

Human Health Risk Assessment of Heavy Metal Accumulation in Aquatic Plants Grown in the Tha Chin River

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Received: March 13, 2022; Revised: April 11, 2022; Accepted: April 22, 2022

Abstract

The Tha Chin River, located in the central of Thailand, has a significant residential area, agricultural site, and industrial site. In this study, the heavy metals (As, Cd, Pb, Ni, and Zn) contaminated in the river in the dry and wet seasons were evaluated at Chai Nat, Pho Phraya, Song Phi Nong, Bang Len, Sampran, and Tha Mai stations. The water spinach (*Ipomoea aquatica* Forssk.) and water mimosa (*Neptunia oleracea* Lour.) grown in the Tha Chin River were collected and analyzed for heavy metal concentration using inductively coupled plasma mass spectrometry (ICP-MS). The result showed that the heavy metal concentration in water at all stations was below the standard limit in dry and wet seasons. The accumulation of heavy metals of water spinach, and water mimosa in edible parts was in order of Zn > Ni > Pb > As > Cd. The non-carcinogenic health risk revealed that Hazard Quotient (HQ) and Hazard Index (HI) of water spinach and water mimosa were below the threshold limit. The cancer risk assessment based on the ingestion of both plants indicated that As, Cd, and Ni might pose to high lifetime cancer risk. This finding will be applied for proper management in the Tha Chin River to avoid the risk for the residents.

Keywords: Heavy metal; The Tha Chin River; Water spinach; Water mimosa

1. Introduction

Heavy metal pollution in an aquatic environment is considered a severe ecological and human health problem due to its persistence and accumulation in the food chain (Lin *et al.*, 2016). Feni River estuary in Bangladesh faces heavy metal contamination problem from industrial zones, which can affect the human health of those who were living near the river (Islam *et al.*, 2018) and also as Wei River in China was reported to have a high As concentration in river potentially adverse health risk to residents (Yang *et al.*, 2015).

In Thailand, case studies of the Tha Chin River reported a higher trend of heavy metal contaminations and poor water quality (Pratum *et al.*, 2019). The primary pollution sources of the upper and middle of the Tha Chin River are from domestic and agricultural

activities, while the lower part is from domestic and industrial activities (Simachaya, 2000). Moreover, the pollution in sediments can be the secondary source of heavy metal pollution in water (Buajan and Pumijumnon, 2010). In addition, the distribution of heavy metals in sediment was detected at the Tha Chin estuary. The results showed that the highest concentration in mangrove sediment was Cd and Zn, which can be affected by living organisms on the surface sediment (Buajan and Pumijumnon, 2010).

The Tha Chin River is an important agricultural area for planting water spinach (*Ipomoea aquatica* Forssk.). It is a local vegetable, cheap, and readily available everywhere; therefore, it is widely used for domestic consumption (Göthberg *et al.*, 2002). Water spinach is aquatic macrophytes that has

a great potential to accumulate heavy metals inside its tissues (Göthberg *et al.*, 2004). Water mimosa (*Neptunia oleracea* Lour.) is also a popular vegetable planted along the Tha Chin River from Suphanburi to Nakhon Pathom. Water mimosa can accumulate Cd, Cu, and Pb in roots > stems > leaves (Wahab *et al.*, 2014). The accumulation of heavy metals is related to pH, which affects the dissolution of heavy metals in water resources (Shehata, 2019).

People who consume the water spinach and water mimosa contaminated with heavy metals will pose health risks such as Cd poisoning, which increases the risk of osteoporosis and lung damage (ATSDR, 2012). The ingestion of vegetables contaminated with As, Cd, Cr, Pb, Hg and Ni can cause severe human health effects in different target organs such as gastrointestinal cancer, fragile immunological mechanisms, mental growth retardation, cardiovascular disease, damage to brain, kidney, and lungs, and producing both of acute and chronic toxicity symptoms in pregnant women, fetuses, children and adults (Kumar *et al.*, 2019). In addition, heavy metals can have adverse effects on the ecological system, including decreasing biodiversity and damaging to invertebrates living in sediment (Sow *et al.*, 2019).

In Thailand, there is a lack of systematic research determining the health risk assessment by consuming aquatic plants grown in a river contaminated by heavy metals. People eat water spinach and water mimosa as part of their regular diet. Finally, some heavy metals gradually accumulate in their body and cause adverse effects. Therefore, the objective of this research was to investigate the concentration of heavy metals (As, Cd, Pb, Ni, and Zn) in water and plants grown in the Tha Chin River. The health risk assessment by consumption of water spinach and water mimosa was evaluated by calculating the hazard quotient (HQ), hazard index (HI), and carcinogenic risk (C_R).

2. Materials and methods

2.1 Study sites

The Tha Chin River basin, located in central Thailand, has 320 km in length, 5.3 - 11.5 m

of water depths, and 46 - 500 m in width (Pratum *et al.*, 2019). The basin covers 13,682 km² and flows through four provinces (Chai Nat, Suphan Buri, Nakhon Pathom, and Samut Sakhon) before flowing to the Gulf of Thailand (Lekphet *et al.*, 2004). It can be separated into three main parts: the upper, middle, and lower zone (Veschasit *et al.*, 2012). The sampling sites were divided into six stations along the river (Figure 1). The Chai Nat (CN) and Pho Phraya (PY) stations were the representatives of the upper part. The Song Phi Nong (SPN) and Bang Len (BL) stations represented the middle part. Lastly, as the exemplar of the lower part, The Sampran (SP) and Tha Mai (TM) stations were selected. The water and plants samples were collected in April (dry season) and July 2020 (wet season).

