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Metal bioaccumulation in fish species from the Danube River in Serbia and evaluation of possible health risks

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ABSTRACT

The aim of the present study was to assess the content of metals in fish meat and to evaluate possible health risks from dietary consumption of fish caught from the Danube River in Serbia in the past fifteen years. Therefore, the metal pollution index (MPI) and the following health risk indexes were calculated: estimated daily intake (EDI), estimated weekly intake (EWI), % of provisional tolerable weekly intake (% PTWI), target hazard quotient (THQ), hazard index (HI), and target cancer risk (TR). Levels of Cd in common carp and Wels catfish from 2011 to 2013 and in silver carp in 2021 exceeded maximum allowed concentrations in fish meat. Wels catfish contained higher contents of Hg from 2011 to 2013 and Pb in 2010 than prescribed by the national regulation. Moreover, MPIs determined for common carp, Wels catfish, and barbel gradually decreased during the observed period, except for silver carp where a slight increasing trend was observed. The HI was higher than 1 in almost all studies, and exceeded maximum allowed levels prescribed by international and national regulations. In all presented studies, TR was lower than the acceptable lifetime risk (ARL) of 10^{-4}, except for As in common carp caught in Zemun and Grocka during 2013 when an unacceptable carcinogenic risk (> 10^{-4}) was detected (1.10 x10^{-4} and 1.43 x10^{-4}, respectively). It is necessary to implement regular monitoring of metal levels in fish from the Danube River in order to preserve human and environmental health.

1. Introduction

The increasing trend of metal pollution of the environment has gathered more attention in recent decades, since metals are toxic to both humans and environment (*Cordeli et al.*, 2023). Elements are divided into essential for living organisms and non-essential, but depending on concentration, both groups are toxic to organisms (*Milošković and Simić*, 2023). Metals are stable, non-biodegradable, and their levels have increased in recent decades due to industrial and agricultural activities (*Azar and Vajargah*, 2023). Once metals enter an aquatic environment, they do not degrade, but accumulate on solid surfaces or in aquatic organisms. After accumulation in a living organism, metals disrupt many physiological processes, leading to oxidative stress, alteration in cellular function, and impaired immune function (*Cordeli et al*., 2023).

Waters in Serbia are loaded with different pollutants, and only 16% of wastewater is processed (*Milošković and Simić,* 2023). One of the waterways, the River Danube, is an international river and the second largest in Europe, flowing for about 588 km through Serbia. The largest part of the territory of the

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Republic of Serbia belongs to the Danube basin (about 92%) (*Official Gazette of the Republic of Serbia*, 2017).

Metal concentrations in the Danube River have increased in past decades (*Cordeli et al.,* 2023). Since the Danube River is important for commercial and recreational fishing (*Smederevac-Lalić et al.,* 2011), fish contaminated with metals could be harmful to human health. To preserve human and environmental health, it is necessary to regularly assess the metal contamination of water, sediment, and various fish species recommended as bioindicators for pollution of potential toxic elements (*Milošković and Simić*, 2023). Therefore, the aim of the present study was to assess the content of metals in fish meat and to evaluate possible health risks from dietary consumption of fish caught from the Danube River in Serbia in the past fifteen years.

2. Materials and Methods

2.1 Material

For calculation of health risks after fish consumption, metal levels in fish muscles were used from studies published in the past 15 years. The inclusion criteria were studies performed on fish species that are recommended as bioindicator species (common carp, Wels catfish, silver carp, and barbel) by *Milošković and Simić* (2023), research that investigated fish from the Danube River in Serbia in the past 15 years, and studies that determined levels of As, Cd, Cr, Cu, Fe, Hg, Pb, and Zn in fish muscles.

2.2. Methods

2.2.1. Metal pollution index (MPI)

The metal pollution index was used to assess the total level of metal accumulation in fish species according to *Usero et al.* (1997). MPI was calculated as the geometric mean of metal levels (As, Cd, Cr, Cu, Fe, Hg, Pb, and Zn) in fish muscle:

$$\text{MPI (mg/kg)} = (C_1 \times C_2 \times C_3 \ldots x\ C_n)^{1/n}$$

where C is the mean level of metal in fish muscle (as mg/kg of w.w.).

In some studies, metal levels were originally presented in dry weight, so these were then recalculated from dry to wet weight according to the following formula:

$$\text{Cww} = \text{Cdw} \times [(100-\%\text{H})]/100$$

where Cww is the metal content expressed as wet weight, Cdw is the metal content expressed as dry weight, and %H is the percentage of water in fish muscle (approximately 80%) (*USEPA*, 2010; *Subotić et al.,* 2021).

2.2.2. Health risk assessment

Health risk assessment was performed on studies that contain metal levels higher than prescribed by international and/or national regulations.

Estimation of daily intake rate (EDI)

The calculation of estimated daily intake (µg/kg of body weight (BW) per day) of As, Cd, Cr, Cu, Fe, Hg, Pb, and Zn for Serbian people was performed according to the *Griboff et al.* (2017):

$$(C\ element \times D\ food\ intake)\ /BW$$

where C, element, is the content of an element in fish muscle (as µg/kg of w.w.), D, food intake, is the average daily intake of fish by people in Serbia (20 g, *Janjić et al.,* 2015), and BW is the average body weight for adults (70 kg, *EFSA,* 2012).

