ORIGINAL ARTICLE

Health Risk Assessment and Bioaccumulation of Heavy Metals in Surface Water and Nile Tilapia (Oreochromis niloticus) in the Huai Luang River Basin, Thailand

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ABSTRACT

Contamination of heavy metal in aquatic ecosystems has the potential to cause toxicity and accumulating in aquatic ecosystem. Human consumption of heavy-metal contaminated water or aquatic animals can have a direct effect on aquatic animals and indirect effects on human health. Therefore, this study evaluated the accumulation of heavy metals in water and Nile tilapia and conducted a health risk assessment from dermal exposure and consumption of the water and Nile tilapia in the Huai Luang River Basin, Thailand. The results found that trace amounts of zinc (Zn), chromium (Cr), copper (Cu), cadmium (Cd) and lead (Pb) in the water samples had an average of 0.56 ± 0.34, 0.04 ± 0.03, 0.11 ± 0.05l, 0.08 ± 0.05 and 0.42 ± 0.66 mg/L, respectively. The average bioaccumulation of Zn, Cr, Cu, Cd and Pb in Nile tilapia were 26.81 ± 14.71, 0.88 ± 060, 4.38 ± 1.97, 1.29 ± 1.56 and 3.45 ± 3.45 mg/kg, respectively. The bioconcentration factors of the heavy metals in Nile tilapia, ordered from highest to lowest values, were Zn, Cu, Cr, Cd and Pb, respectively. However, the results of the human health risk assessment showed that the exposure to contaminated water with heavy metals would not be harmful. Nonetheless, the target hazard quotient for Cd and Pb and the hazard index from water and Nile tilapia consumption were higher than 1.0. These values indicated that consumption of water and Nile tilapia from Huai Luang River Basin could have risks to health effects from non-cancerous substances. These results are important information for the prevention and monitoring of water quality, including the safety of human health from water utilisation from this resource.

Keywords: heavy metal, Nile tilapia, health risk assessment

INTRODUCTION

Heavy metals are important pollutants, which are highly contaminated in aquatic ecosystems. Sources of heavy metals originate naturally and anthropogenically through factories, municipal solid waste, agricultural practices, mining and electronic waste.[1] Heavy metals are high-density substances that cannot be decomposed by biological processes so they can persist in the environment for a long time. They are toxic and when they accumulate in the aquatic environment, they can be transferred to other aquatic organisms through various pathways. Bioaccumulation in organisms occurs when heavy metals enter the food chain. They also have the potential for biomagnification along the food chain. This causes disturbance in ecosystem function and affects physiology and morphology, not just to aquatic organisms but also to human health.[2] Based on ecotoxicology data, heavy metals cause changes in biodiversity and ecosystems.[3]

There are two groups of heavy metals. The first group contains essential metals for growth and function of living things, including zinc (Zn), copper (Cu) and iron (F). Another group contains non-essential metals that cause high toxicity to living things, even in trace concentrations; these include cadmium (Cd), lead (Pb) and mercury (Hg). However, accumulation of heavy metals in both groups can cause acute and chronic toxicity to aquatic organisms and humans.[4] Heavy- metal toxicity has resulted in loss of function for biomolecules such as proteins, enzymes and DNA, which stops working because the heavy metal mimics and replace essential cations necessary for enzyme function. The heavy metals can bind with DNA and cause genetic abnormalities and induce cancer in humans and non- human animals.[5] In the human body, heavy metals disrupt chemical and biological transformation, causing accumulation in tissues such as liver, kidneys and brain. The accumulation leads to toxicity on organs; for example, Pb can damage the brain, kidneys, gastrointestinal tract, red blood cells, immunity and may cause leukaemia. For aquatic organisms (i.e. fish, heavy metal affect growth, reproduction rate and physiological processes as well as causing histopathological alterations in the skin, gills, liver, spleen and kidneys.[6] For example, the chronic toxicity of Zn affects hatching, haematological structures of fish and changing the behaviour of fish.[7] Contamination of heavy metals in the aquatic ecosystem is, therefore, an important issue that should be given priority. Because this problem does not only affect water quality and aquatic organisms, but also affects human health from water utilisation. This is especially due to consumption of aquatic organisms for food; the heavy metals in the aquatic ecosystem transfer to humans through the hierarchy of consumption in the food chain of aquatic organisms. Thus, humans are at risk of health effects from heavy metal contamination.[8]

