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REVIEW

The Concentration of Potentially Toxic Elements in Common Carp (*Cyprinus carpio*) in Fish: Systematic Review and Meta-Analysis and Dietary Health Risk Assessment

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Abstract

Common carp (*Cyprinus carpio*) is one of the most consumed fish in the world and can be exposed to various forms of pollution, such as potential toxic elements (PTEs). Several studies have been conducted on the concentration of PTEs in common carp fish. The aims of the current study were to meta-analyze the concentration of PTEs in common carp fish and estimate human health risks in consumers. A search was conducted in international databases, including Scopus, PubMed, Science Direct, Web of Science, and Embase to retrieve papers up to January 20, 2024. The non-carcinogenic risk due to PTEs in fish fillets was calculated via the target hazard quotient (THQ), and the carcinogenic risk due to iAs in fish fillets was calculated via cancer risk (CR). The highest concentrations of Cu, methyl-Hg, and Ni were observed in the fillets of common carp fish. The non-carcinogenic risk was lower than 1 in all countries; hence, consuming common carp fish does not pose a non-carcinogenic risk. Adult consumers in Iraq were exposed to an unacceptable carcinogenic due to iAs in common carp fish. Hence, it is recommended that plans be conducted to reduce the concentration of PTEs in common carp fish in Iraq.

Keywords Common carp · Heavy metals · Meta-analysis · Non-carcinogenic risk · Carcinogenic risk

Introduction

Various environmental pollutants, followed by the food chain, have increased consumer health concern [1–5]. These contaminants include potentially toxic elements (PTEs), mycotoxins [6] in doughs [7], maize [8], yogurt [9], and pathogens in milk [10–12]. PTEs contamination is a worldwide issue and following with other variables disrupting the ecosystem and leading to serious health risks for organisms [13–16]. In the World Health Organization classification, low concentrations of essential elements such as copper (Cu), cobalt (Co), manganese (Mn), selenium (Se), and zinc (Zn) are necessary for the natural metabolism of organisms [17–20]. For example, zinc is involved in more than 300 enzymatic and hormonal activities [21] and has catalytic, structural, and regulatory roles [22]. At the same time, potentially toxic elements (PTEs) such as cadmium (Cd), inorganic arsenic (iAs), lead (Pb), and mercury (Hg) are biologically non-essential elements. PTEs interfere with normal biological functions and exhibit toxicity even at low concentrations [22–25]. The occurrence of PTEs in aquatic ecosystems can originate from anthropogenic activities, including industry, mining, agriculture, and transportation, or from natural sources, such as erosion, atmospheric precipitation, and geological weathering [26–28]. The subsequent presence of environmental pollutants such as Pb, Cd, Hg, and As in the aquatic food chain has become inevitable [29]. Unlike environmental organic pollutants, heavy metals are not degraded by chemical or biological processes and accumulate in ecosystems [30].

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Exposure to PTEs and other pollutants can have several adverse effects on human health, depending on the dose, duration of exposure, and the health status of the exposed people [31–35]. Human exposure to Pb can cause intestinal, nervous, hematological, and cardiovascular problems [36]. Cd can exhibit mutagenic, carcinogenic, and teratogenic effects, and it can cause kidney, liver, bone, and reproductive dysfunctions [37]. Hg can cause damage to the central nervous system (CNS), cardiovascular system, skin, lungs, liver, and kidney [38].

Fish at the top of the food web are bioindicators of metal contamination in aquatic ecosystems [39]. The amount of heavy metals uptake and accumulation in fish can be correlated with various physiological, ecological, physical, chemical, and biological conditions [40]. Abiotic and biotic factors, including acidity, temperature, hardness, size, life cycle, history, age, sex, habitat preferences, and feeding habits, can affect the accumulation of the metal in fish tissues [41]. Notably, the levels of PTEs accumulation in fish organs and skin are generally higher than in fish muscle; however, muscles are the most commonly consumed parts by humans [42]. The Food and Drug Administration, World Health Organization, and Environmental Protection Agency warn about exceeding levels of heavy metals in some aquatic organisms. However, they also recognize the importance of omega-3 fatty acids (n-3 FAs), essential metals like selenium, and fat-soluble vitamins found in fish [43–45].

The common carp (*Cyprinus carpio*) is one of the most common species of commercially farmed fish worldwide [46]. Studies have revealed that omnivorous fish species, such as common carp, may exhibit higher concentrations of heavy metals than carnivorous and benthivorous fish species [47, 48]. Majnoni et al. reported that high concentrations of PTEs (Hg et al.) in common carp from the Zarivar River (Iran) could be linked to wastewater discharge. This study suggests that the bioaccumulation and biomagnification of heavy metals in water may lead to increased levels of PTEs in aquatic organisms in the future [49].

The study by Pazooki et al. has shown acceptable Pb, Zn, and Cu levels in the muscle and skin of wild and cultured common carp from the Southeastern Caspian Sea of Iran [50]. In Hosseini Alhashemi's study, the levels of Cd, Cr, and Cu in the muscle of common *Carpio* from freshwater wetlands in Iran were found to be higher than in the muscle of other studied fish species such as *Barbusgrypus*, *Barbus luteus*, *Barbussharpeyi*, *Liza abu*, and *Siluriustrisostegus* [51]. Heshmati et al. found that the concentration of Pd, Cd, Hg, and Mn was higher in the wild *C. carpio* fish muscles from the Caspian Sea than in farmed carp samples. However, the estimated daily intake of all examined PTEs was acceptable [52]. Similarly, in Aryaee's study, the concentrations of Cd, Fe, Cu, Pb, Co, Ni, Zn, and Cr in fish species from the Zabol Chahnimeh Reservoirs of Iran were below levels of concern for human consumption [53]. Several investigations have been performed on the concentration of PTEs in common carp fish (Appendix 1). Therefore, the main aims of this study were to meta-analyze the concentration of PTEs in common carp fish based on the defined subgroups and to calculate the health risks (both non-carcinogenic and carcinogenic risks) for consumers.

Materials and Method

Search Strategy

We systematically searched according to preferred reporting items for systematic reviews and meta-analyses (PRISMA) protocol [54–56]. The two authors searched international databases, including Scopus, PubMed, Science Direct, Web of Science, and Embase, to find published papers up to January 20, 2024. The search syntaxes for finding papers were obtained using medical subject headings (MeSH) and published papers. Syntaxes included "Toxic elements," "Heavy metals," "Potential toxic elements," "Potential hazard elements," "Elements," "trace metals," AND "fish" OR "marine foods," OR "carp fish" OR "common carp" OR "*Cyprinus carpio*." The titles and abstracts of retrieved papers were screened, and duplicate papers were excluded [56]. Subsequently, the full text of the papers was downloaded, and after reading the complete text, the required data was extracted. Disagreements between the authors in the selection or exclusion of papers were resolved by the corresponding author, who made the final decision. Duplicate papers were removed and screened using EndNote software version 8.0.