Estimation of weekly intake rate (EWI) and percentage of provisional tolerable weekly intake (% PTWI)

Estimation of weekly intake rate was calculated according to the following equation:

$$\text{EWI} = EDI \times 7\ days$$

EWIs were compared with their respective provisional tolerable weekly intake (PTWI) rates. PTWI represents the provisionally allowed metal weekly intake that is determined for Cd (5.75 µg/kg BW per week), Cu (3500 µg/kg BW per week), Fe (5600 µg/kg BW per week), Hg (4 µg/kg BW per week), and Zn (7000 µg/kg BW per week) (*JECFA*, 2011). With respect to Pb and As, we used the withdrawn PTWI rates for Pb (25 µg/kg BW per week) and As (15 µg/kg BW per week), since new PTWI rates have not been established (*JECFA*, 2011). When EWI is lower than PTWI, consumption of the food does not pose a risk for human health. Percentage of provisional tolerable weekly intake (% PTWI) was calculated according to the following formula:

$$\%\ \text{PTWI} = \frac{EWI}{PTWI} \times 100$$

Target hazard quotient (THQ)

Target hazard quotient is a type of non-carcinogenic health risk assessment method and it was calculated according to *Ahmed et al.* (2015):

$$\text{THQ} = \frac{Efr \times ED \times FIR \times C}{RfD \times BW \times AT} \times 100^{-3}$$

where Efr is the exposure frequency (365 days a year), ED is the exposure duration (70 years, the average human life time), FIR is the fish ingestion rate (20 g per day in Serbia), C is the average content of a metal in fish muscle (mg/kg of w.w.), RfD_o is the reference oral dose, i.e., an estimate of the daily exposure to which humans could be continually exposed during their lifetime without harmful effects to health. RfD_o for As, Cd, Cr, Cu, Fe, Hg, and Zn is 0.0001, 0.0003, 0.0001, 0.005, 0.003, 0.04, and 0.30 mg/kg of BW per day, respectively (*USEPA*, 2015), BW is the average body weight (for adult 70 kg), AT is the average time of non-carcinogenic exposure (365 days per year × number of exposure years, assuming 70 years). The reference oral dose for Pb was withdrawn by the *USEPA* (2015). Therefore, THQ for Pb was calculated according to *Jovic and Stankovic* (2014):

$$\text{THQ} = \frac{C}{MRL}$$

where C is the detected Pb level in fish muscle (as mg/kg of w.w.), MRL is the maximum residue limit, set by Regulation (EC) No 2023/915, and in fish meat is 0.3 mg/kg of w.w. A THQ value of less than 1 implies that no evident risk will arise from fish consumption, while THQ higher than 1 poses a potential non-carcinogen risk to the exposed population.

Hazard index (HI)

Hazard index (HI) was calculated as the sum of THQ for all metals detected in fish muscle (*Li et al.,* 2013):

$$HI = \sum_{i=1}^{n} \text{THQ}i$$

where HI value lower than 1 indicates safe fish consumption, while HI ≥1 represents a hazard for consumers.

Target cancer risk (TR)

Target cancer risk evaluates the risk of possible development of cancer over a lifetime due to exposure to Cr, Pb, and As. Acceptable risk levels range from 10^{-4} (risk of developing cancer over a human lifetime is 1 in 10,000) to 10^{-6} (risk of developing cancer over a human lifetime is 1 in 1,000,000) and are calculated according to following equation (*USEPA*, 2000):

$$\text{TR} = \frac{Efr \times ED \times FIR \times C \times CSFo}{BW \times AT} \times 100^{-3}$$

where Efr is the exposure frequency (365 days per year), ED is the exposure duration (70 years, the average human life time), FIR is the fish ingestion rate (20 g, *Janjić et al.,* 2015), C is the average heavy metal level detected in fish muscle (mg/kg of w.w.), CSFo is the carcinogenic slope factor (Cr: 0.5 mg/kg/day; Pb: 8.5 $\times 10^{-3}$ mg/kg/day; As: 1.5 mg/kg/day, determined by the *USEPA* (2015)), BW is the average body weight (70 kg for adults), AT is the mean exposure period for the carcinogen (365 days per year × number of exposure years, assuming 70 years).

3. Results and discussion

3.1. Level of metals in fish meat from the Danube River in Serbia for the period 2010–2021

In Table 1, levels of metals detected in meat from fish caught in the Danube River from 2010 to 2021 are presented.