Fish are a major source of human food; they contain high protein content, are rich in vitamins and essential nutrients, lack unsaturated fatty acids and provide two nutritionally important omega-3 polyunsaturated fatty acids, namely eicosapentaenoic acid and docosahexaenoic acid.[9] It has also been suggested that fish consumption can help reduce heart disease and rheumatoid arthritis, so fish are a popular human food.[10] However, fish can absorb heavy metals from the water through their gills, skin and digestive tract, which can cause accumulation of heavy metals in tissues. High amounts of heavy metals can be accumulated in fish tissue, which negatively affects food safety.[11] The issue of heavy-metal contamination in fish has received global attention, not only for the effect of heavy metals on fish but also the human health risks of consuming heavy metal contaminated fish. If humans consume fish that contain heavy metals in a concentration exceeding the recommended level, this will greatly affect the health of people who consume the contaminated fish. The consumption of the heavy-metal contaminated fish can lead to various pathological disorders such as hyper-tension, sporadic fever, kidney damage or cramps.[12] Hasmi and Anwar[13] found that if a person weighing 86 kg consumed bulanak fish that had an accumulation of Pb 2.47 mg/kg for 61 years, there was a risk of health consequence from contaminated Pb. Therefore, fish have been used as a bio-logical index to assess and monitor heavy metal contamination in aquatic ecosystems.

Huai Luang River Basin is an important watershed in northeast Thailand. It covers an area of approximately 4,141 km^2 before flowing into the Mekong River. This water resource has been used as a water supply for consumption, fishery and agricultural purposes. Due to the increase in population and the expansion of the agricultural and industrial sectors, which has a result in increasing land use around the Huai Luang Basin, especially for communities and agriculture. When rainwater or wastewater drains from the surrounding activities, it makes the Huai Luang River Basin to be full of the waste and deteriorates the water quality and increases the accumulation of pollutants in the water source, which can harm the aquatic organisms in this area[14], especially fish that are important food for humans. If there is an accumulation of pollutants in the fish, it has the potential to be toxic to humans, the final consumers in the food chain.[15] Therefore, this study assessed health risks and bioaccumulation of heavy metals in water and Nile tilapia from Huai Luang River Basin, Thailand. The information obtained from this study will serve as supplement data for water quality prevention and surveillance, including for the safety of human health for water utilisation from this water source. It is also important information that informs people about the importance of water pollution and health care problems.

METHODOLOGY

Sampling site

The sampling site was covered an area of approximately 1,529 km^2 in the Central Huai Luang River Basin (CHLB) in Udon Thani province, Thailand. The sampling was conducted from March to August 2019 by collecting samples three times at each sampling point. Three sampling points were purposefully selected in this study after a preliminary study through a surveying method, which revealed that the selected sample point could be hot spots of anthropogenic pollutions (Table 1).

Table 1. Sampling points at Huai Luang River Basin, Thailand.

Sampling point	Geographic coordinates		Description
	Longitude (degrees E)	Latitude (degrees N)	
1	102.37500	17.60083	It is located the upstream with normal domestic and touristic activities.
2	102.59682	17.38218	It is located near the dominant agricultural activities and normal domestic activity.
3	102.61912	17.41791	It is located near dominant industrial activities and normal agricultural activity.