2.2 Water sampling and heavy metal analysis

Water sampling was collected at the 30 centimeters depth from the water surface. The 1L of water was added in a polyethylene bottle and preserved at 4 °C with the icebox. The heavy metal concentration in water was determined in the laboratory by introducing 10 mL of water sample and 5 mL of 65% HNO₃ in the digestion vessel. The vessel was placed microwave digestion (Milestone, Series 135931, Italy) and heated at 175 °C for 20 minutes (EPA 3051). Then, the vessel was cooled down, and the solution was filtrated using Whatman No. 42. Finally, the solution was diluted with deionized water in a volumetric flask of 50 mL and analyzed for As, Cd, Pb, Ni, and Zn by inductively coupled plasma mass spectrometry (ICP-MS) (Agilent 240AA, USA).

2.3 Plant sampling and analysis

The polyethylene plot size of 1 × 1 m was prepared for plant sampling. The criteria for site selection were abundant and healthy plants. All plant samples in plot were collected, taken in a polyethylene bag, and returned to the laboratory. Water spinach was collected from 6 stations, but only water mimosa was collected from SPN and SP stations. Then, plant samples were washed thoroughly with tap water, followed by a rinse with deionized water.

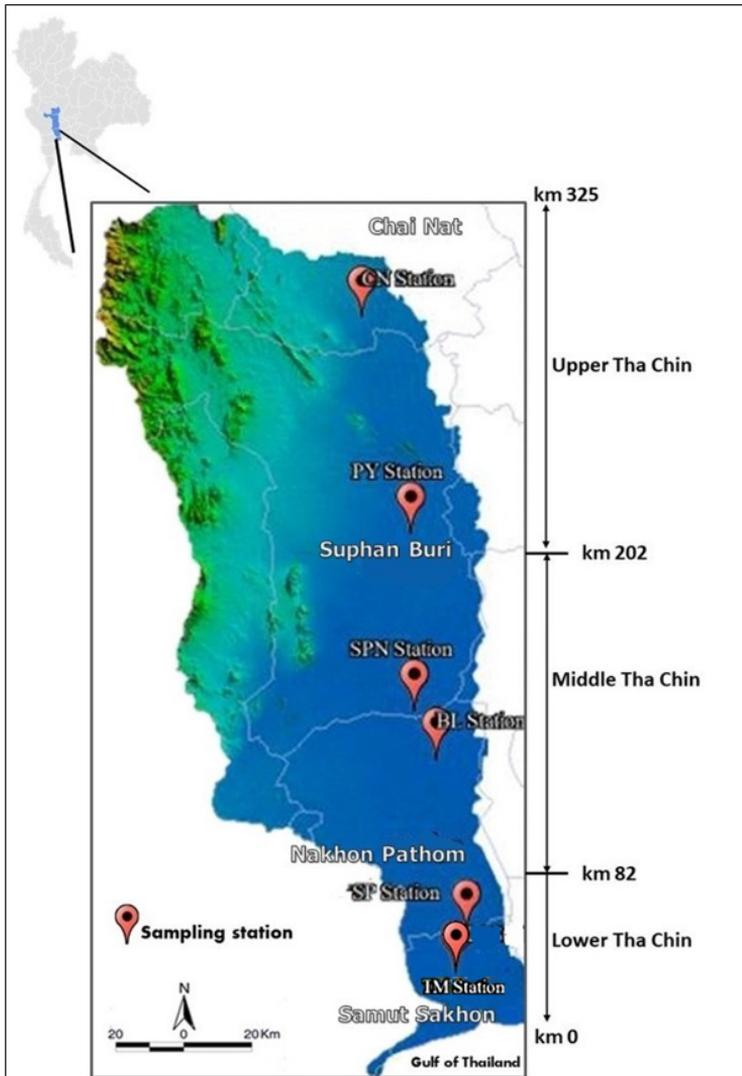


Figure 1. The sampling stations in the Tha Chin River in this study

The plants were separated into roots, stems, and leaves. Each part of the plant was weighed at least 1 kg and oven-dried at 65 °C for 48 hr. or until the weight was constant (Shehata, 2019). The dried samples were weighed again, ground in a mortar until size like a powder, and passed 200 mm diameter stainless steel sieve (ASTM). Then, 0.5 g of dry sample was placed in a digestion vessel with 10 mL 65% HNO₃. The vessel was placed microwave digestion (Milestone, Series 135931, Italy) and heated at 175 °C for 25 minutes (EPA 3051). Then, the vessel was cooled down, and the solution was filtrated using Whatman No. 42. Finally, the solution was diluted with deionized water

in a volumetric flask of 50 mL and analyzed for As, Cd, Pb, Ni, and Zn by inductively coupled plasma mass spectrometry (Agilent 240AA, USA.).