In common carp, levels of toxic elements ranged for As from 0.01 to 0.333 mg/kg w.w., for Cd from 0.001 to 0.082 mg/kg w.w., for Hg from 0.022 to 0.466 mg/kg w.w., and for Pb from 0.007 to 0.084 mg/kg w.w. In Wels catfish, heavy metal levels ranged for As from 0.0016 to 0.211 mg/kg w.w., for Cd from 0.0008 to 0.09 mg/kg w.w., for Hg from 0.0028 to 0.62 mg/kg w.w., and for Pb from 0.0012 to 1.58 mg/kg w.w. In silver carp, levels of As were from 0.0072 to 0.1968 mg/kg w.w., of Cd were 0.0028 to 0.0808 mg/kg w.w., of Hg were 0.012 to 0.16 mg/kg w.w., and of Pb were 0.003 to 0.14 mg/kg w.w. In barbel, levels of As in fish meat ranged from 0.189 to 0.314 mg/kg w.w., of Cd from 0.052 to 0.062 mg/kg w.w., of Hg from 0.054 to 0.325 mg/kg w.w., and of Pb from 0.022 to 0.062 mg/kg w.w.

The highest level of As was detected in common carp (0.333 mg/kg w.w.) in 2013 by *Jovanović et al.* (2017) and in barbel (0.314 mg/kg w.w.) in 2012 by *Morina et al.* (2016), but these levels did not exceed the maximum allowable level prescribed by international and national regulations (*FAO*, 1983; *FAO/WHO*, 1998; *WHO/FAO*, 2015; *Official Gazette of the Republic of Serbia*, 2019). Regarding Cd, higher levels than permissible were found in 2013 by *Jovanović et al.* (2017) in common carp (0.059 mg/kg w.w., 0.082 mg/kg w.w.) and in Wels catfish (0.068–0.069 mg/kg w.w.). Higher values of Cd than permissible were found in Wels catfish (0.09 mg/kg w.w.) during 2011–2013 (*Milošković et al.,* 2016) and in silver carp (0.0808 mg/kg w.w.) in 2021 (*Aleksić et al.,* 2025). The highest level of Hg was detected in common

Table 1. Metal bioaccumulation in fish meat from the Danube River in Serbia for period 2010–2021 and maximum allowed concentrations in fish meat (mg/kg w.w.) established by European Commission Regulation (*EU*, 2006), Codex Alimentarius Commission (*WHO/FAO*, 2015), *FAO* (1983), *FAO/WHO* (1998), and Serbian national regulation (*Official Gazette of the Republic of Serbia (OG RS)*, 81/2019) (*Cordeli et al.,* 2023; *Milošković and Simić,* 2023; *Aleksić et al.,* 2025)

As	**Cd**	**Cr**	**Cu**	**Fe**	**Hg**	**Pb**	**Zn**	**Reference**
-	0.05	-	-	-	0.5	0.3	-	European Commission Regulation (*EU*, 2006)
-	-	-	-	-	-	0.3	-	Codex Alimentarius Commission (*WHO/FAO*, 2015)
1.0	0.05	0.15–1.0	30	100	0.5	0.5	30	FAO (*FAO*, 1983)
-	0.5	-	30	-	0.5	0.5	40	FAO/WHO (*FAO/WHO*, 1998)
-	0.05	-	-	-	0.5	0.3	-	Serbian national regulation (*OG RS*, 81/2019)