Sample collection

The water was collected by grab sampling method. The polyethylene plastic bottles were submerged in the flow to collect the sample. After collection, 5 mL/L of HNO_3 was added to reduce pH to < 2. Then the samples were preserved by freezing at < 4°C.

Samples of fish were Nile tilapia *(Oreochromis niloticus)* because it can generally be found at Huai Luang River Basin, is commonly consumed by local people and is an economic product of Thailand. The total number of fish was 9 samples (at least 5-7 fish were caught per sampling point), which were collected directly at the sampling sites through the assistance of local fisherman. The samples were kept in a polyethylene bag, preserved by deep freezing at -20°C in the laboratory and stored until they were prepared for analysis.

Sampling preparation

Water samples: Water samples were prepared by acid digestion based on standard methods for the examination of water and wastewater.[16] The volume of the water sample was 25 mL and acidified with concentrated HNO_3 to concentrated H_2SO_4 in a 4:1 solution. The solution was digested by block digestion at 60 °C - 150 °C to be a clear solution. Then 1 mL of HNO_3 was added into the digested samples and left to cool at room temperature. The solution was filtered through Whatman size No. 42 filter paper and the final volume was adjusted to 25 mL with distilled water.

Fish samples: The body weight and total body length of each fish were measured, then fish were cleaned by deionised water and dissected to obtain muscle samples for the heavy metal analysis following the methodology of Campbell et al.[17] The tissue samples were dried at 105°C for 24 hours. The dried samples were allowed to cool at room temperature in the desiccator and crushed into powder by using a porcelain mortar and a pestle. A 0.5 g dry weight sample was taken to digest by adding 1.5 mL concentrated HNO_3 and 1.5 mL H_2O_2 (30%); this was placed in a block digestion at 80°C for 24 hours. The digested samples were filtered through Whatman No. 42 filter paper and then diluted with deionised water to a total volume of 25 mL.

Heavy metal analysis

The water and fish samples were analysed for Zn, Cu, Cr, Cd, and Pb. These heavy metals were analysed by using inductively coupled plasma optical emission spectrometer (ICP-OES). All reagents used in this study were certified analytical grade. Quality control was performed with spike samples analysed in duplicate for every 10 samples; a certified standard and a blank solution were run to check for contamination and drift. Recovery percentage from spike samples range from 96.60% to 103.48% and the relative standard deviation was 0.06% to 9.65%. Blanks were determined through the analyses and used to correct the measured concentrations. The detection limit was calculated with reagent blank and used for verification as well. The limit of detection (LOD) of individual metal with reagent was in the range 0.0003 to - 0. 04 g/L. Samples were analysed in triplicate. The heavy metal concentrations obtained from the ICP- OES analysis in mg/L were then converted into mg/kg.

The bioconcentration factor (BCF)

The BCF is the ratio of the pollutant concentration in the fish (mg/kg) to that in water (mg/L).[18]

$$\text{BCF} = \frac{\textit{concentration of heavy metal in fish}}{\textit{concentration of heavy metal in water}} \quad (1)$$

Human health risk assessment

The estimated daily intake (EDI) is used for evaluating daily intake of heavy metal through the ingestion route (water and fish consumption), which was calculated by equation (2).[19,20] Daily intake of heavy metal through dermal exposure was calculated by equation (3). [19,20] The target hazard quotient (THQ; Equation 4) was used for assessing health risks of human health in case of non-carcinogenic risk from intake heavy metal through consumption.[19,21] The Hazard Quotient (HQ) was used for estimating health risk when people intake more than one type of heavy metal, which can be calculated by equation (5).[22]

$$\text{EDI}_{\text{ingestion}} = \frac{C \times IR \times EF \times ED}{BW \times AT} \quad (2)$$

$$\text{EDI}_{\text{demal}} = \frac{C \times SA \times KP \times ET \times EF \times ED \times CF}{BW \times AT} \quad (3)$$