2.4 Human Health risk assessment

Exposure assessment

The average daily dose (ADD) was used to calculate heavy metals intake per day from water spinach and water mimosa (edible part, ingestion route) in the dry and wet seasons. The equation used for estimating the ADD is as follows:

$$ADD = \frac{C \times IR \times EF \times ED}{BW \times AT} \quad (1)$$

where ADD is the Average Daily Dose (mg/kg/day)

C = Heavy metals in water spinach and water mimosa (mg/kg, wet weight)

IR = The vegetable ingestion rate (g/day) (The daily vegetable consumption rate for Thai adults was an average of 124.6 g/day) (Phulkerd *et al.*, 2020)

EF = Exposure frequency (365 day/year)

ED = Exposure duration (30 years for non-carcinogenic and carcinogenic risk assessment) (US.EPA, 1989)

BW = Body weight (assuming 60 kg for Thai adult) (Wongsasuluk *et al.*, 2014).

AT = Average time (AT for non-carcinogenic risk is 10,950 days (30 years) and AT for carcinogenic risk is 25,550 days (70 years)

Risk characterization

Hazard quotients (HQ) and cancer risk (C_R) were used to estimate non-carcinogenic, and carcinogen risk applied according to USEPA. The equation used for estimating the HQ is as follows:

$$HQ = \frac{ADD}{RfD} \quad (2)$$

$$C_R = ADD \times CSF \quad (3)$$

Where RfD is oral reference, doses of the non-carcinogenic risk were based on USEPA, and CSF is the oral carcinogenic slope factor, as shown in Table 1.

If the HQ was below 1.0 for the non-carcinogenic risk, the adverse effects of no concern and CR below 10⁻⁶ for the carcinogenic risk showed no concern. However, if C_R above 10⁻⁴ is considered harmful, the cancer risk is troublesome (Quispe *et al.*, 2021).

C_R = Cancer risk

ADD = Average daily dose (mg/kg/day)

CSF = Cancer slope factor (mg/kg/day)

Hazard Index (HI)

In this study, the cumulative health risk was evaluated by summing HQ value of the individual metal and expressed as total HQ or HI as the following equation:

$$HI = \sum HQ = HQ_{As} + HQ_{Cd} + HQ_{Pb} + HQ_{Ni} + HQ_{Zn} \quad (4)$$

The greater the values of HI, the greater the level of should be a concern. It generally indicates a potential for adverse human health effects if the HI value is above 1.

2.5 Statistical analysis

The concentration of As, Cd, Pb, Ni, and Zn in the water of six stations between the dry and wet seasons was compared using one-way ANOVA and Tukey’s range test at 95% significance on SPSS for Windows version 22.0. Moreover, the HQ, HI, and C_R of water spinach and water mimosa were also statistically compared.

3. Results and Discussion

3.1 The heavy metal concentration in The Tha Chin River

The heavy metal concentration between dry and wet seasons in rivers varied depending on many factors, including turbidity, conductivity, total dissolved solids (TDS), suspended solids (SS), and total hardness (Silas *et al.*, 2018). This study showed that the concentration of As, Pb, Ni, and Zn in water in the dry season was significantly higher than in the wet season except for Cd (Table 2).

Table 1. The toxicity responses to heavy metals as the oral reference dose (RfD) and the cancer slope factor (CSF) (Kan *et al.*, 2021)

Heavy metal	Oral RfD (mg/kg/day)	Oral CSF (mg/kg/day)
As	0.003	1.5
Cd	0.001	6.1
Ni	0.02	1.7
Pb	0.0035	0.0085
Zn	0.3	-

The As concentration in the dry season ranged from 0.0034 ± 0.0002 to 0.0043 ± 0.0004 mg/L. The Pb level in water in the dry season was 0.0403 ± 0.0003 to 0.0578 ± 0.0011 mg/L. The Ni level in water in the dry season was 0.0302 ± 0.0032 to 0.0353 ± 0.0028 mg/L. The Zn concentration in the dry season ranged from 0.0496 ± 0.0046 to 0.0862 ± 0.0015 mg/L. However, the level of Cd in water in the wet season was 0.0012 ± 0.0001 to 0.0013 ± 0.0001 mg/L. The standard limit for surface water quality in Thailand was as followed: As < 0.01 mg/L, Cd < 0.005 mg/L, Pb < 0.5 mg/L, Ni < 0.1 mg/L and Zn < 1 mg/L (Pollution Control Department, 1994). This study indicated that the heavy metal concentrations at all stations were below the standard limit in the dry and wet seasons. The five kinds of heavy metals in water at CN and PY station (representative of upper the Tha Chin River) were lower than the other stations. The most area beside the CN and PY station was the agriculture site. 70% of the area in Chai Nat and Suphan Buri was rice cultivation (Water Resources Regional Office7, 2018), which needs fertilizers and pesticides. These organic compounds contain heavy metals that surface runoff or soil erosion can contaminate

the river. The heavy metal concentration in water at TM station was higher than the other stations because this area was located in urban and industrial sites.