As	**Cd**	**Cr**	**Cu**	**Fe**	**Hg**	**Pb**	**Zn**	**Region**	**Year of sampling**	**Reference**
Common carp (*Cyprinus carpio*)										
0.1262	0.0137	0.022	0.351	8.72	0.0223	0.0142	31.00	Novi Sad	2021	*Aleksić et al.* (2025)
0.1268	0.0132	0.023	0.213	4.92	0.0223	0.0165	26.90	Zemun	2021	*Aleksić et al.* (2025)
0.1007	0.0175	0.026	0.298	4.85	0.0240	0.0165	29.61	Grocka	2021	*Aleksić et al.* (2025)
0.01	0.01	-	-	-	0.240	0.048	-	Vinča	2013	*Ivanović et al.* (2016)
0.258	**0.059**	-	0.688	9.38	0.393	0.059	6.16	Zemun	2013	*Jovanović et al.* (2017)
0.333	**0.082**	-	0.757	9.68	0.466	0.084	6.17	Grocka	2013	*Jovanović et al.* (2017)
0.0026	0.0028	-	-	-	0.0414	0.007	-	Belgrade	2012	*Milanov et al.* (2016)*
0.132	0.001	0.002	0.26	3.924	0.178	-	11.80	Belgrade	2010	*Subotić et al.* (2013b)*
0.132	-	-	-	-	0.0468	-	10.85	Belgrade	2010	*Subotić et al.* (2013a)*
0.079	-	-	-	1.484	-	-	10.94	Belgrade	2010	*Lenhardt et al.* (2012)*
Wels catfish (*Silurus glanis*)										
0.0568	0.0080	0.0158	0.101	4.37	0.1160	0.0157	7.65	Novi Sad	2021	*Aleksić et al.* (2025)
0.0365	0.0102	0.0193	0.133	5.00	0.1390	0.0107	7.69	Zemun	2021	*Aleksić et al.* (2025)
0.0393	0.0115	0.0183	0.123	3.12	0.1750	0.0093	6.34	Grocka	2021	*Aleksić et al.* (2025)
0.161	**0.068**	-	1.55	8.32	0.208	0.058	7.06	Zemun	2013	*Jovanović et al.* (2017)
0.211	**0.069**	-	1.62	8.17	0.260	0.069	6.68	Grocka	2013	*Jovanović et al.* (2017)
0.10	**0.09**	0.145	0.07	0.95	0.33	0.17	7.62	Novi Sad	2011–2013	*Milošković et al.* (2016)
0.09	0.001	0.13	0.07	1.33	0.20	0.18	2.97	Zemun	2011–2013	*Milošković et al.* (2016)
0.11	0.004	0.14	0.07	0.55	**0.62**	0.16	3.00	Radujevac	2011–2013	*Milošković et al.* (2016)
0.0262	0.0008	0.0276	0.1898	3.892	0.3196	0.0012	3.92	Belgrade	2013	*Jovičić et al.* (2016)*
0.003	0.01	-	-	-	**0.53**	0.06	-	Vinča	2013	*Ivanović et al. (2016)*
0.0016	-	-	-	0.0654	0.0028	-	0.0016	Belgrade	2012	*Milanov et al.* (2016)*
-	-	-	-	-	-	**1.582**	-	Belgrade	2010	*Lenhardt et al.* (2012)*
Silver carp (*Hypophthalmichthys molitrix*)										
0.1968	0.0143	0.0358	0.391	21.08	0.0238	0.0315	10.11	Novi Sad	2021	*Aleksić et al.* (2025)
0.0852	0.0145	0.0305	0.639	8.44	0.0230	0.027	8.54	Zemun	2021	*Aleksić et al.* (2025)
0.1558	**0.0808**	0.0252	0.272	10.62	0.0120	0.0237	10.59	Grocka	2021	*Aleksić et al.* (2025)
0.0072	0.0028	-	-	-	0.028	0.0112	-	Belgrade	2012	*Milanov et al.* (2016)*
0.04	0.01	-	-	-	0.16	0.14	-	Vinča	2013	*Ivanović et al.* (2016)
-	-	-	-	2.51	-	0.003	6.38	Belgrade	2010	*Lenhardt et al.* (2012)*
Barbel (*Barbus barbus*)										
0.189	0.052	-	0.826	12.22	0.222	0.048	5.20	Zemun	2013	*Jovanović et al.* (2017)
0.239	0.062	-	0.839	11.91	0.325	0.062	6.02	Grocka	2013	*Jovanović et al.* (2017)
0.314	-	0.082	0.380	-	0.054	0.022	3.67	Belgrade	2012	*Morina et al.* (2016)*
0.280	-	-	-	-	-	-	2.58	Belgrade	2010	*Sunjog et al.* (2012)*

Legend: *In studies by *Lenhardt et al.* (2012), *Sunjog et al.* (2012), *Subotić et al.* (2013a), *Subotić et al.* (2013b), *Jovičić et al.* (2016), *Morina et al.* (2016), *and Milanov et al.* (2016), metal levels were originally presented in μg/g d.w., so in the current study, these levels were recalculated from dry to wet weight according to the following formula: $Cww = Cdw \times \frac{(100-\%H)}{100}$, where Cww is the metal content expressed as wet weight, Cdw is the metal content expressed as dry weight, %H is the percentage of water in fish muscle (approximately 80%) (*USEPA*, 2010; *Subotić et al.,* 2021) carp (0.393–0.466 mg/kg w.w.) in 2013 (*Jovanović et al.,* 2017), while higher levels of Hg than permissible were detected in Wels catfish during 2011–2013 (0.62 mg/kg w.w.) by *Milošković et al.* (2016) and in 2013 (0.53 mg/kg w.w.) by *Ivanović et al.* (2016). Regarding Pb, a higher level than permissible was detected in Wels catfish (1.582 mg/kg w.w.) in 2010 by *Lenhardt et al.* (2012).

3.2. The metal pollution index (MPI)

The metal pollution index (MPI) of four fish species (common carp, Wels catfish, silver carp, and barbel) caught from the Danube River in Serbia from 2010 to 2021 is presented in Figure 1.

MPI ranged from 0.007 to 1.086 in common carp, from 0.005 to 1.582 in Wels catfish, from 0.009 to 0.364 in silver carp, and from 0.190 to 0.850 in barbel. The highest values of MPI were observed in 2010, then decreased during 2012, and thereafter increased in 2013. Moreover, MPI determined for common carp, Wels catfish, and barbel gradually decreased during the observed period, except for silver carp where a slight increasing trend was noticed. Since the content of metals in the meat of the four fish species was not measured from 2013 to 2021, this lack of information cannot provide a reliable conclusion about the trends of metal levels in meat from fish caught in the Danube River. *Subotić et al.* (2013a) found that MPI in 2010 ranged from 0.840 (Wels catfish) to 1.140 (common carp), emphasizing that MPI was higher in omnivorous than in carnivorous fish species. Similarly, *Aleksić et al.* (2025) reported the highest MPI was in silver carp (herbivorous), followed by the MPI in common carp (omnivorous), while the lowest MPI was in Wels catfish (carnivorous), due to its different feeding behaviour. *Milošković et al.* (2016) pointed out that MPI is reliable indicator of metal contamination of fish.