Eligibility Criteria

Our inclusion criteria comprised studies that detected PTEs in common carp, with full-text available in English, employing valid methods of detection and presenting statistical data on PTE levels (such as mean, standard deviation, and/or range). Review papers, letters to editors, thesis, books, conference proceedings, book chapters, and experimental or intervention studies were excluded. The country of study, sample size, statistical information on PTE concentrations (mean, standard deviation), and the method of detection were extracted.

Meta-Analysis of Data

A meta-analysis of PTE levels in common carp fish fillets was conducted using the mean (µg/kg-ww) and standard error (SE). We employed I^2 index and chi-square statistics to assess heterogeneity [57, 58]. If the I^2 index statistic exceeded 50%, indicating substantial heterogeneity, the random effects model (REM) was employed to calculate a pooled effect size. The meta-analysis of concentration in fillets of common carp fish was conducted using the Stata software (Version 17.0 College Station, TX, USA).

Health Risk Assessment

The daily intake of consumers was calculated by Eq. 1[15, 59–61]:

$$\text{CDI} = \frac{\text{C} \times \text{IR} \times \text{ED} \times \text{EF}}{\text{BW} \times \text{AT}} \times 10^{-3} \qquad (1)$$

In this equation, CDI is chronic daily intake (mg/kg-day); C, levels of PTEs in fillets of fish (µg/kg-ww); IR, ingestion rate (g/day); ED, exposure duration (year); EF, exposure frequency (350 day/year); AT, mean lifetime (day) and BW, body weight for children and adults is 15 and 70 kg, respectively [62]. ED for children and adults equals 6 and 70 years, respectively. AT for non-cancer risk is 2190 days and 25,550 days for children and adults, respectively, and AT for cancer risk equals 25,550 days for both children and adults. The ingestion rate of common carp fish is shown in Appendix 2.

The non-cancer risk was estimated using the below equation [63]:

$$\text{THQ} = \frac{\text{CDI}}{\text{RfD or TDI}} \qquad (2)$$

In this equation, RfD and TDI are oral reference doses and tolerable daily intake [18]. RfD for Cd, Ni, Cu, and iAs and methyl-Hg equals 0.001, 0.011, 0.04, 0.0003, and 0.0001 mg/kg-d, respectively [64, 65]. TDI for Pb is 0.0036 mg/kg-d [64, 65]. When the target hazard quotient (THQ) ≤ 1, the non-cancer risk is acceptable[63].

The cancer risk of iAs in carp fish was estimated by the below equation [66, 67]:

$$\text{CR} = \text{CDI} \times \text{CSF} \qquad (3)$$

where CSF is the cancer slope factor, CSF for iAs is 1.5 $(\text{mg/kg-d})^{-1}$ [65]. CR is classified as ignorable carcinogenic risk: $\text{CR} < 1.00\text{E}-06$; acceptable carcinogenic risk: $1.00\text{E}-06 \leq \text{CR} < 1.00\text{E}-04$; and unacceptable carcinogenic risk: $\text{CR} \geq 1.00\text{E}-04$ [68].

Results and Discussion

Method of Detection

Sixty-eight papers with 148 data reports were included in our study (Fig. 1). Monitoring the amount of PTEs in fish sample matrices is one of the most important research topics in health hazards [69]. Different research laboratories and regulatory agencies employ several analytical techniques for routinely observing, evaluating, and quantifying PTEs from

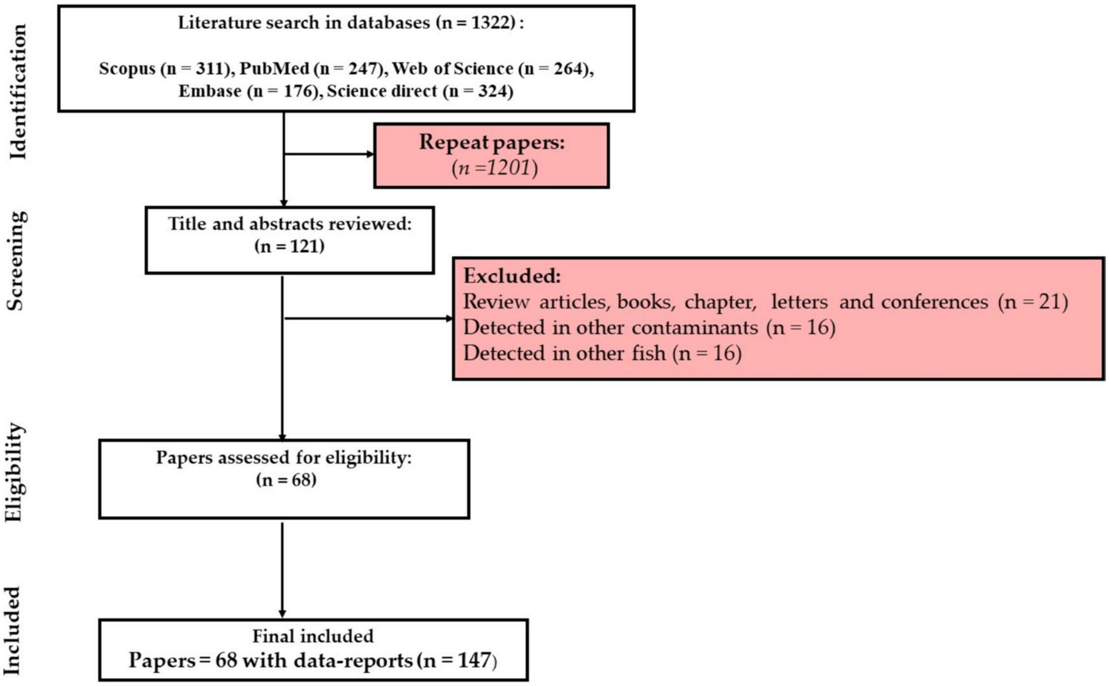


Fig. 1 Process of selection of papers based on PRISMA

water, air, soil, animal, plant, and food samples. Information about the application range of different analytical techniques may be essential for selecting the appropriate method, which, in turn, guides the sampling and sample preparation processes [70]. In the current study, the rank order of method of detection based on percentage use in detection was AAS (54%) > ICP-OES; ICP-AES, and ICP (25%) > ICP-MS (20%) > XRF (1%) (Fig. 2). Flame or graphite furnace AAS, ICP-OES, ICP-AES, and ICP are the common spectral techniques utilized in the estimation of PTEs in investigated studies. On the other hand, a specific technique like XRF can effectively identify trace levels of metals. It was shown that metals were measured using XRF in only one study [71] (Appendix 1). ICP is commonly used for multi-element analysis at low detection limits, whereas AAS is preferred for analyzing specific elements at higher concentrations [72]. AAS is a widely used and quantitative technique for metal analysis that can identify approximately 70 metals [73]. It was found that more than 50% of articles utilized AAS as the detection method for various PTEs. Numerous nebulizers, such as a graphite furnace and flame, are applied in hydride and mercury cold vapor AAS techniques to identify PTEs [74]. Flame AAS is a suitable technique that can measure heavy metals at concentrations of part per million (ppm) levels with appropriate accuracy [75]. It is a fast and relatively inexpensive procedure, completing the entire analysis within 10–15 s per sample with high accuracy (repeatability) and negligible interferences [76].