$$\text{THQ} = \frac{EDI}{Rfd} \quad (4)$$

$$\text{HQ} = \text{THQ}\ (THQ_1 + THQ_2 + THQ_3 \ldots + THQ_n \quad (5)$$

Where C is the concentration of heavy metal in the sample (mg/L or mg/kg), IR is ingestion rate (fresh fish ingest is 0.142 kg/day or water ingestion is 2.1 L/day)[23,24], EF is the exposure frequency (365 days/year), ED is the exposure duration (67 years) [25], BW is the average adult body weight (70 kg for adults) [22], AT is the average exposure time (365 days/year × number of exposure years), SA is the exposed skin area (4,350 cm^3),[26] CF is the volumetric unit conversion factor (0.7),[27] ET is the exposure time (0.5 hour/day), KP is the dermal permeability coefficient (0.001)[28] and RfD is the reference dose (mg/kg/day or mg/L/day).[22,29]

For human research ethics aspect in this research, the methodology was about only surface water quality survey and experimental laboratory which were not related to human. However, in further research involving human subjects, the researcher will follow the ethical guidelines for human research absolutely.

RESULTS AND DISCUSSION

Heavy metal concentration in water samples

The mean concentrations of heavy metals in water samples from Huai Luang Basin are shown in Table 2. The heavy metal concentrations range in water samples were Zn 0.56 ± 0.34 mg/L, Cr 0.04 ± 0.03 mg/L, Cu 0.11 ± 0.05 mg/L, Cd 0.08 ± 0.05 mg/L and Pb 0.42 ± 0.66 mg/L. The highest to the lowest trend of metals detected in water samples were Zn > Pb > Cu > Cd > Cr.

Table 2. Heavy metals concentrations in water samples from Huai Luang River Basin

Parameters	Heavy metal concentrations (mg/L)				
	Zn	Cr	Cu	Cd	Pb
rang	0.25–0.93	0.01–0.07	0.07–0.16	0.05–0.14	0.02–1.18
mean ± SD	0.56 ± 0.34	0.04 ± 0.03	0.11 ± 0.05	0.08 ± 0.05	0.42 ± 0.66
water quality standard[30]	1	<0.05	≤0.1	≤0.05	≤0.05

The results indicated that the water samples contained Cd and Pb concentrations exceeding the surface water quality standard class 2.[30] Cu concentration was slightly over the limit value. The high concentration of Cu, Cd, and Pb could have originated from land use around Huai Luang River Basin, especially from agricultural and industrial areas along the studied site. That could be the cause of detecting heavy metal concentrations at a high level in the water sample according to Hamada et al.,[31] who reported that the highest concentration of Pb and Cd in an aquatic environment may have resulted from heavy agricultural runoff containing fertiliser, agrochemicals and pesticides. More than 10% of insecticides and fungicides that have been utilised for agricultural purposes contain Cu, Hg, Mn, Pb and Zn. Impurity fertilisers have been applied in farmland contaminated with Cd, Pb, As and Cu, such as phosphate base fertiliser, as well as other types, which contain average Cd concentrations of 13.4 µg/g.[32]

Bioaccumulation of heavy metals in fish

The concentration of heavy metals in *O. niloticus* samples collected from Huai Luang River Basin is presented in Table 3, representing the average concentration of heavy metals in *O. niloticus* at Huai Luang River Basin. Zn accumulated the most followed by Cu, Pb, Cd and Cr. Table 3 depicts the comparison of heavy metals of *O. niloticus*, as was observed in this study and other published studies.