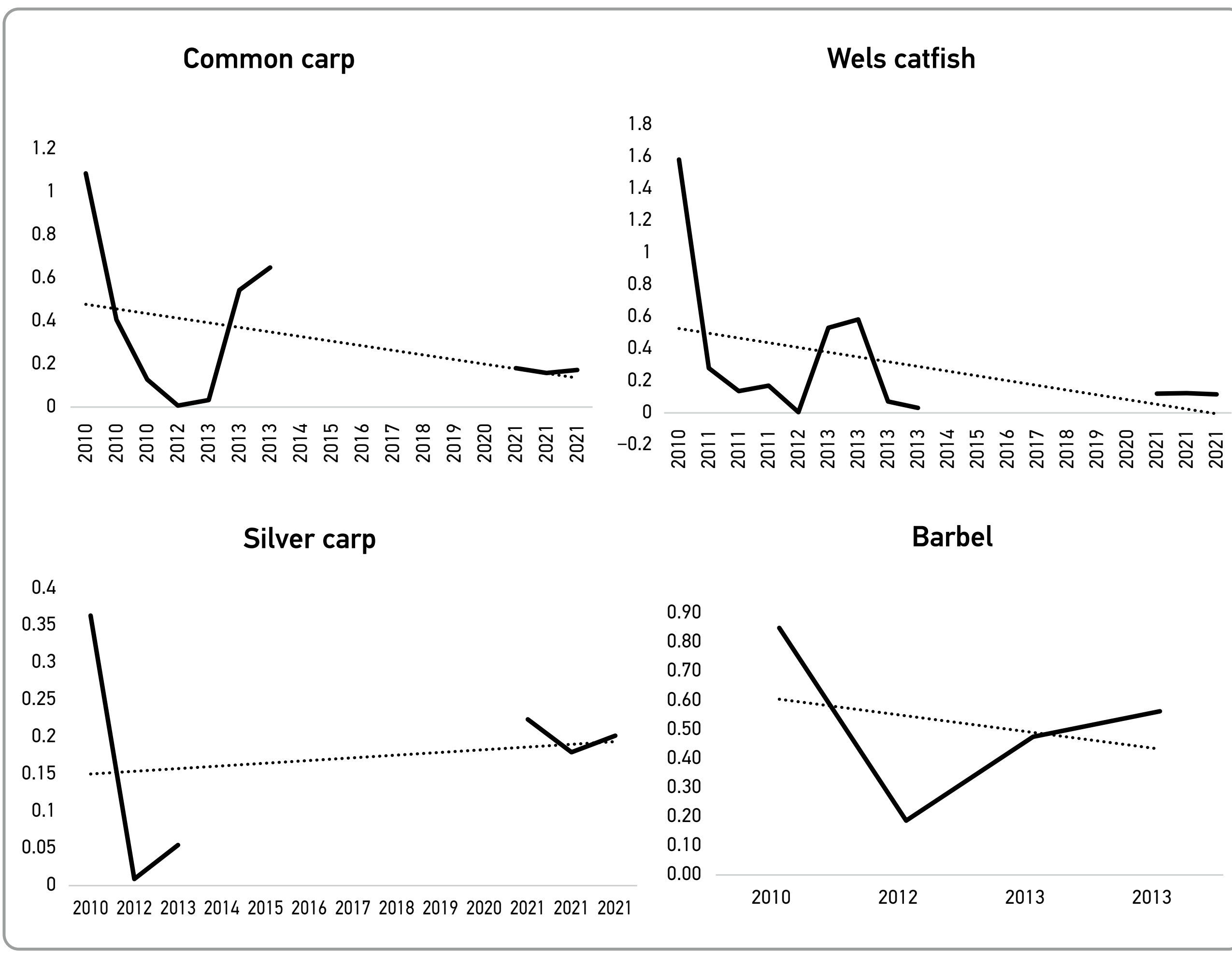

Figure 1. The metal pollution index (MPI) of four fish species (common carp, Wels catfish, silver carp, and barbel) from the Danube River in Serbia for period 2010-2021 (geometric mean of As, Cd, Cr, Cu, Fe, Hg, Pb, and Zn levels)

3.3. Estimation of daily intake rate (EDI), weekly intake rate (EWI), and percentage of provisional tolerable weekly intake (% PTWI)

Table 2 presents the EDI, EWI, and % PTWI for meat of fish collected from the Danube River in Serbia, 2010–2021.

The data are from studies that reported the maximum allowed levels for metals in fish meat had been exceeded. The EDI and EWI rates were presented as µg/kg of BW per day and week, respectively. The highest EDI rate for As was found in common carp (0.0912 µg/kg BW per day) by *Jovanović et al.* (2017), for Cd (0.0247 µg/kg BW per day) and Hg (0.1699 µg/kg BW per day) in Wels catfish by *Milošković et al.* (2016), and for Pb in Wels catfish (0.4334 µg/kg BW per day) by *Lenhardt et al.* (2012). EWI rates were seven times greater than EDI rates, and followed the same pattern as EDI

Table 2. EDI (µg/kg BW per day), EWI (µg/kg BW per week), % PTWI, THQ, and TR for fish meat from the Danube River in Serbia for the period 2010-2021 (presented data are from studies in which the maximum allowed metal levels in fish meat were exceeded)