Flame AAS is practical for finding PTEs from several sample matrices. Unfortunately, this technique suffers from poor sensitivity compared with graphite furnace AAS or ICP-MS. Hence, flame AAS is inappropriate for identifying arsenic (As) because of the insufficient maximum temperatures required for atomization [73, 76]. In contrast, as an atomization procedure, graphite furnace AAS can distinguish metals in both aqueous and solid samples with great precision at parts per billion (ppb) levels [77]. Graphite furnace AAS is comparable to flame AAS except for the atomization process. This technique includes warming at high temperatures in order to volatilize and atomize the sample [77]. The advantages of graphite furnace AAS include the requirement for smaller samples (20 µ) for analysis than flame AAS and lower detection limits. However, there are drawbacks to graphite furnace AAS, including the expense of the furnace, lower sample throughput, more troublesome operation, low precision, limited range of working, slow analytical processes, and matrix interferences [78]. Following AAS (54%), the following most commonly used techniques were ICP-OES; ICP-AES and ICP collectively accounted for 25% of identifications of heavy metals in common carp (*Cyprinus carpio*) fish in the literature review (Appendix 1).

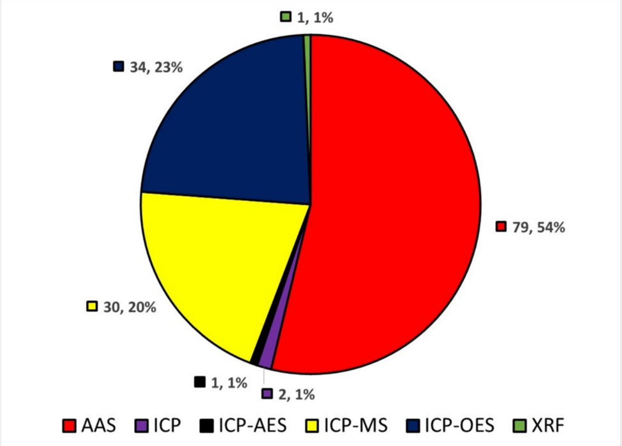


Fig. 2 Number and percentage method of detection PTEs in carp fish

ICP is the most sensitive and widely applied analytical method for detecting trace metals in various sample types. In the appendix, it was reported in only 1% of studies for heavy metal measurement.

ICP is the most sensitive and widely applied analytical method for detecting trace metals in various samples [73]. It was reported in 1% of studies for heavy metal measurement (Appendix 1). ICP operates using a plasma where energy transfer to generate and preserve the ionized gas is carried out via electromagnetic induction [79]. Both ICP-OES and ICP-AES are similar analytical techniques used for heavy metal estimation. Approximately 24% of articles examined in the current study demonstrated how heavy metals can be measured using these techniques (Appendix 1).

Since its commercial introduction in the mid-1970s, ICP-OES has rapidly become broadly utilized and acknowledged for numerous applications of metal determination in a wide assortment of samples [80]. Whereas AAS measures the quantity of light absorbed at a specific wavelength as elemental atoms enter an excited state, ICP-OES measures the light elements emit in a sample as they enter an ICP source [77]. Both techniques can detect trace metal concentrations in complex matrices with excellent precision and accuracy. However, ICP-OES offers several advantages over AAS. It can evaluate concentrations of multiple elements in a single sample with a single aspiration. Therefore, this situation leads to significant speed over AAS when the goal is to quantify several elements in a sample[74]. Additionally, ICP-OES has a much broader analytical working range and operates without recalibration. It can measure samples varying in concentration from 1 µg/L to 1 g/L without requiring recalibration, whereas AAS spans only three orders of magnitude, from 1 µg/L to 1 mg/L [77]. ICP-OES is particularly well-suited for detecting trace heavy metals, especially when all elements are consistently present at concentrations above ten ppb.

However, for lower concentrations of metals, especially heavy elements like arsenic, ICP-MS is recommended due to its superior sensitivity based on the literature review, it was shown that ICP-Ms is reported for measuring heavy metals in 20% of articles [81]. In contrast, XRF was mentioned in only 1% of articles (Appendix 1). XRF is a fast, affordable, and non-destructive analytical method for detecting a variety of hazardous materials, capable of simultaneously identifying up to 30 elements [71] through the interaction of X-ray radiation with atoms [82].

The ICP-OES technique offers superior sensitivity, broader elemental coverage, and lower detection limits than the XRF method. This condition makes ICP-OES an ideal technique for trace-level analysis of trace heavy metals. On the other hand, XRF is a versatile technique suited for qualitative and semi-quantitative analysis, especially when analyzing bulk samples with minimal preparation [83]. Overall, selecting a technique should consider factors such as detection limit, accuracy, sensitivity, expected concentration levels of heavy metals, the number of elements, the frequency of sample observation, and the presence of interfering components in sample matrices.

Concentration of PTEs in Fish

Fish is an exceptional source of high-quality protein, micronutrients, vitamins, and n-3 fatty acids, in specific unique fatty acids such as eicosapentaenoic (EPA 20:5) and docosahexaenoic (DHA 22:6) acid. The scientific report shows the association of fish consumption with various health benefits [84]. However, fish can be a source of potentially toxic elements if exposed to contamination in water. The results indicate a significant disparity in heavy metal in common carp (*Cyprinus carpio*) fish and sampling areas.

The bioaccumulation of toxic trace elements in fish depends on non-biotic criteria such as water pH and the chemical form of the element. In contrast, some intrinsic factors of the fish, such as age and physiologic conditions, are vital in accumulating PTEs in the body of fish [85]. Scientific reports on the levels of heavy metals in fish tissues are vital for human consumption. Significant differences have been observed worldwide in the levels of PTEs in fish, which may be attributed to this fish species' metabolism and feeding patterns [86].

The rank order of PTEs in the fillet of common carp (*Cyprinus carpio*) based on pooled concentration was Cu (0.4550 mg/kg-ww) > MeHg (0.2000 mg/kg-ww) > Ni (0.1540 mg/kg-ww) > iAs (0.0260 mg/kg-ww) > Pb (0.0036 mg/kg-ww) > Cd (0.0030 mg/kg-ww) (Tables 1, 2, 3, 4, 5, and 6). Statistical comparisons revealed that metals in varying quantities could be attributed to the examined tissues (gill, gut, liver, muscle, kidney, skin) in common carp (*Cyprinus carpio*). This suggests the physiological potential of different organs in the accumulating heavy metals [87]. In aquatic environments, the health status of fish and the different organs of this animal serve as indicators of water pollution and quality [88]. The consumption of fish muscle is considered an important part of the routine metal contamination [89]. Different amounts of heavy metals are mentioned in fish tissue, which might result from their capacity to induce metal-binding proteins such as metallothioneins [90, 91].

