WHO). Seven out of the eight selected freshwater fish species exceeded the permissible limit of 1.50 mg/kg for Pb set by FAO and WHO. Chronic exposure to Pb, particularly through the consumption of fish exceeding the recommended limits, can lead to a range of detrimental health effects. These include neurological disorders such as impaired cognitive function, developmental delays, and behavioural issues, especially in children whose developing brains are particularly vulnerable to lead toxicity. Additionally, Pb exposure has been linked to cardiovascular problems, kidney damage, reproductive issues, and gastrointestinal disturbances (11). Pb can accumulate in sediments and subsequently enter the food chain through bioaccumulation in fish. Investigating local industrial activities, land use patterns, and historical pollution sources can provide insights into the Pb levels detected in fish from the Bernam River (26,27).

Cu can enter water bodies through agricultural runoff (from fertilizers and pesticides) and industrial effluents. The results of this study suggest that the concentration of Cu in all eight species of freshwater fish examined was below the permissible limit set by the FAO and WHO, which stands at 30 mg/kg. Cu tends to accumulate more in the liver rather than other fish organ due to the liver's role in detoxification and metal storage processes. The liver serves as a primary site for the metabolism and detoxification of various substances, including heavy metals like Cu. Additionally, Cu is often bound to metallothionein proteins in the liver, which aids in its storage and regulation within the fish's body (28,29). Cu indeed serves as an indispensable trace mineral and micronutrient vital for various physiological functions within living organisms. Its significance spans multiple biological processes, ranging from aiding in the formation of red blood cells to facilitating the function of enzymes involved in energy metabolism, antioxidant defence, and connective tissue synthesis (29). Additionally, Cu contributes to the proper functioning of the nervous and immune systems, supports the maintenance of healthy bones and blood vessels, and assists in the absorption and utilization of iron (30). Despite its essential role, excessive exposure to Cu can lead to adverse health effects. In certain circumstances, such as through contaminated water sources or dietary supplements, overconsumption of Cu may occur. Excessive Cu intake can result in gastrointestinal disturbances such as nausea, vomiting, and diarrhea. Furthermore, prolonged exposure to high levels of Cu may lead to more severe health issues including Liver damage, kidney dysfunction, and neurological symptoms such as headaches, dizziness, and confusion (30).

Cd is not considered essential for human health, unlike some other metals like Zn or Fe. The permissible limit set by the FAO and WHO for Cd was very low which is 0.05 mg/kg. In this study, Cd was detected in only three out of eight species of freshwater fish, with very low concentrations observed in the Muscle tissue, which is commonly consumed by humans. The harmful effects of Cd on human health are well-documented and diverse. Cd is a known carcinogen, with prolonged exposure linked to lung cancer and potentially cancers of the kidney, prostate, and bladder (31). It also targets the kidneys, where it accumulates over time and can lead to renal dysfunction and eventually kidney failure (31). Additionally, Cd exposure has been associated with bone demineralization, leading to osteoporosis and skeletal deformities, as well as cardiovascular diseases and adverse effects on reproductive health (31).

The findings demonstrate the variability in the occurrence of heavy metals among different fish species and within their respective organs. The variation in heavy metal concentrations can be linked to fish habitat and feeding habits, the weight and length of fish, and their reproductive system (19). The findings showed that the accumulation of Zn, Pb, Cu, Cr, and Cd was highest in Gills, and the lowest in Muscle. Ingestion of food or water in aquatic organisms is one of the major routes for metal uptake. Thus, there are high concentrations of heavy metals in the Gills, and Liver (19). Another reason Gills have higher contamination levels compared to other organs is because Gills have direct exposure to water. The high concentrations of pollutants in water are absorbed through Gills thus increasing the bioavailability of pollutants in fish (17). Although Gills and the Liver are rarely consumed by people, they can be used as indicators for pollutants present in the ecosystem.

Potential health risk

The Estimated Daily Intake (EDI) serves as a pivotal parameter in both carcinogenic and non-carcinogenic risk evaluations, offering a framework for assessing potential health hazards linked to exposure to contaminants present in consumed fish. The research unveils that the EDI values for Zn, Pb, Cu, and Cd were notably lower and negligible in comparison to their respective Reference Dose (RfD) values. Additionally, the Target Hazard Quotient (THQ) and Hazard Index (HI), utilized in appraising non-carcinogenic risks, were also below 1 (Table III). As per the risk-based concentration table outlined by the United States Environmental Protection Agency (USEPA) in 2004, THQ and HI values below 1 signify a lack of significant risk for non-carcinogenic effects. Conversely, increasing THQ and HI values indicate a heightened risk of non-carcinogenic effects (7). Therefore, there is no potential noncarcinogenic health risk for humans from consuming fish from the Bernam River.

The potential risk of developing cancer due to exposure to specific heavy metals throughout an individual's lifetime is commonly measured as the target cancer risk (TR). Generally, a target risk of less than 10-4 is considered safe, while a value of TR between 10-3 and 10-4 is deemed acceptable, and a value of more than 10-3 implies an unacceptable level of cancer risk (24). In this study, the Target Risk (TR) values for lead (Pb) were determined to be within a lower range than the acceptable threshold, suggesting the absence of any potential cancer risk associated with Pb exposure. However, Cd exhibited slightly elevated TR values, indicating a potential cancer risk linked to Cd exposure from the consumption of selected freshwater fish in the Bernam River. Exposure to Cd has been associated with various health conditions including high blood pressure, osteoporosis, and lung cancer (31). The accumulation of Cd poses a significant environmental concern due to its slow excretion rate (23). Therefore, it is imperative to address Cd exposure within the ecosystem, especially considering that Cd concentrations have already exceeded the standard limits set by the FAO and the WHO. Failure to manage Cd exposure may lead to an increased risk of cancer development among consumers of fish species containing Cd over their lifetime (24).

CONCLUSION

In conclusion, this study evaluated the concentrations of heavy metals in eight selected freshwater fish species collected from the Bernam River, Malaysia. The analysis revealed varying heavy metal concentrations ranging from 0.03 mg/kg to 15.95 mg/kg across different fish organs. The Gills and Liver exhibited the highest concentrations, while the Muscles displayed the lowest. Statistical analysis indicated significant variations in Zn and Cu levels among the fish species, with no significant differences in Pb and Cd concentrations. Assessment of health risks revealed negligible non-carcinogenic implications (HI < 1) for local communities consuming fish from the Bernam River, but highlighted potential carcinogenic risks associated with Cd exposure. This underscores the importance of ongoing monitoring and regulatory measures to ensure the safety of fish consumption from the Bernam River, emphasizing the need for effective environmental management to safeguard both ecosystem integrity and human health.

ACKNOWLEDGMENT

The authors extend their appreciation to the staff and personnel engaged in data collection and analysis at the Centre for Environmental Health and Safety, Faculty of Health Sciences, for their dedicated cooperation throughout this project.

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