	As	Cd	Cr	Cu	Fe	Hg	Pb	Zn	Region	Year of sampling	Reference
					Common carp (*Cyprinus carpio*)						
EDI	0.0707	0.0162	-	0.1885	2.57	0.1077	0.0162	1.69	Zemun	2013	*Jovanović et al.* (2017)
EWI	0.4948	0.1132	-	1.32	17.99	0.7537	0.1132	11.81			
% PTWI	3.30	1.97	-	0.0377	0.3212	18.84	0.4526	0.1688			
THQ	0.2457	0.1686	-	0.0049	0.0038	1.12	0.1967	0.0059			
TR	1.11E-04	-	-	-	-	-	1.43E-07	-			
EDI	0.0912	0.0225	-	0.2074	2.65	0.1277	0.0230	1.69	Grocka	2013	*Jovanović et al.* (2017)
EWI	0.6386	0.1573	-	1.45	18.56	0.8937	0.1611	11.83			
% PTWI	4.26	2.74	-	0.0415	0.3315	22.34	0.6444	0.1690			
THQ	0.3171	0.2343	-	0.0054	0.0040	1.3314	0.2800	0.0059			
TR	1.43E-04	-	-	-	-	-	2.04E-07	-			
					Wels catfish (*Silurus glanis*)						
EDI	-	-	-	-	-	-	0.4334	-	Belgrade	2010	*Lenhardt et al.* (2012)
EWI	-	-	-	-	-	-	3.03	-			
% PTWI	-	-	-	-	-	-	12.14	-			
THQ	-	-	-	-	-	-	5.27	-			
TR	-	-	-	-	-	-	3.84E-06	-			
EDI	0.0441	0.0186	-	0.4247	2.28	0.0570	0.0159	1.93	Zemun	2013	*Jovanović et al.* (2017)
EWI	0.3088	0.1304	-	2.97	15.96	0.3989	0.1112	13.54			
% PTWI	2.06	2.27	-	0.08	0.28	9.97	0.44	0.19			
THQ	0.1533	0.1943	-	0.0111	0.0034	0.5943	0.1933	0.0067			
TR	6.90E-05		-	-	-	-	1.41E-07	-			
EDI	0.0578	0.0189	-	0.4438	2.2384	0.0712	0.0189	1.83	Grocka	2013	*Jovanović et al.* (2017)
EWI	0.4047	0.1323	-	3.11	15.67	0.4986	0.1323	12.81			
% PTWI	2.70	2.30	-	0.0888	0.2798	12.47	0.5293	0.1830			
THQ	0.2010	0.1971	-	0.0116	0.0033	0.7429	0.2300	0.0064			

	As	Cd	Cr	Cu	Fe	Hg	Pb	Zn	Region	Year of sampling	Reference
Wels catfish (*Silurus glanis*)											
TR	9.04E-05	-	-	-	-	-	1.68E-07	-			
EDI	0.0274	0.0247	0.0397	0.0192	0.2603	0.0904	0.0466	2.09	Novi Sad	2011-2013	*Milošković et al.* (2016)
EWI	0.1918	0.1726	0.2781	0.1342	1.82	0.6329	0.3260	14.61			
% PTWI	1.28	3.00	1.8539	0.0038	0.0325	15.82	1.30	0.2088			
THQ	0.0952	0.2571	0.0138	0.0005	0.0004	0.9429	0.5667	0.0073			
TR	4.29E-05	-	2.07E-05	-	-	-	4.13E-07	-			
EDI	0.0301	0.0011	0.0384	0.0192	0.1507	0.1699	0.0438	0.8219	Radujevac	2011–2013	*Milošković et al.* (2016)
EWI	0.2110	0.0077	0.2685	0.1342	1.05	1.19	0.3068	5.75			
% PTWI	1.41	0.1334	1.79	0.0038	0.0188	29.73	1.23	0.0822			
THQ	0.1048	0.0114	0.0133	0.0005	0.0002	1.77	0.5333	0.0029			
TR	4.71E-05		2.00E-05	-	-	-	3.89E-07	-			
EDI	0.0008	0.0027	-	-	-	0.1452	0.0164	-	Vinča	2013	*Ivanović et al.* (2016)
EWI	0.0058	0.0192	-	-	-	1.02	0.1151	-			
% PTWI	0.0384	0.3335	-	-	-	25.41	0.4603	-			
THQ	0.0029	0.0286	-	-	-	1.51	0.2000	-			
TR	1.29E-06	-	-	-	-	-	1.46E-07	-			
Silver carp (*Hypophthalmichthys molitrix*)											
EDI	0.0427	0.0221	0.007	0.0745	2.91	0.0033	0.0065	2.90	Grocka	2021	*Aleksić et al.* (2025)
EWI	0.2988	0.1550	0.048	0.5216	20.37	0.0230	0.0455	20.31			
% PTWI	1.99	2.69	0.32	0.01	0.36	0.58	0.18	0.29			
THQ	0.1484	0.2309	0.0024	0.0019	0.0043	0.0343	0.0790	0.0101			
TR	6.68E-05	-	3.60E-06	-	-	-	5.76E-08	-			