The gill plays a main role in fish exposure at the interface and direct contact with the marine environment. This organ regulates metal ions and nitrogenous waste excretion [92].

Table 1 Meta-analysis concentration of iAs in filled of carp fish based on country (mg/kg-ww)

Study	Number study	ES*	Lower	Upper	Weight (%)	Heterogeneity statistic	Degrees of freedom	*p* value	I^2
Iraq	3	3.3420	0.0010	6.7730	5.69	64,246.54	2	0	100.00%
Iran	13	0.0010	0.0000	0.0010	28.79	11,662.05	12	0	99.90%
Pakistan	5	0.2930	0.1950	0.3910	0.94	531.61	4	0	99.20%
China	11	0.0720	0.0560	0.0890	9.30	433.76	10	0	97.70%
Mexico	2	0.0090	0.0010	0.0280	6.68	34.62	1	0	97.10%
Turkey	11	0.0510	0.0420	0.0600	20.39	1632.75	10	0	99.40%
Cyprus	1	0.4130	0.3420	0.4840	0.01	0	0		.%
Poland	1	0.0020	0.0020	0.0020	5.65	0	0		.%
South Korea	1	0.0130	0.0010	0.0290	0.20	0	0		.%
Serbia	4	0.0430	0.0250	0.0610	12.05	1224.35	3	0	99.80%
Montenegro	1	0.0300	0.0270	0.0330	2.83	0	0		.%
Bosnia and Herzegovina	1	0.2230	0.2120	0.2340	0.41	0	0		.%
Spain	3	0.0640	0.0130	0.1140	7.06	1236.21	2	0	99.80%
Overall	**57**	0.0260	0.0250	0.0270	**100**	**3.10E + 06**	**56**	**0**	**100.00%**

*Effect size: Pooled concentration of PTEs

Table 2 Meta-analysis concentration of Cd in filled of carp fish based on country (mg/kg-ww)

Study	Number study	ES*	Lower	Upper	Weight (%)	Heterogeneity statistic	Degrees of freedom	*p* value	I^2
Iraq	26	0.3120	0.2750	0.3480	0.23	9135.54	25	0	99.70%
Iran	18	0.0490	0.0450	0.0520	18.60	21,557.64	17	0	99.90%
Pakistan	13	1.1310	0.9100	1.3510	0.00	1322.85	12	0	99.10%
Algeria	1	0.0010	0.0001	0.0260	0.00	0	0		.%
China	13	0.0160	0.0080	0.0230	10.87	20,523.54	12	0	99.90%
Mexico	2	0.1130	0.0001	0.3300	0.12	106.58	1	0	99.10%
Philippines	1	1.6700	1.3520	1.9880	0.00	0	0		.%
Turkey	14	0.0130	0.0100	0.0160	18.72	6174.8	13	0	99.80%
Bulgaria	5	0.0200	0.0070	0.0330	0.73	958.23	4	0	99.60%
Cyprus	1	0.0120	0.0090	0.0150	0.04	0	0		.%
Poland	1	0.0001	0.0000	0.0002	6.85	0	0		.%
Vietnam	5	0.0220	0.0130	0.0300	0.22	123.07	4	0	96.70%
Tunisia	1	0.0200	0.0110	0.0290	0.01	0	0		.%
South Korea	1	0.0130	0.0080	0.0180	0.02	0	0		.%
Serbia	4	0.0040	0.0030	0.0060	14.64	260.93	3	0	98.90%
Montenegro	1	0.0120	0.0120	0.0120	4.25	0	0		.%
Ethiopia	1	0.0060	0.0040	0.0090	0.06	0	0		.%
Bosnia and Herzegovina	1	0.0120	0.0110	0.0130	1.06	0	0		.%
Spain	3	0.0001	0.0000	0.0000	20.62	210.27	2	0	99.00%
Australia	1	0.0010	0.0010	0.0010	2.97	0	0		.%
India and Pakistan	1	11.6000	8.7380	14.4620	0.00	0	0		.%
Overall	**114**	**0.0030**	**0.0026**	**0.0030**	**100.00**	**94,144.73**	**113**	**0**	**99.90%**

*Effect size: Pooled concentration of PTEs

Heavy metals have been detected in fish lungs, likely due to their thin epithelium and susceptibility to metal penetration [86]. In some reports, the liver was mentioned as the tissue with the highest concentration of heavy metals. The liver is an active central site for uptaking and storing the metals and their detoxification excretion [93, 94]. The high concentration of heavy metals mentioned in the liver of carp in a study in Serbia was attributed to the high level in the gut and transferred to the liver [90].

The concentration of elements in the gut is valuable because this part can indicate the levels of elements in sediment and natural food sources. The analysis of the gut of fish provides evidence of an accessible pool of elements and the potential for transfer through the gastrointestinal tissue and accumulation in different tissues [90]. The three countries with the highest concentration of iAs observed were Iraq (3.3420 mg/kg-ww), Cyprus (0.4130 mg/kg-ww), and Pakistan (0.2930 mg/kg-ww) (Table 1); Cd, in India and Pakistan (11.600 mg/kg-ww), the Philippines (1.670 mg/kg-ww), and Pakistan (1.131 mg/kg-ww) (Table 2); Pb, in Iraq (0.770 mg/kg-ww), Turkey (0.754 mg/kg-ww), and Cyprus (0.362 mg/kg-ww) (Table 3); Ni, in the Philippines (2.170 mg/kg-ww), Iraq (1.615 mg/kg-ww), and Cyprus (1.470 mg/kg-ww) (Table 4); MeHg, in Turkey (3.074 mg/kg-ww), Pakistan (0.455 mg/kg-ww), and Iraq (0.321 mg/kg-ww) (Table 5); and Cu, in Iraq (3.985 mg/kg-ww), Vietnam (3.499 mg/kg-ww), and Spain (1.517 mg/kg-ww) (Table 6). Many influential factors contribute to differences in heavy metal levels in fish, including the bioavailable metal concentration in the abiotic components of their surroundings, their feeding habits, ecological requirements, metabolism, age, and size of the fish in different countries [86, 95]. Each of these criteria can significantly impact the metals present in fish.