Table 3. Heavy metal concentrations in Nile tilapia (*Oreochromis niloticus*) from this study and other studies and maximum permitted number of fish recommended by FAO/WHO.[33]

Sample description	Heavy metal concentration (mg/kg)					References
	Zn	Cr	Cu	Cd	Pb	
Huai Luang Basin, Thailand	26.81	0.88	4.38	1.29	3.45	This study
Bang Pakong River, Thailand	5.59	0.005	5.37	0.00	<.03	Chawpaknum et al.[34]
Phayao Lake, Thailand	-	-	-	nd	nd	Juwa et al.[35]
Huay Heng, Thailand	67.92	-	nd	1.55	8.32	Tanee et al.[36]
Nampong River, Thailand	16.53	0.058	0.33	< 0.05	< 0.02	Tokun and Iwai[37]
Taihu lake, China	–	0.34	0.21	0.12	0.61	Rajeshkumar and Li[38]
Klatantan River, Malaysia	–	–	–	0.10 – 0.15	0.34 – 0.54	Mohamed et al.[39]
Maximum recommended permissible in fish	40	10	30	0.5	0.5	FAO/WHO [33]

Note: nd = not detected

Bioaccumulation of Cd and Pb in *O.niloticus* were higher than the recommended maximum permitted in fish.[33] Therefore, the human health risk assessment was carried out to estimate the potential risk from these metals. Cd and Pb are non-essential and the most toxic heavy metals at low concentrations; they are also non-biodegradable and have no role in biological processes. Thus, even in low concentrations, they could be harmful to fish. For example, Sehar et al.[40] have shown that chronic toxicity of Cd could change the deviations of the electrophoretic arrangements of protein segments in *O.mossambicus* gills and muscles. Abdel et al.[41] found Pb (1.5-3 mg/kg) and Cd (1-2 mg/kg) caused significantly reduced growth and survival of *O.niloticus*. In humans, Cd causes severe kidney damage and produces signs of chronic toxicity, including impaired reproductive capacity and kidney function, tumours, hypertension and hepatic dysfunction. Cd can be bound to proteins in the human body called metallothionein. Accumulation of Cd 3-330 mg/day can be deadly and 1.5-9.0 mg/day could be toxic to humans.[42] Pb can cause renal damage and failure, cause birth defects and interfere with bone formation and normal growth.

Bioaccumulation of heavy metals in aquaculture is an indirect index that can indicate abundance and availability of heavy metals in the aquatic environment. The heavy metals from the aquatic environment can accumulate in the tissue of fish through two main pathways: direct uptake by diet or through contaminated water that sluices through gills, skin, oral cavity and digestive tract.[20] The fish tissues uptake metal ions from the surroundings when they live in highly contaminated heavy-metal water resources. Therefore, heavy metal could be found in the tissues of fish at a higher level than the surrounding water. The results of this study are the same as other studies that found an accumulation of heavy metal in *O. niloticus* greater than in the water resource. However, accumulation patterns of contaminants in fish could be different depending on uptake and elimination rates of contaminant, species, size, sex, age, behaviour and water quality.[42,36]

Bioconcentration factor

Bioconcentration factor (BCF) of heavy metals in fish tissue is the ratio of the concentration of heavy metal in the tissues of fish to the concentration of heavy metal in the surrounding environment, including uptake from food. The BCF of this study is presented in the Figure 1. All heavy metals in tissues of *O.niloticus* fish at the studied site had BCFs lower than the recommended limit in edible tissue of freshwater fish, which was in accordance with the results of Karlssson[43] who found Zn (1000), Cr (200), Cu (200), Cd (200) and Pb (300).

The BCFs in *O. niloticus* followed the order of Zn > Cu > Cr > Cd > Pb. The high value of BCF indicated the fish can intake heavy metal from the aquatic environment at a high rate and incur bioaccumulation in the food chain. Zn and Cu showed the highest levels of accumulation in the tissues. Essential metals (Zn and Cu) are vital for the health of fish and involved in all aspects of biological function. However, an excess amount of such metals generates dangerous free radicals and causes cellular and tissue damage. Consequently, there is a fine balance between metal deficiency and surplus; it is crucial for organisms to maintain metal homeostasis via tight regulation of a balance between uptake and excretion.[44]