rates. Moreover, EWI rates were lower than PTWI rates set by *JECFA* (2011) and for As and Cd, did not exceed 5%, indicating a low health risk for population. However, % PTWI for Pb was higher than 10% in Wels catfish (12.14%) (*Lenhardt et al.*, 2012), while for Hg, % PTWIs were even higher than 20%, representing a moderate health risk (*Alvarado et al.,* 2021). Determined % PTWIs for Hg were 22.34% in common carp found by *Jovanović et al.* (2017), and 25.41% and 29.73% in Wels catfish found by *Ivanović et al.* (2016) and *Milošković et al.* (2016), respectively. Since in all observed studies from 2010 to 2021, the content of Hg in fish meat from the Danube River exceeded 20 µg/kg of w.w., according to the International Commission for the Protection of the Danube River, the Danube River is not of good ecological status (*ICPDR*, 2021**).** Therefore, it is necessary to regularly monitor Hg levels and limit fish consumption when needed, especially for children and pregnant women (*Alvarado et al.,* 2021).

3.4. Target hazard quotient (THQ), hazard index (HI), target cancer risk (TR)

Table 2 presents THQ and TR, while Figure 2 shows HI for meat from fish collected from the Danube River in Serbia during 2010–2021.

THQ and HI represent the risk of non-carcinogenic effects of ingested metals from fish meat, and THQ decreased in the following order, Pb > Hg > As > Cd > Cr > Cu > Zn > Fe. THQs for all analysed metals were lower than 1, except for Pb in Wels catfish (5.27) determined by *Lenhardt et al.* (2012), Hg in common carp (1.12 and 1.33) found by

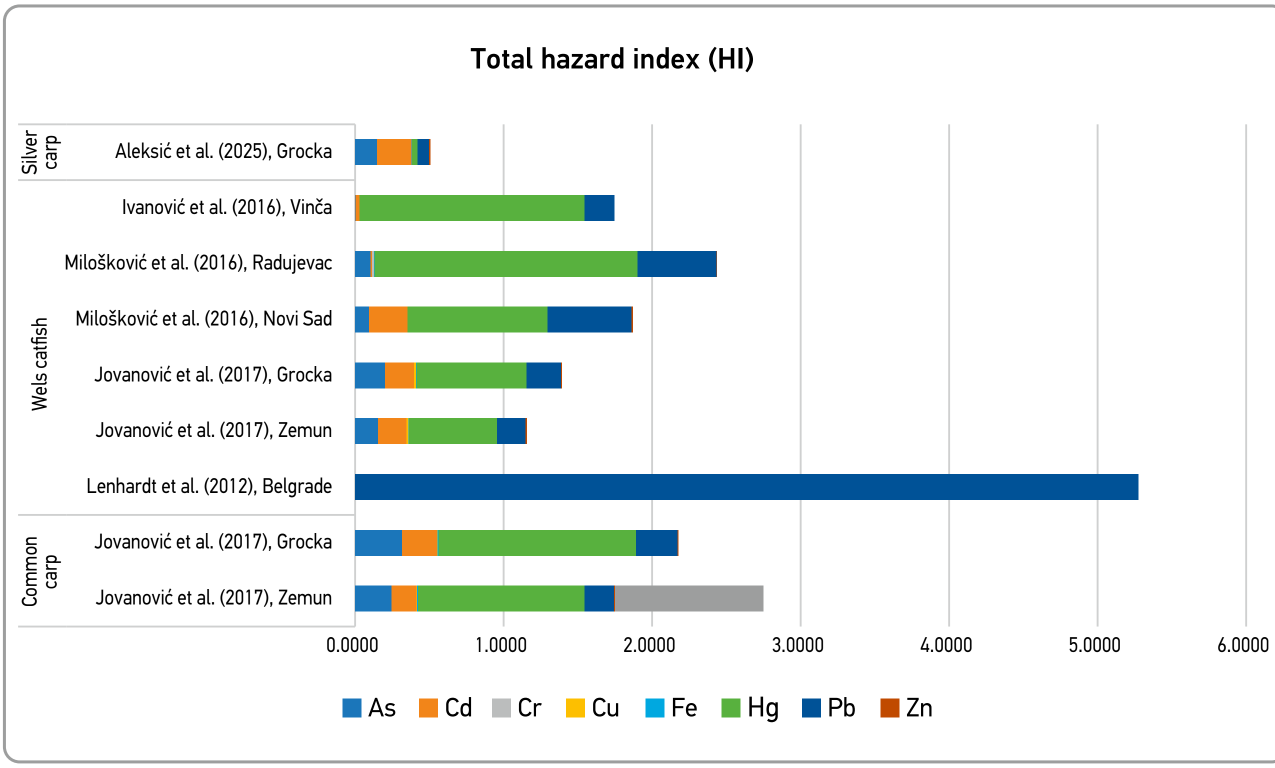

Figure 2. Estimated total hazard index (HI) from consumption of fish from the Danube River in Serbia for the period 2010–2021 (presented data are from studies in which the maximum allowed metal levels in fish meat were exceeded)

Jovanović et al. (2017), and Hg in Wels catfish found by *Milošković et al.* (2016) (1.77) and *Ivanović et al.* (2016) (1.51). In those studies where THQ values were higher than 1, consuming a fish from the Danube River posed a significant risk for human health. Similarly, HI was higher than 1 in all studies, and so exceeded the maximum allowable level prescribed by international and national regulations, except for one study (*Aleksić et al.*, 2025) where HI was 0.5089. In all other studies, HI ranged from 1.1564 to 5.2733, being the highest in Wels catfish found by *Lenhardt et al.* (2012). In those previously mentioned studies with HI > 1, consuming a fish represented a hazard for consumers.