Health Risk Assessment

Non-Carcinogenic Risk

Iraq, Cyprus, and South Korea were the three countries with the highest THQ of iAs (Fig. 3). However, excluding children in Iraq (THQ = 1.5E + 00), THQ for both adults and children in all countries was less than 1. Hence, the non-carcinogenic risk due to iAs is acceptable. For Cd, the countries with the highest THQ were the Philippines, Pakistan, and Iraq. Except for children in the Philippines (THQ = 1.0E + 00), THQ for both adults and children in all countries was less than 1. Hence, the non-carcinogenic risk due to Cd is acceptable (Fig. 4). Cyprus, Vietnam, and the

Table 3 Meta-analysis concentration of Pb in filled of carp fish based on country (mg/kg-ww)

Study	Number study	ES*	Lower	Upper	Weight (%)	Heterogeneity statistic	Degrees of freedom	*p* value	I^2
Iraq	23	0.7700	0.6470	0.8940	0.81	23,259.31	22	0	99.90%
Iran	18	0.3530	0.3080	0.3980	11.93	9711.92	17	0	99.80%
Pakistan	27	0.0440	0.0400	0.0480	28.39	11,646.71	26	0	99.80%
Algeria	1	0.0200	0.0160	0.0250	0.05	0	0		.%
China	15	0.1200	0.1030	0.1370	0.79	1792.11	14	0	99.20%
Mexico	1	0.0190	0.0160	0.0220	0.13	0	0		.%
Philippines	1	0.3300	0.1730	0.4870	0.00	0	0		.%
Turkey	14	0.7540	0.7080	0.8000	15.95	71,496.77	13	0	100.00%
Bulgaria	1	0.2000	0.1770	0.2230	0.00	0	0		.%
Cyprus	1	0.3620	0.0001	0.8700	0.00	0	0		.%
Poland	1	0.0360	0.0290	0.0440	0.02	0	0		.%
Vietnam	5	0.3330	0.2410	0.4260	0.01	143.31	4	0	97.20%
Tunisia	1	0.0590	0.0440	0.0740	0.00	0	0		.%
South Korea	1	0.0100	0.0080	0.0120	0.29	0	0		.%
Serbia	2	0.0270	0.0001	0.0670	0.43	60.02	1	0	98.30%
Montenegro	1	0.1120	0.1060	0.1180	0.03	0	0		.%
Bosnia and Herzegovina	1	0.2480	0.2380	0.2580	0.01	0	0		.%
Spain	2	0.0001	0.0000	0.0003	29.24	0	1	1	0.00%
Australia	1	0.0003	0.0010	0.0004	11.91	0	0		.%
Overall	**117**	**0.0036**	**0.0030**	**0.0039**	**100.00**	**160,000.00**	**116**	**0**	**99.90%**

*Effect size: Pooled concentration of PTEs

Table 4 Meta-analysis concentration of Ni in filled of carp fish based on country (mg/kg-ww)

Study	Number study	ES*	Lower	Upper	Weight (%)	Heterogeneity statistic	Degrees of freedom	*p*value	I^2
Iraq	8	1.615	1.185	2.046	6.6	1186.72	7	0	99.40%
Iran	8	0.035	0.019	0.052	36.72	461.1	7	0	98.50%
Pakistan	10	0.346	0.309	0.383	22.51	4538	9	0	99.80%
China	1	0.04	0.033	0.047	4.63	0	0		.%
Philippines	1	2.17	2.013	2.327	0.33	0	0		.%
Turkey	9	0.338	0.278	0.399	14	1874.26	8	0	99.60%
Bulgaria	1	0.08	0.069	0.091	4.44	0	0		.%
Cyprus	1	1.47	0.659	2.281	0.01	0	0		.%
Serbia	2	0.003	0.003	0.004	9.48	0.08	1	0.782	0.00%
Montenegro	1	0.152	0.081	0.223	1.29	0	0		.%
Overall	**42**	**0.154**	**0.145**	**0.163**	**100**	**17,767.31**	**41**	**0**	**99.80%**

*Effect size: Pooled concentration of PTEs

Philippines are the three countries with the highest THQ of Pb. THQ for both adults and children in all countries was less than 1 value. Hence, the non-carcinogenic risk due to Pb is acceptable (Fig. 5). Turkey, South Korea, and China were the three countries with the highest THQ of MeHg. Except turkey (adult = 2.2E + 00 and children = 1.06E + 01) and South Korea (adult = 1.32E + 00 and children = 6.18E + 00). THQ for adults and children in all countries was less than 1; hence, the non-carcinogenic risk due to MeHg is acceptable (Fig. 6). The highest THQ for Ni was found in the Philippines, Cyprus, and Iraq. However, the THQ for both adults and children in all countries was less than 1 value; hence, the non-carcinogenic risk due to Ni is acceptable (Fig. 7). Vietnam, Cyprus and Iraq were the three countries with the highest THQ of Cu. THQ for both adults and children in tall countries was less than 1 value. Hence, the non-carcinogenic

Table 5 Meta-analysis concentration of MeHg in filled of carp fish based on country (mg/kg-ww)

Study	Number study	ES*	Lower	Upper	Weight (%)	Heterogeneity statistic	Degrees of freedom	*p* value	I^2
Iraq	1	0.3210	0.2770	0.3650	0.88	0	0		.%
Iran	9	0.0440	0.0300	0.0580	29.06	28,248.47	8	0	100.00%
Pakistan	5	0.4550	0.3810	0.5290	9.72	692.09	4	0	99.40%
China	9	0.0700	0.0550	0.0840	19.34	172.8	8	0	95.40%
Mexico	1	0.0010	0.0000	0.0020	3.47	0	0		.%
Turkey	8	3.0740	1.0860	5.0610	8.97	2.10E+05	7	0	100.00%
Poland	1	0.0010	0.0000	0.0010	3.48	0	0		.%
Tunisia	1	0.0340	0.0100	0.0580	1.88	0	0		.%
South Korea	1	0.2460	0.1570	0.3350	0.27	0	0		.%
Serbia	4	0.0150	0.0130	0.0180	12.16	1179.95	3	0	99.70%
Montenegro	1	0.1120	0.0960	0.1280	2.5	0	0		.%
Bosnia and Herzegovina	1	0.1000	0.0970	0.1030	3.44	0	0		.%
Spain	1	0.0190	0.0160	0.0210	3.44	0	0		.%
Australia	1	0.0110	0.0100	0.0420	1.4	0	0		0.8
Overall	**44**	**0.2000**	**0.1950**	**0.2050**	**100**	**2.70E+05**	**43**	**0**	**100.00%**

*Effect size: Pooled concentration of PTEs

Table 6 Meta-analysis concentration of Cu in filled of carp fish based on country (mg/kg-ww)