Heavy metals contaminating rivers cause bioaccumulation of toxic elements in fishes, crabs, shrimp, and other aquatic animals. People consume these animals, and heavy metals accumulate in the body (Zaynab *et al.*, 2022). The toxicity of heavy metals on human health depends on the route of exposure, the concentration of substances, and the chemical compound of the metal (Mahurpawar, 2015). Pb has adversely affected mental growth, causing neurological and cardiovascular diseases in humans. Cd can produce kidney problems, severe lung damage, increased blood pressure, irreversible nephropathy, damage to the skeleton, stomach irritation, vomiting, and diarrhea (Rai *et al.*, 2019).

3.2 Heavy metals accumulation in water spinach and water mimosa

Residents along the Tha Chin River planted water spinach and water mimosa for daily consumption. However, the cultivation of water spinach was more widespread than

Table 2. Comparison of heavy metal concentration in the Tha Chin River between the dry and wet season (mg/L)

Station	As		Cd		Pb		Ni		Zn	
	dry	wet	dry	wet	dry	wet	dry	wet	dry	wet
CN	0.0034 ^d ± 0.0002	0.0010 ^a ± 0.0001	0.0007 ⁱ ± 0.0001	0.0012 ^j ± 0.0001	0.0403 ^q ± 0.0003	0.0224 ^k ± 0.0002	0.0302 ^p ± 0.0032	0.0201 ^o ± 0.0005	0.0496 ^p ± 0.0046	0.0218 ^A ± 0.0023
PY	0.0035 ^{de} ± 0.0002	0.0015 ^b ± 0.0001	0.0008 ⁱ ± 0.0001	0.0013 ^j ± 0.0001	0.0478 ^r ± 0.0002	0.0226 ^k ± 0.0004	0.0311 ^q ± 0.0005	0.0205 ^x ± 0.0003	0.0517 ^p ± 0.0025	0.0246 ^e ± 0.0007
SPN	0.0056 ^h ± 0.0004	0.0043 ^f ± 0.0002	0.0009 ^j ± 0.0001	0.0013 ^j ± 0.0001	0.0553 ^u ± 0.0003	0.0231 ^l ± 0.0003	0.0316 ^{tb} ± 0.0003	0.0208 ^z ± 0.0005	0.0716 ^h ± 0.0010	0.0312 ^c ± 0.0008
BL	0.0048 ^g ± 0.0004	0.0030 ^c ± 0.0003	0.0009 ^j ± 0.0002	0.0014 ^j ± 0.0005	0.0531 ^s ± 0.0012	0.0324 ^m ± 0.0004	0.0366 ^R ± 0.0012	0.0211 ^β ± 0.0005	0.0828 ^o ± 0.0038	0.0594 ^δ ± 0.0008
SP	0.0037 ^e ± 0.0002	0.0031 ^c ± 0.0002	0.0009 ^j ± 0.0002	0.0012 ^j ± 0.0001	0.0549 ^t ± 0.0015	0.0335 ⁿ ± 0.0002	0.0371 [†] ± 0.0004	0.0234 ^u ± 0.0012	0.1152 ^p ± 0.0022	0.0742 ^Z ± 0.0027
TM	0.0043 ^f ± 0.0004	0.0036 ^{de} ± 0.0003	0.0009 ^j ± 0.0001	0.0013 ^j ± 0.0001	0.0578 ^v ± 0.0011	0.0367 ^p ± 0.0021	0.0353 ^g ± 0.0028	0.0226 ^δ ± 0.0002	0.0862 ^E ± 0.0015	0.0653 ³ ± 0.0067

*The superscript letter indicated that the mean of heavy metal concentration in water was significantly different at $p < 0.05$.

water mimosa. This study revealed that the heavy metals accumulation in roots of water spinach was more significant than in stems and leaves (edible part) (data not shown). The concentration of As, Pb, Ni, and Zn in the edible part of water spinach in the dry season was higher than in the wet season at every station (Table 3). However, the level of Cd in the edible part of water spinach in the dry season was lower than wet season, which is related to the concentration of Cd in water. In the dry season, the harvesting time of water spinach was about 45 - 50 days longer than in the wet season (30 - 35 days). Ketkrai *et al.* (2018) reported that in May, the average dry weight of water spinach of the upper, middle, and lower parts of the Tha Chin River was 4.34, 2.45, and 1.95 kg/m², respectively. The maximum concentration of As, Cd, Pb, Ni, and Zn accumulated by water spinach were 0.3624 ± 0.0239, 0.1559 ± 0.0495, 0.9896 ± 0.0203, 3.1804 ± 0.1771 and 76.6442 ± 1.6138 mg/kg DW, respectively. Rattanapaiboon *et al.* (2015) reported about the water spinach (*Ipomoea aquatica* Forsk.) grown in the Tha Chin River (Songphenong district, Suphan Buri to Sampran district, Nakhon Pathom) in May 2014. The highest heavy metal accumulated in water spinach were roots > stems > branches > leaves > shoots. The concentration of As, Ni, Pb, and Hg accumulated in the shoots of water spinach were 0.323 ± 0.068, 0.100 ± 0, 0.0079 ± 0.006, and 0.0015 ± 0.004 mg/kg, respectively. The research compares the heavy metal concentration in plants grown near the industrial area in Shanghai. It found that water spinach (*Ipomoea aquatica* Forsk.) accumulated the highest level of Pb and As when compared to bok choy (*Brassica campestris* L. ssp. *chinensis* Makino), Shanghai Green cabbages (*Brassica chinensis* L.), and lettuces (*Lactuca sativa* L. var. *ramosa* Hort.) (Bi *et al.*, 2018).