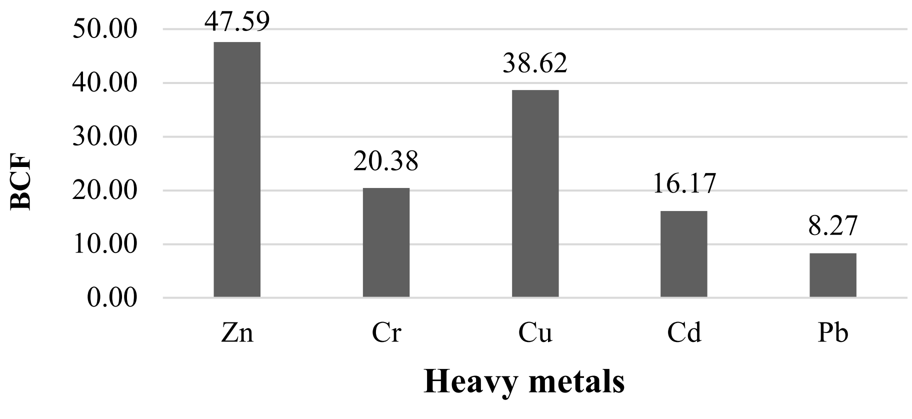

Figure 1: Bioconcentration factors of heavy metals in tissues of *O. niloticus* in the Huai Luang River Basin, Thailand

Human health risk assessment

Heavy metal concentration of contaminated water or aquatic organisms could be at a level that would is acutely harmful to humans. However, low levels of heavy metal concentration intake could be chronic after long-term exposure, which may lead to adverse health effects. Therefore, human health evaluation of heavy metal toxicity from intake through water consumption and aquatic organism consumption should be a priority issue. The health risk assessment of heavy metal intake through ingestion, dermal exposure of water and consumption of *O. niloticus* from the Huai Luang River Basin was conducted by estimated daily intake (EDI), target hazard quotients (THQs) and hazard index (HI).

The results of human health risk from Huai Luang River Basin are presented in Tables 4 and 5. The EDIs through ingestion and dermal exposure with contaminated water ranged from 0.001–0.151 mg/L/day. EDI of Zn and Cu were less than the recommended dose so the risk was minimal (Rfd of ≤ 1)[45]; however, Cr, Cd and Pb were above the recommended dose for ingestion. The ratio of EDIs of heavy metals to their dose for Cd and Pb were approximately threefold and Cr was approximately fivefold, so the risk was low (Rfd of >1–5 fold).[45] Therefore, direct water contact would not cause adverse effects on human health. However, consumption of water from Huai Luang Basin could cause low effects on human health from contamination of Cr, Cd and Pb in the water.

The THQ values showed health risk through ingestion and dermal exposure ranged from 2.05×10^{-4} to 3.574. THQs for dermal exposure of the consumer were lower than 1, while THQ values of Cd and Pb ingestion had the highest potential for health risk with a value greater than 1. Individual heavy metals such as Zn, Cu and Cr could be a non-carcinogenic health risk from their THQ values. The Hazard Index (HI) value for ingestion of water was greater than 1 (6.545), indicating a potential health risk from consumption of water in the Huai Luang River Basin (Table 4).

Table 4. Human health risk assessment parameters of heavy metals from intake through dermal exposure and ingestion of water from the Huai Luang River Basin, Thailand.

Heavy metal	EDI_{ingest} (mg/L/day)	RfD_{ingest}[22]	THQ_{ingest}	EDI_{dermal} (mg/L/day)	RfD_{dermal}[29]	THQ_{dermal}
Zn	0.197	0.3	0.056	0.012	60	2.04×10^{-3}
Cr	0.151	0.03	0.430	0.009	0.015	0.624
Cu	0.004	0.04	0.085	0.003	12	2.05×10^{-4}
Cd	0.003	0.001	2.400	0.002	0.005	0.348
Pb	0.013	0.0035	3.574	0.001	0.42	0.022