Study	Number study	ES*	Lower	Upper	Weight (%)	Heterogeneity statistic	Degrees of freedom	*p* value	I^2
Iraq	10	3.985	3.363	4.607	9.19	110,000	9	0	100.00%
Iran	13	0.980	0.855	1.104	13.34	10,601.26	12	0	99.90%
Pakistan	21	0.184	0.167	0.201	33.12	24,172.6	20	0	99.90%
Algeria	1	0.034	0.030	0.037	2.37	0	0		.%
China	11	0.396	0.356	0.436	13.58	6912.58	10	0	99.90%
Mexico	2	1.271	0.001	3.246	1.46	416.85	1	0	99.80%
Philippines	1	0.330	0.173	0.487	0.43	0	0		.%
Turkey	10	0.006	0.001	0.011	5.4	4334.69	9	0	99.80%
Bulgaria	5	0.462	0.298	0.625	7.89	408.88	4	0	99.00%
Cyprus	1	1.500	0.608	2.392	0.02	0	0		0.8
Poland	1	0.035	0.031	0.039	2.37	0	0		0.8
Vietnam	5	3.499	2.002	4.996	1.25	384.37	4	0	99.00%
Serbia	2	0.111	0.106	0.115	4.71	1.18	1	0.278	15.20%
Montenegro	1	0.580	0.486	0.674	0.9	0	0		0.8
Spain	2	1.517	1.264	1.771	0.67	3.51	1	0.061	71.50%
Australia	1	0.221	0.196	0.246	2.12	0	0		.%
Kosovo	1	0.647	0.573	0.721	1.19	0	0		.%
Overall	**88**	**0.455**	**0.444**	**0.467**	**100.00**	**470,000**	**87**	**0**	**100.00%**

*Effect size: Pooled concentration of PTEs

risk due to Cu is acceptable (Fig. 8). In a study conducted by Bagheri et al. in Iran on edible fishes of Gorgan Bay, Capsian Sea, the results of THQ value were less than one [89]. Similarly, in a study conducted on the farmed common carp (CYPRINUS CARPIO) in Poland, the THQ index for Cd, As, Pb, Cr, Ni, and Cu were less than 1, indicating the intake of a single metal does not pose health risk [96]. This situation demonstrated for provisional intakes and THQ estimated for a common carp. This means that the consumption of any of the fish above did not appear to be potentially hazardous for the health of Tunisian consumers as they were far below threshold values [97]. Furthermore, in different

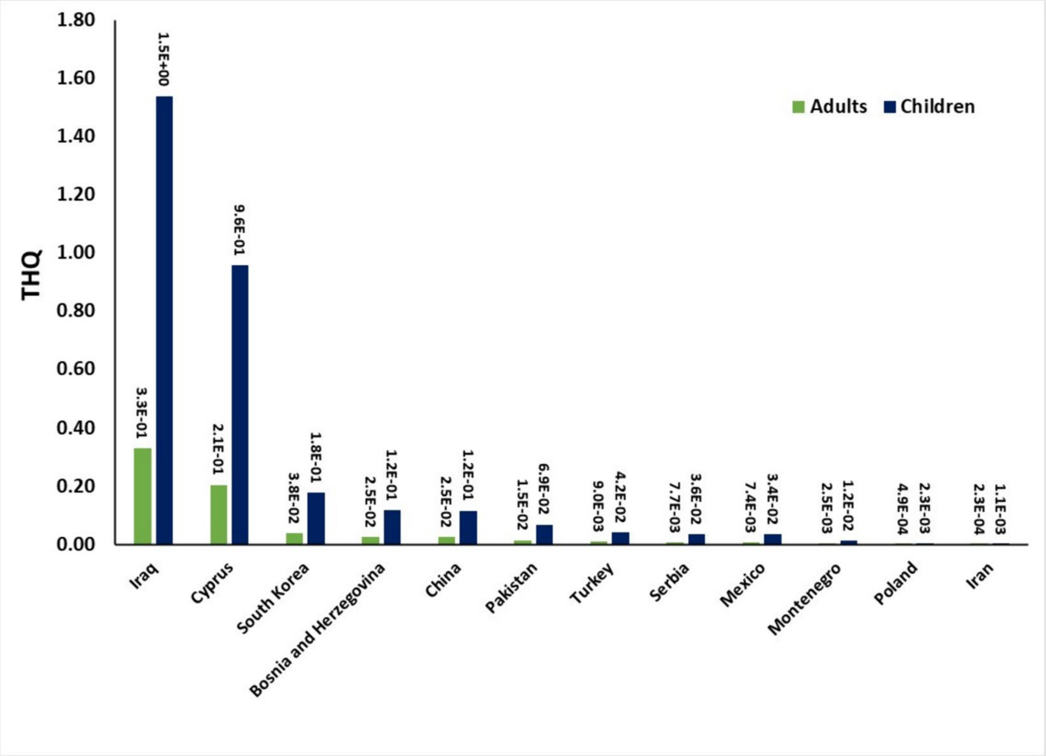
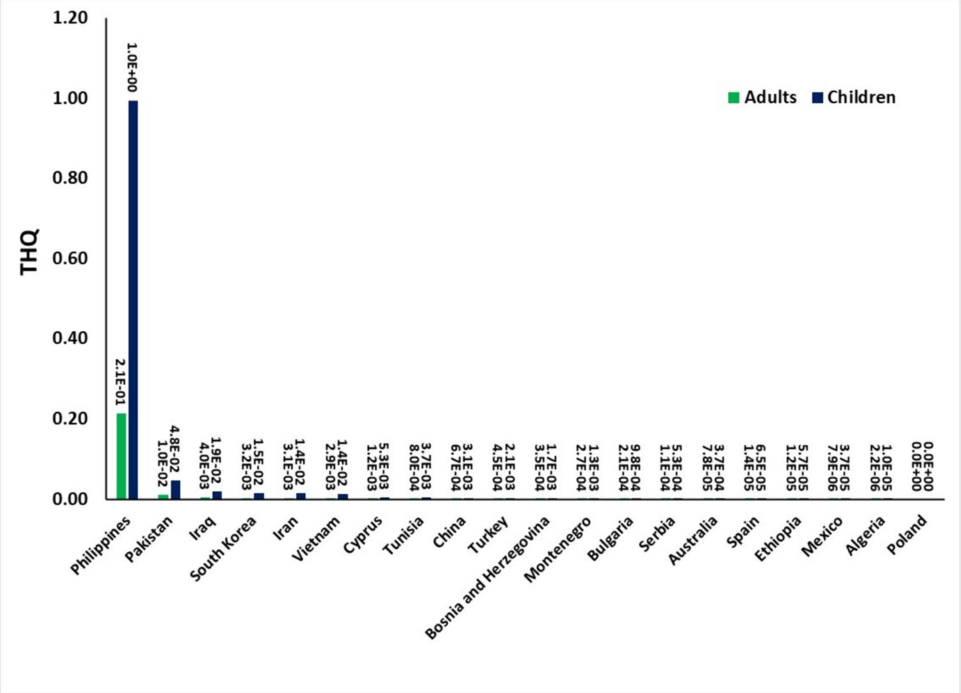


Fig. 3 THQ due to ingestion carp fish content of iAs in adults and children

Fig. 4 THQ due to ingestion carp fish content of Cd in adults and children



studies in China, THQ of heavy metals was lower than 1 in examined common carp fish [98, 99]. Totally, based on the results of the current meta-analysis, THQ was less than 1 for all examined heavy metals (iAs, Cd, Pb, MeHg, Cu, and Ni), revealing no serious non-carcinogenic risk for each heavy metal, and it does not have a side effect on consumers. However, continuing exposure to more than one pollutant can synergistically affect consumers.