Regarding the risk from developing cancer after consuming a fish from the Danube River, TR of the analysed studies ranged for As from 1.29E-06 to 1.43E-04, for Cr from 3.60E-06 to 2.07E-05, and for Pb from 5.76E-08 to 3.84E-06. Regarding As and Cr, TR was lower than the acceptable lifetime risk (ARL) of 10^{-4}, except for As in common carp caught in Zemun and Grocka during 2013, when an unacceptable carcinogenic risk ($\geq 10^{-4}$) was detected (1.10 x10^{-4} and 1.43 x10^{-4}, respectively) by *Jovanović et al.* (2017). The carcinogenic risk for Pb was lower than 10^{-6} and recognized as negligible in most studies, except for in Wels catfish (3.84E-06) caught in 2010, when TR was regarded as acceptable (*Lenhardt et al.,* 2012).

4. Conclusion

Higher levels of toxic elements than permissible were found for Cd in common carp and Wels catfish during 2011–2013 and in silver carp in 2021. Higher levels of Hg than permissible were detected in Wels catfish from 2011 to 2013. The content of Pb exceeded the maximum allowed concentration in Wels catfish in 2010. MPIs determined for common carp, Wels catfish, and barbel gradually decreased during the observed period, except for silver carp, where a slight increasing trend was noticed. Determined % PTWIs for Hg were higher than 20% in common carp and Wels catfish during 2011–2013, representing a moderate health risk. THQs for all analysed metals were generally lower than 1, except for Pb in Wels catfish in 2010, for Hg in common carp and for Hg in Wels catfish during 2011–2013. Moreover, HI was higher than 1 in almost all studies, so this exceeded the maximum allowable level prescribed by international and national regulations, indicating a hazard for consumers.

Carcinogenic risk in all analysed studies was lower than the acceptable lifetime risk (ARL) of 10^{-4}, except for As in common carp caught during 2013. Since there are no published data concerning measured toxic elements in fish meat from the Danube River from 2013 to 2021, it is necessary to implement regular monitoring of metal levels in fish from the Danube River and to limit fish consumption when needed, especially for children and pregnant women.

Bioakumulacija metala u ribama izlovljenih iz reke Dunav i procena mogućih zdravstvenih rizika

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INFORMACIJE O RADU

Ključne reči:
Reka Dunav
Šaran
Som
Tolstolobik
Mrena

APSTRAKT

Cilj ovog rada je bio da se utvrdi sadržaj metala u mesu riba i procene mogući zdravstveni rizici nakon konzumacije ribe izlovljene iz reke Dunav u Srbiji u poslednjih petnaest godina. Zbog toga su izračunati indeks zagađenosti mesa riba metalima (Metal pollution index — MPI), procenjena dnevna stopa unosa metala (Estimated daily intake rate — EDI), procenjena nedeljna stopa unosa metala (Estimated weekly intake rate — EWI), procenat privremenog podnošljivog nedeljnog unosa metala (% of provisional tolerable weekly intake — % PTVI), koeficijent opasnosti od određenog metala (Target hazard quotient — THQ), ukupni rizik štetnosti od metala (Hazard index — HI) i rizik od nastanka raka nakon konzumacije ribe (Target cancer risk — TR). Sadržaj kadmijuma (Cd) u šaranu i somu od 2011. do 2013. godine i u tolstolobiku 2021. godine bio je veći od maksimalno dozvoljene vrednosti za meso riba. U mesu soma zapažen je veći sadržaj žive (Hg) od 2011. do 2013. godine i olova (Pb) u 2010. godini nego što je dozvoljeno nacionalnim propisom. Pored toga, utvrđen MPI za šarana, soma i mrenu postepeno se smanjivao tokom posmatranog perioda, osim kod tolstolobika gde je uočen blagi trend rasta. Utvrđeno je da je HI indeks veći od 1 u skoro svim studijama koje su premašile maksimalno dozvoljene nivoe metala propisane međunarodnim i nacionalnim propisima. U svim prikazanim studijama TR je bio niži od prihvatljivog životnog rizika od 10^{-4}, osim za arsen (As) kod šarana izlovljenog u Zemunu i Grockoj tokom 2013. godine kada je otkriven neprihvatljiv kancerogen rizik ($> 10^{-4}$) (1.10×10^{-4} i 1.43×10^{-4}, redom). Stoga, neophodno je redovno pratiti sadržaj metala u ribama izlovljenih iz Dunava u cilju očuvanja zdravlja ljudi i životne sredine.

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