Table 5 presents the human health risk parameters of heavy metal consumption of *O. niloticus* from Huai Luang River Basin. In terms of the recommended daily allowance, the fish consumption rate (mg/ day/ 70 kg body weight)[46] found heavy metals in the essential metal group (Zn and Cu) in *O. niloticus* were lower the recommended consumption rate. Metals in the non-essential metal group (Cr, Cd and Pb) that were accumulated in *O. niloticus* exceeded the recommended daily allowance for fish consumption rate. Therefore, people who consume *O. niloticus* from Huai Luang River Basin have a health risk from this heavy metal group.

For consumption of *O. niloticus*, the EDI values ranged from 0.003 to 0.055 mg/kg/day. The EDI of Zn, Cr and Cu through consumption of *O. niloticus* were lower than the reference dose; Cd and Pb recorded values that were higher than the reference dose, implying that there was a minimum potential health risk for consumption of *O. niloticus*. The THQ values of *O. niloticus* for individuals showed that Cd and Pb had THQ values greater than 1 (2.624 and 2.005, respectively), which present a non-carcinogenic health risk. The HI for *O. niloticus* was greater than 1 (5.094), indicating that a relative potential health risk occurs from the intake of metal through consumption of heavy-metal contaminated *O. niloticus*. This result is a source of concern because of the potential health risk consequences from the intake of heavy metals through the consumption of water and fish from Huai Luang River Basin

Table 5. Human health risk assessment parameters of heavy metals from the consumption of *Oreochromis niloticus* from the Huai Luang River Basin, Thailand.

Heavy metals	Average concentration in *O. niloticus* (mg/kg)	Recommended daily allowance (mg/ day/70kg body weigh)[46]	EDI (mg/kg/day)	RfD[22]	THQ
Zn	0.56	70	0.055	0.3	0.182
Cr	0.43	0.23	0.002	0.03	0.060
Cu	0.11	35	0.009	0.04	0.223
Cd	0.08	0.07	0.003	0.001	2.624
Pb	0.42	0.25	0.007	0.0035	2.005

CONCLUSION

This study collected water samples and fish samples (*O. Niloticus*) in the Huai Luang River Basin to assess heavy metals (Zn, Cr, Cu, Cd and Pb); the results determined that Cd and Pb concentrations exceed maximum permissible limits.[30] Bioconcentration factors in *O. niloticus* at Huai Luang River Basin was Zn > Cu > Cr > Cd > Pb. Human risk assessment indicates that dermal exposure of heavy metal contaminated water is not harmful to human health. However, THQs of Cd and Pb and HI for the consumption of water and *O. niloticus* from the Huai Luang River Basin were higher than 1; thus, they were a significant non-cancer risk for consuming water and fish contaminated with Cd, Pb, Cu, Cr and Zn. Therefore, the presence of heavy metal in water and fish should be a concern for the potential effect of heavy metals on the aquatic environment and human health. Water quality monitoring should be conducted continuously. For future studies, other species of fish and other aquatic organisms that are a common human food should be monitored to obtain more information on the impacts of heavy metal contamination in this area. The results from this study can be applied for decision making to inform people about treatment before consuming water or fish for their safety and to reduce long-term of health risks. Moreover, it can be used as information to improve laws and measures to control the safety of food and to monitor heavy metal contamination in aquatic organisms.

Limitation of study, heavy metals can be accumulated in tissues of fish such as muscles, intestines, gills, livers and bones. However, this study focused on the accumulation of heavy metals in the muscles of fish, which are usually consumed by the consumers. Health risk assessment was conducted by assessing the toxicity of accumulated heavy metals in water and fish. However, there are various types of toxic substances in the aquatic ecosystem that could be accumulated in water and fish that possibly contained a higher quantity than the heavy metals. Therefore, the level of health risk of water and fish consumption from the Huai Luang River Basin could be higher than the results that have been assessed in this study.

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