Fig. 5 THQ due to ingestion carp fish content of Pb in adults and children

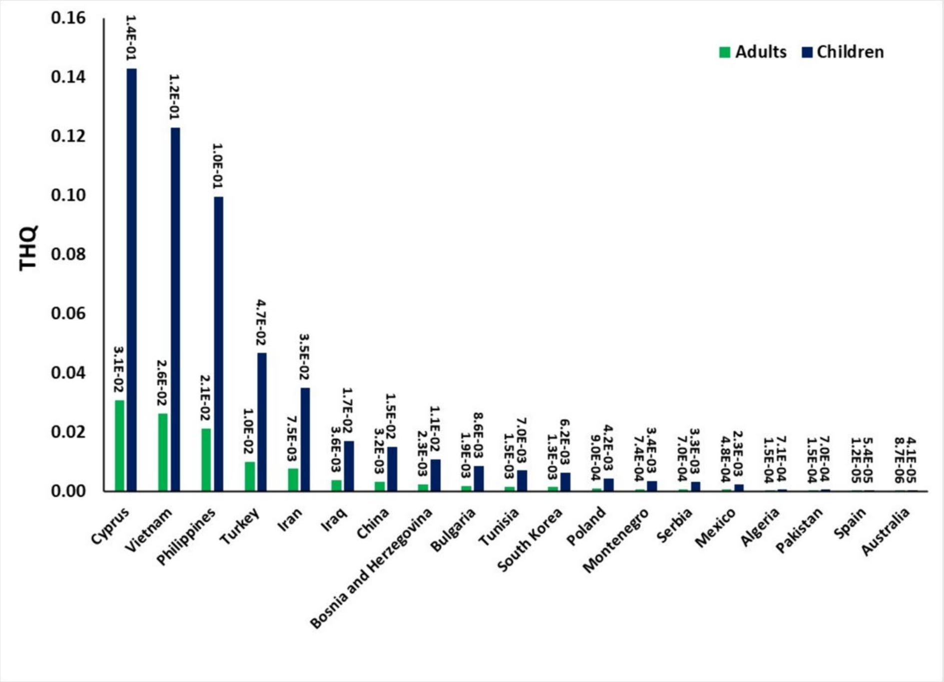
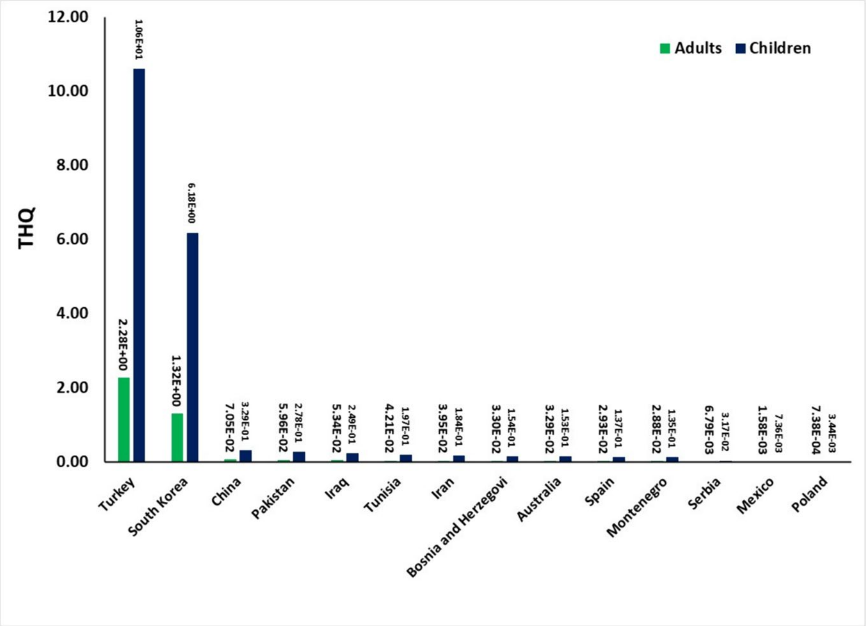


Fig. 6 THQ due to ingestion carp fish content of MeHg b in adults and children



Carcinogenic Risk

Iraq, Cyprus, and South Korea were the countries with the highest CR of iAs. Except for adult consumers in Iraq, the cancer risk in the other countries was ignorable and/or acceptable due to iAs (Fig. 9). It has been reported that both forms of As (organic and inorganic: Total As) are present in fish [100]. The latter form (iAs) is the most toxic to humans. Based on the current examination, CR for adults and children due to consumption of common carp was not considerable.