In this study, water mimosa collected from SPN and SP stations had a taproot attached to the edges of water bodies, including rivers and banks. The plant produced long, woody, brown-purple stems. The concentration of As, Pb, Cu, Ni, and

Zn in the edible part of water mimosa in the dry season were significantly greater than in the wet season at every station (Table 4). The level of Cd in the edible part of the water mimosa in the dry season was significantly lower than wet season, which was related to the concentration of Cd in water. The maximum concentration of As, Cd, Pb, Ni, and Zn accumulated by water mimosa were 0.2567 ± 0.0085, 0.3948 ± 0.0204, 0.5612 ± 0.0306, 2.5021 ± 0.1188 and 77.173 ± 1.2827 mg/kg DW, respectively. Both water spinach and water mimosa accumulated heavy metal in their tissues, but the physiological characteristic of plants did not change. Biomass or root elongation was in the normal range.

As seen in Tables 3 and 4, among the five kinds of heavy metals, the concentration of Zn in water spinach and water mimosa was the highest in their tissues. Zn is an essential trace element with great importance in human and food crops. However, it can be toxic to humans and plants at high concentrations (Bi *et al.*, 2018). The level of Zn in leaves of *Plantago lanceolata* L. grown in the natural area, mine site, and urban/industrial was 45.6, 46.7, and 36.9 mg/kg DW, respectively. However, the accumulation of Zn in roots of *P. lanceolata* grown in the natural area, mine site, and urban/industrial was 108.7, 143.0, and 97.4 mg/kg DW, respectively (Drava *et al.*, 2019).

3.3 Human health risk assessment in water spinach and water mimosa

3.3.1 Non-carcinogenic health risk

A high concentration of heavy metal accumulated in the edible part of water spinach and water mimosa will adversely affect consumers. Therefore, it is necessary to use the newest data to evaluate the human health risk before consuming the aquatic plant. In this study, the calculation for the non-carcinogenic risk of As, Cd, Pb, Ni, and Zn at six stations indicated that HQ and HI were lower than 1 (Table 5).

Table 3. Heavy metal accumulation in water spinach (edible part) during the dry and wet season (mg/kg DW)

Station	As		Cd		Pb		Ni		Zn	
	dry	wet	dry	wet	dry	wet	dry	wet	dry	wet
CN	0.1605 ^a ±0.0053	0.1270 ^a ±0.0110	0.0596 ^m ±0.0099	0.1294 ^s ±0.0200	0.5147 ^p ±0.0754	0.3615 ^A ±0.0222	0.7969 ^l ±0.0513	0.7729 ^h ±0.0769	40.2415 ^v ±1.8520	23.3619 [®] ±0.1490
PY	0.1804 ^c ±0.0067	0.1625 ^b ±0.0060	0.0466 ^l ±0.0058	0.1422 ^t ±0.0151	0.4226 ^m ±0.0208	0.2455 ^r ±0.0252	2.7681 ^o ±0.1611	0.5838 ^G ±0.0552	42.8016 ^x ±6.1587	25.9493 ^s ±0.6038
SPN	0.3624 ^k ±0.0239	0.3347 ^l ±0.0218	0.0865 ^a ±0.0058	0.1478 ^u ±0.0093	0.9793 ^q ±0.0440	0.2388 ^u ±0.0101	1.9054 ^k ±0.1407	0.5373 ^j ±0.0444	48.5450 ^x ±3.0534	28.6724 ^p ±0.7952
BL	0.2151 ^f ±0.0072	0.2123 ^a ±0.0053	0.0697 ^p ±0.0002	0.1493 ^v ±0.0101	0.6542 ^g ±0.0439	0.4095 ^b ±0.0832	3.1804 ^s ±0.1771	2.7530 ^r ±0.1199	56.1562 ^x ±1.0972	42.1216 ^o ±0.4508
SP	0.2162 ^f ±0.0177	0.2056 ^d ±0.0150	0.1129 ^r ±0.0114	0.1725 ^x ±0.0578	0.9764 ^p ±0.0579	0.5872 ^v ±0.0537	3.1413 ^{-a} ±0.1355	2.3219 [®] ±0.0617	76.6442 ^J ±1.6138	65.2817 [®] ±2.0770
TM	0.2570 ^h ±0.0175	0.2518 ^b ±0.0200	0.0631 ⁿ ±0.0058	0.1559 ^w ±0.0495	0.9896 ^z ±0.0203	0.6269 ^h ±0.0159	2.6434 ^q ±0.0858	1.3533 ^{2b} ±0.0266	69.8709 ^u ±2.5364	61.8075 ^K ±25.3427

*The superscript letter indicated that the mean of heavy metal accumulation in water spinach was significantly different at $p < 0.05$.