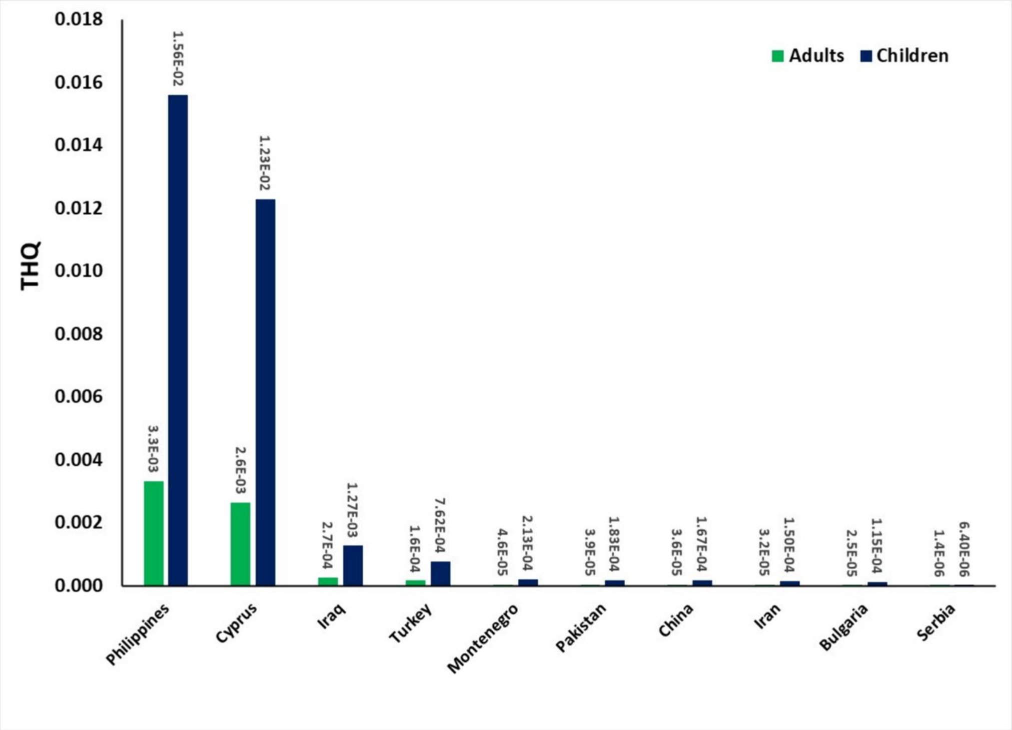


Fig. 7 THQ due to ingestion carp fish content of Ni in adults and children

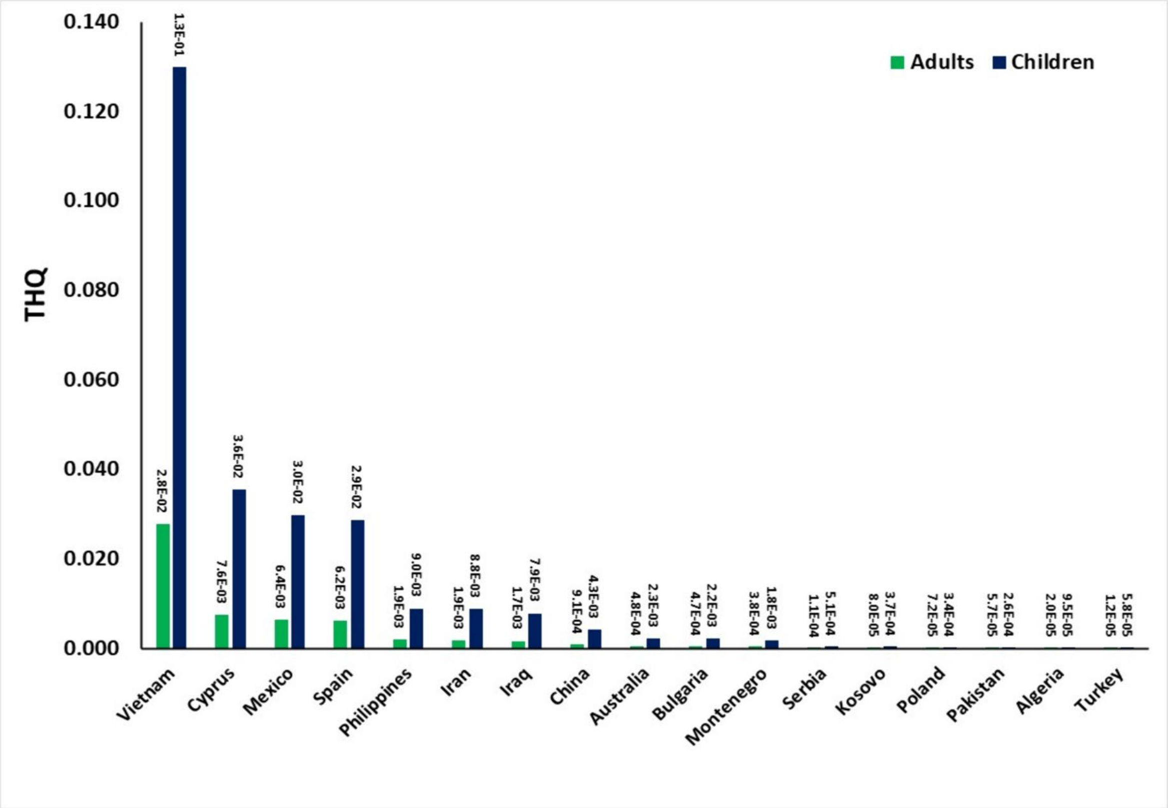


Fig. 8 THQ due to ingestion carp fish content of Cu in adults and children

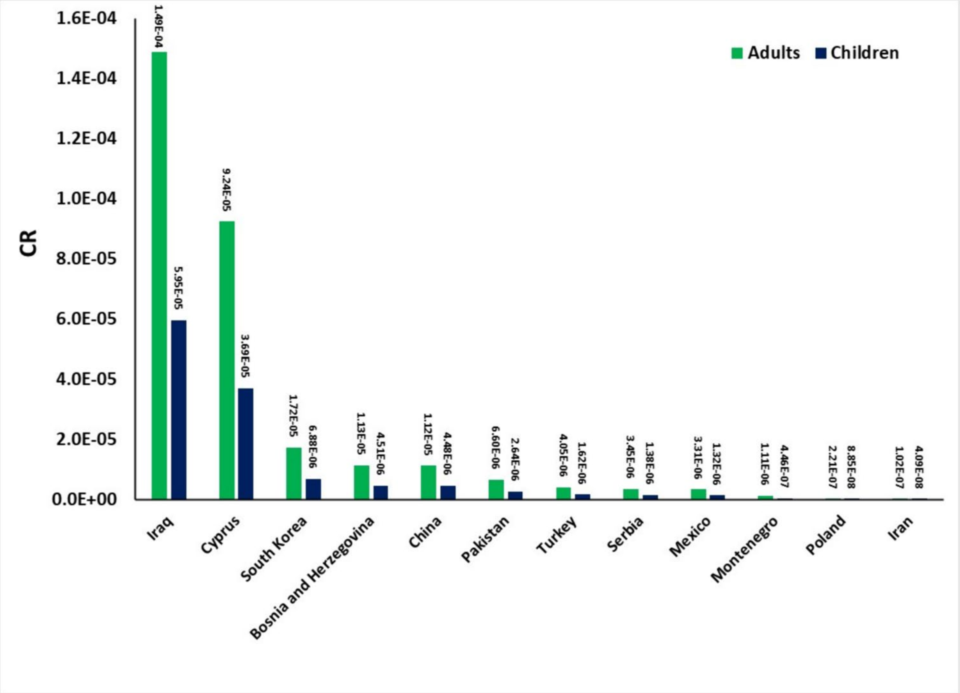


Fig. 9 CR due to ingestion carp fish content of iAs in adults and children

Conclusion

The highest concentrations of Cu, methyl-Hg, and Ni were observed in the fillet of common carp fish. Therefore, effective monitoring of sources emitting these elements should receive more attention. Additionally, the concentration of PTEs in the fillet of common carp fish was higher in Iraq, India, Pakistan, the Philippines, and Turkey than in other countries. However, the non-carcinogenic risk was less than 1 value for both adult and child consumers in all countries; hence, the consumption of common carp fish cannot have a non-carcinogenic risk for consumers. Adult consumers in Iraq were exposed to an unacceptable carcinogenic due to iAs in common carp fish. Therefore, it is recommended that plans be implemented to reduce the concentration of PTEs in common carp fish in Iraq. Therefore, the control of iAs in water and food resources of common carp should be given more attention.

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Data Availability No datasets were generated or analysed during the current study.

Declarations

Consent to Participate The authors declare their consent to participate in this study.

Consent for Publication The authors declare their consent to publish this study.

Competing Interests The authors declare no competing interests.

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