Table 4. Heavy metal accumulation in water mimosa (edible part) during the dry and wet season (mg/kg DW)

Station	As		Cd		Pb		Ni		Zn	
	dry	wet	dry	wet	dry	wet	dry	wet	dry	wet
SPN	0.2567 ^h ±0.0085	0.2088 ^e ±0.0115	0.1257 ^a ±0.0074	0.2076 ^d ±0.0128	2.7532 ⁿ ±0.6358	0.2487 [®] ±0.0142	2.2378 ^p ±0.0038	1.4532 ^m ±0.0565	61.7819 ^r ±3.1141	52.7376 ^v ±2.0342
SP	0.2104 ^f ±0.0124	0.1763 ^c ±0.0076	0.1563 ^b ±0.0056	0.2348 ^j ±0.0204	2.4396 ^q ±0.1681	0.2112 ^k ±0.0306	2.9021 ^r ±0.1188	1.7463 ⁿ ±0.0973	77.173 [®] ±1.2827	31.0984 ^x ±1.0060

*The superscript letter indicated that the mean of heavy metal accumulation in water mimosa was significantly different at $p < 0.05$.

It revealed that consumption of water spinach growing along the Tha Chin River might not pose non-cancer-related health risks in both the wet and dry seasons at $P < 0.05$. From the HQ value of water spinach, it can be concluded that the contribution of five metals to the non-carcinogenic health risk was in the order of As > Cd > Pb > Zn > Ni. Mohammadi *et al.* (2019) reported that the non-carcinogenic health risk assessment of heavy metals (HQ) in drinking water in Iran was in the order of Zn > Ba > Cr > Cu > Mo > Pb > Ni > Cd.

The HQ and HI of water mimosa were below 1 (Table 6), suggesting an acceptable non-carcinogenic health risk of the edible part of water mimosa grown in SPN and SP stations. From the HQ value of the water mimosa, the contribution of five metals to the non-carcinogenic health risk was in the order of As > Cd > Pb > Zn > Ni. The HI level of water mimosa at SPN and SP station was higher than water spinach. These results are related to the different heavy metal concentrations in both kinds of plants.

Table 5. Non-carcinogenic risk assessment of water spinach in the dry and wet season in the Tha Chin River

Station	HQ of water spinach												HI																																																															
	As				Cd				Pb				Ni				Zn		dry	wet																																																								
	dry	wet	dry	wet	dry	wet	dry	wet	dry	wet	dry	wet	dry	wet	dry	wet																																																												
CN	0.2268 ^h ± 0.0050	0.1020 ^a ± 0.0047	0.0468 ^p ± 0.0020	0.0742 ^v ± 0.0048	0.0414 ^q ± 0.0061	0.0248 st ± 0.0015	0.0106 ^{ph} ± 0.0006	0.0093 ^v ± 0.0009	0.0378 ^u ± 0.0007	0.0187 ^z ± 0.0001	0.36 ^v	0.23 ^r	PY	0.1694 ^c ± 0.0063	0.1301 ^b ± 0.0048	0.0331 ^m ± 0.0007	0.0781 ^u ± 0.0036	0.0168 ^e ± 0.0017	0.0370 ^{ph} ± 0.0016	0.0070 ^z ± 0.0007	0.0402 ^z ± 0.0024	0.0208 ^z ± 0.0003	0.31 ^Δ	0.25 ^r	SPN	0.3404 ^m ± 0.0225	0.2744 ^k ± 0.0175	0.0644 ^s ± 0.0011	0.0855 ^w ± 0.0001	0.0789 ^y ± 0.0035	0.0164 ^q ± 0.0007	0.0256 ^{aa} ± 0.0040	0.0064 ^{ll} ± 0.0005	0.0456 ^z ± 0.0009	0.0229 ^{ss} ± 0.0004	0.55 ^Ω	0.41 ^R	BL	0.2021 ^g ± 0.0067	0.1699 ^f ± 0.0042	0.0597 ^r ± 0.0004	0.0858 ^w ± 0.0024	0.0527 ^{jl} ± 0.0035	0.0281 ^z ± 0.0057	0.0425 ^{yl} ± 0.0016	0.0330 ^{ss} ± 0.0014	0.0528 ^t ± 0.0010	0.0337 ^z ± 0.0004	0.41 ^R	0.36 ^v	SP	0.1933 ^e ± 0.0166	0.1619 ^d ± 0.0089	0.0726 ^t ± 0.0013	0.1014 ^z ± 0.0139	0.0786 ^p ± 0.0047	0.0403 ^e ± 0.0037	0.0422 ^o ± 0.0052	0.0279 ^{yl} ± 0.0007	0.0720 ^{ph} ± 0.0044	0.0522 [*] ± 0.0017	0.46 ^{Hb}	0.38 ^Δ	TM	0.2414 ^l ± 0.0165	0.2015 ⁱ ± 0.0160	0.0578 ^q ± 0.0016	0.0879 ^s ± 0.0002	0.0797 st ± 0.0016	0.0430 ^z ± 0.0011	0.0354 ^π ± 0.0023	0.0162 ^d ± 0.0003	0.0656 ^Ω ± 0.0024	0.0495 ^{ml} ± 0.0010	0.48 ^{Hb}	0.41 ^R

*The superscript letter indicated that the mean HQ and HI of water spinach in the dry and wet season were significantly different at p < 0.05.

Table 6. Non-carcinogenic risk assessment of water mimosa during the dry and wet season in the Tha Chin River

Station	HQ of water mimosa										HI	
	As		Cd		Pb		Ni		Zn		dry	wet
	dry	wet	dry	wet	dry	wet	dry	wet	dry	wet		
SPN	0.3064^z ± 0.0125	0.2072 ^v ± 0.0112	0.0900 ^q ± 0.0041	0.1234 ^t ± 0.0057	0.2044 ^r ± 0.0112	0.0211 ^b ± 0.0008	0.0401 ^s ± 0.0013	0.0216 ^c 0.0005	0.0737 ^p ± 0.0009	0.0522 ^m ± 0.0003	0.71 ^{-w}	0.43 ^e
SP	0.2511 ^x ± 0.0016	0.1745^u ± 0.0061	0.1119 ^s ± 0.0032	0.2346^r ± 0.0035	0.2295^v ± 0.0071	0.0477 ^k ± 0.0008	0.0448^h ± 0.0004	0.0259 ^e ± 0.0002	0.0921^r ± 0.0004	0.0308 ^f ± 0.0001	0.73 ^{-w}	0.51 ^o

*The superscript letter indicated that the mean HQ and HI of water mimosa in the dry and wet season were significantly different at $p < 0.05$.

3.3.2 Carcinogenic risk

The International Agency for Research on Cancer (IARC) categorized Cd and As in group 1 as human carcinogens, while Ni is classified in group 2B as possibly carcinogenic to humans (IARC, 2012). The results showed that C_R of water spinach for As at SPN and TM stations in the dry and wet seasons were more significant than the threshold cancer risk limit ($> 10^{-4}$) (Table 7). The C_R for Cd and Ni in water spinach collected from all stations was higher than the standard limit in the dry and wet seasons, indicating that people consuming water spinach may be exposed to high lifetime cancer risk. The monitoring of heavy metal content in ten kinds of vegetables, including brinjal (*Solanum melongena*), spinach (*Spinacia oleracea*), potato (*Solanum tuberosum*), tomato (*Solanum lycopersicum*), red amaranth (*Amaranthus paniculatus*), green amaranth (*Amaranthus*

viridis), bottle gourd (*Lagenaria siceraria*), yardlong bean (*Vigna sesquipedalis*), pumpkin (*Cucurbita maxima*), and carrot (*Daucus carota*), indicated that human carcinogenic risk for As was higher than the threshold cancer risk limit for all the vegetables (Haque *et al.*, 2021).

In the case of water mimosa, the results revealed that C_R of for As in the dry season at SPN and SP stations in the dry and wet season were greater than 10^{-4} while Cd and Ni were exceptional than 10^{-4} every station, which is in the range of high carcinogenic risk (Table 8). Among four heavy metals, Ni has the highest chance of cancer risks. Ni, the most extraordinary C_R of water spinach and water mimosa were $1.4 \times 10^{-3} \pm 5.5 \times 10^{-5}$ and $1.5 \times 10^{-3} \pm 1.3 \times 10^{-5}$ in the dry season. The cancer risk assessment based on ingestion of Pb, Ni, Cr, Cu, Cd, and Zn pollution in the Noyyal River of South India indicated that the order of risk is Ni > Cr > Cu (Karunanidhi *et al.*, 2022).

Table 7. Carcinogenic risk assessment in water spinach during the dry and wet season in the Tha Chin River

Station	C_R of water spinach							
	As		Cd		Pb		Ni	
	dry	wet	dry	wet	dry	wet	dry	wet
CN	6.0×10^{-5f} $\pm 2.3 \times 10^{-6}$	4.6×10^{-5a} $\pm 2.1 \times 10^{-6}$	1.0×10^{-4m} $\pm 1.2 \times 10^{-5}$	1.9×10^{-4s} $\pm 2.9 \times 10^{-5}$	$1.2 \times 10^{-6z\Omega}$ $\pm 1.8 \times 10^{-7}$	7.4×10^{-79c} $\pm 4.5 \times 10^{-8}$	3.6×10^{-4e} $\pm 1.9 \times 10^{-5}$	$3.1 \times 10^{-4=}$ $\pm 3.1 \times 10^{-5}$
PY	7.6×10^{-5c} $\pm 2.8 \times 10^{-6}$	5.8×10^{-5b} $\pm 2.2 \times 10^{-6}$	1.8×10^{-4k} $\pm 4.1 \times 10^{-6}$	2.1×10^{-4t} $\pm 2.2 \times 10^{-5}$	1.0×10^{-6yz} $\pm 5.0 \times 10^{-8}$	5.0×10^{-7y} $\pm 5.1 \times 10^{-8}$	1.3×10^{-3e} $\pm 5.4 \times 10^{-5}$	$2.4 \times 10^{-4A=}$ $\pm 2.3 \times 10^{-5}$
SPN	1.5×10^{-4j} $\pm 1.0 \times 10^{-5}$	1.2×10^{-4h} $\pm 7.9 \times 10^{-6}$	1.5×10^{-4u} $\pm 6.9 \times 10^{-6}$	2.2×10^{-4u} $\pm 1.5 \times 10^{-7}$	$2.3 \times 10^{-6\Omega}$ $\pm 1.1 \times 10^{-7}$	4.9×10^{-7y} $\pm 2.1 \times 10^{-8}$	8.7×10^{-4AV} $\pm 7.6 \times 10^{-5}$	2.2×10^{-4u} $\pm 1.8 \times 10^{-5}$
BL	9.1×10^{-5j} $\pm 3.0 \times 10^{-6}$	7.6×10^{-5b} $\pm 1.9 \times 10^{-6}$	1.2×10^{-4p} $\pm 2.7 \times 10^{-6}$	2.2×10^{-4u} $\pm 1.5 \times 10^{-7}$	$1.6 \times 10^{-6z\Omega}$ $\pm 1.1 \times 10^{-7}$	8.4×10^{-7k} $\pm 1.7 \times 10^{-7}$	1.4×10^{-30O} $\pm 5.5 \times 10^{-5}$	1.1×10^{-30} $\pm 4.9 \times 10^{-5}$
SP	8.7×10^{-5J} $\pm 7.5 \times 10^{-6}$	7.3×10^{-5b} $\pm 4.0 \times 10^{-6}$	1.9×10^{-4r} $\pm 8.1 \times 10^{-6}$	2.5×10^{-4x} $\pm 8.5 \times 10^{-5}$	$2.3 \times 10^{-6\Omega}$ $\pm 1.4 \times 10^{-7}$	$1.2 \times 10^{-6z\Omega}$ $\pm 1.1 \times 10^{-7}$	1.4×10^{-30O} $\pm 1.8 \times 10^{-4}$	9.5×10^{-4W} $\pm 2.5 \times 10^{-5}$
TM	1.2×10^{-4e} $\pm 7.4 \times 10^{-6}$	1.0×10^{-4j} $\pm 7.2 \times 10^{-6}$	1.1×10^{-4n} $\pm 1.0 \times 10^{-5}$	2.3×10^{-4w} $\pm 1.4 \times 10^{-6}$	$2.4 \times 10^{-6\Omega}$ $\pm 4.9 \times 10^{-8}$	$1.3 \times 10^{-6z\Omega}$ $\pm 3.2 \times 10^{-8}$	1.2×10^{-30e} $\pm 7.7 \times 10^{-5}$	5.5×10^{-4k} $\pm 1.1 \times 10^{-5}$

*The superscript letter indicated that the mean C_R of water spinach in the dry and wet season were significantly different at $p < 0.05$.

Table 8. Carcinogenic risk assessment of water mimosa during the dry and wet season in in Tha Chin River

Station	C _R of water mimosa							
	As		Cd		Pb		Ni	
	dry	wet	dry	wet	dry	wet	dry	wet
SPN	1.4×10 ^{-4d}	9.3×10 ^{-5e}	2.7×10 ^{-4e}	3.8×10 ^{-4g}	1.2×10 ^{-5a}	6.8×10 ^{-6j}	1.4×10 ^{-3q}	7.3×10 ⁻⁴ⁿ
	±5.6×10 ⁻⁶	±5.0×10 ⁻⁶	±1.2×10 ⁻⁵	±1.7×10 ⁻⁵	±3.3×10 ⁻⁷	±2.3×10 ⁻⁸	±4.3×10 ⁻⁵	±1.8×10 ⁻⁵
SP	1.1×10 ^{-4e}	7.8×10 ^{-5b}	3.1×10 ^{-4f}	7.2×10 ^{-4h}	6.4×10 ^{-6m}	3.9×10 ^{-6k}	1.5×10 ^{-3r}	8.8×10 ^{-4p}
	±7.2×10 ⁻⁷	±2.7×10 ⁻⁶	±9.8×10 ⁻⁶	±1.1×10 ⁻⁵	±2.1×10 ⁻⁷	±2.5×10 ⁻⁸	±1.3×10 ⁻⁵	±5.3×10 ⁻⁶

*The superscript letter indicated that the mean C_R of water mimosa in the dry and wet season were significantly different at p < 0.05.

4. Conclusion

This study investigated the water and plants in the Tha Chin River in April and July 2020. The heavy metals, including As, Cd, Pb, Ni, and Zn, contaminated in water at all stations were below the standard limit of surface water setting by PCD. The concentration of As, Pb, Ni, and Zn in the edible part of water spinach and water mimosa in the dry season were higher than in the wet season at every station, while the level of Cd in the edible part of both plants in the dry season was lower than the wet season. Non-carcinogenic health risk indicated that HQ of water spinach for As, Cd, Pb, Ni, and Zn at six stations were lower than 1, and HI was below 1. The HQ of water mimosa for As, Cd, Pb, Ni, and Zn at SPN and SP station was lower than 1, and HI was below 1. From the HQ value of water spinach and water mimosa, the contribution of five metals to the non-carcinogenic health risk was in the order of As > Cd > Pb > Zn > Ni, respectively. In this study, it can be concluded that consumption of water spinach and water mimosa grew in the Tha Chin River may pose a cancer risk due to As, Cd and Ni contamination. This finding should be applied to properly manage heavy metal pollution in the Tha Chin River. Education about consuming various plants in daily life is necessary for the residents to avoid risk.

Acknowledgments

This research was supported by CU GRADUATE SCHOOL THESIS GRANT from Graduate School, Chulalongkorn University. The grant number was GCUGR1225633037M.

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