DOI: 10.46793/SBT30.35AM

CONTENT OF POTENTIALLY TOXIC ELEMENTS IN FRESHWATER FISH *SANDER LUCIOPERCA* IN SERBIA: MINI REVIEW

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Abstract: This review examines the bioaccumulation of potentially toxic elements (PTEs) in pikeperch (*Sander lucioperca*) across various aquatic ecosystems in Serbia, emphasizing its significance in the human diet. Thirteen studies were identified, focusing mainly on Serbia's largest rivers—the Danube and Sava—as well as the Gruža, Garaši, and Zlatar reservoirs. The findings poin to elevated Zn concentrations in pikeperch meat from the Danube River, elevated levels of Zn, Cd, and Hg in pikeperch meat from the Danube, Sava, and Kolubara rivers. Additionally, elevated Hg concentrations were noted in the Sava River. In the Garaši Reservoir, concentrations of Hg and Cd have been reported to exceed the MPC.

Keywords: heavy metals, pikeperch, top predator, edible species, human health risk

Introduction

Pikeperch (*Sander lucioperca* L.) is a widely distributed fish species across Europe and Asia and native species in the Danube basin (Simonović, 2001). Classified as a first-quality fish and highly valued, pikeperch is one of the most attractive fish species, both in recreational and commercial inland fisheries in Serbia (Simonović, 2001; Kottelat and Freyhof, 2007). Pikeperch is greatly appreciated for its nutritional benefits, including its high-quality protein content, beneficial fatty acid profile, and low-fat levels (1–2%) (Nikolić et al., 2021).

Pikeperch populations face several significant threats, including climate change, environmental fluctuations, lack of reproduction habitats, lack of food

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availability for juveniles, increasing predation pressure, and pollution (Jakubavičiūtè et al., 2024).

Recognizing the significance of pikeperch in the human diet in Serbia, it is essential to assess the concentrations of potentially toxic elements (PTEs) in this species. This review offers a comprehensive overview of PTEs bioaccumulation in pikeperch across various aquatic ecosystems in Serbia.

Materials and methods

In this traditional review, studies on fish species *Sander lucioperca* contamination with PTEs in Serbia were identified and assessed. International databases such as Scopus, PubMed, Web of Science, and Science Direct were searched for publications from January 1, 2000, to December 31, 2024, using keywords like "heavy metals" OR "metals" OR "elements" OR "trace metals" OR "toxic elements" OR "toxic metal" OR "potentially toxic elements" AND "*Sander lucioperca*" OR "pikeperch" AND "Serbia". After initial screening, eligible articles in English were downloaded, and references were examined to find additional studies.

Inclusion criteria were: (1) full-text articles in English; (2) research conducted in Serbia; (3) studies on wild (non-farmed) fish; and (4) reporting PTEs concentrations (mean and/or range). Excluded were review articles, books, letters to editors, and conference papers due to the lack of a peer-review process.

Data included study year, publication year, water body type, sampling site, total sample size, fish species, fish tissue analyzed, list of assessed PTEs, units of measurement, and detection methods.

In this review, concentrations of PTEs in *Sander lucioperca*, expressed on a wet weight basis (mg kg^{-1} or μg g^{-1}), were compared to the maximum permitted concentrations (MPCs) for these elements in fish meat intended for human consumption, as specified by national legislation (Official Gazette of the Republic of Serbia, 2018), European Union regulations (EU, 2006), and FAO guidelines (FAO, 1983). This information serves as an early warning for public health and aids in identifying "hot spots" of PTEs pollution.

Results and discussion

In line with the primary objectives of this review, 13 studies focusing on PTEs in pikeperch (*Sander lucioperca*) from Serbian waters were identified. Table

1 provides a summary of these studies, including type of water body, analyzed PTEs, measurement units, detection methods, and references.

Regarding aquatic ecosystems, pikeperch was primarily studied in Serbia's largest rivers, the Danube and Sava, as well as in the reservoirs Gruža, Garaši, and Zlatar. The Danube River, along with the Sava River, is essential for commercial fishing (Smederevac-Lalić et al., 2011). This could explain why most sampling sites for PTEs assessment in fish species are located along these rivers, especially near their confluence in the Belgrade area, as highlighted in this review. Among standing water bodies, the Garaši and Gruža reservoirs were the most studied ecosystems. According to Karadžić et al. (2010) and Milošković et al. (2024), despite the absence of direct anthropogenic impact, agricultural runoff and wastewater treatment plants are the primary sources of heavy metal pollution in these reservoirs. This review highlights that small water bodies have been overlooked in the assessment of PTEs in pikeperch fish species, aligning with Declerck et al. (2006), who found that these freshwater ecosystems are among the least studied worldwide.

Among the 13 studies, only three focused exclusively on pikeperch, examining the accumulation of potentially toxic elements in three tissues - muscle, liver, and gills. In the other studies, pikeperch was examined together with various fish species from different trophic levels. This aligns with the findings of Jorgensen (2016) and Milošković et al. (2016), suggesting that analyzing species with different traits offers a more comprehensive assessment of the risks associated with PTEs pollution in aquatic ecosystems.

Three studies focused exclusively on PTEs accumulation in pikeperch focused on the liver, gills, and muscle tissues. Since muscle tissue does not play an active role in ion uptake, detoxification, or biotransformation, the transfer of PTEs from other tissues is limited (Alhashemi et al., 2012). This tissue is commonly analyzed because PTEs in the edible portion of fish not only indicate environmental contamination but also represent a potential negative impact on human health (Jovanović et al., 2017).

This review indicates that the concentrations of certain elements in the muscle tissue (meat - the edible part) of pikeperch from the Danube and Sava rivers exceeded the MPC. In the study by Subotić et al. (2013a), elevated concentrations of Zn were observed in pikeperch meat from the Danube River. Similarly, Jovičić et al. (2014) reported increased levels of Zn, Cd, and Hg in pikeperch meat from the Danube, Sava, and Kolubara rivers. Additionally, Zuliani et al. (2019) recorded elevated Hg concentrations in the Sava River.

Table 1. Summary of the studies reporting concentrations of PTEs found in fish species *Sander lucioperca* in Serbia

Water body type	PTEs	Expressed unit	Method of detection	Reference
Danube River	As, Cu, Fe, Hg, Mn, Zn	μg/g dw	ICP-OES	Subotić et al. 2013a
Gruža Reservoir	Fe, Pb, Cd, Cu, Mn, Hg, As	mg/kg dw	ICP-OES and HG-ICP-OES	Milošković et al. 2013
Danube River	Al, As, B, Ba, Cd, Co, Cr, Cu, Fe, Hg, Li, Mn, Mo, Ni, Pb, Se, Sr, Zn	mg/kg dw	ICP-OES	Subotić et al. 2013b
Bovan Reservoir	Cu, Zn, Pb, Cd, Hg, Cr, Mn	mg/kg ww	ICP-OES ICP-MS	Milošković et al. 2014
Danube, Sava, Kolubara rivers	Al, As, B, Ba, Cd, Co, Cr, Cu, Fe, Hg, Li, Mn, Mo, Ni, Pb, Se, Sr, Zn	μg/g dw	ICP-OES	Jovičić et al. 2014
Bovan Reservoir	As, Al, Co, Fe, Ni, Sn, Se	mg/kg ww	ICP-OES ICP-MS	Milošković and Simić 2015
Danube, Sava, Tisa, Great Morava, West Morava, South Morava, Ibar, Drina, Kolubara, Great Timok, Mlava, Pek rivers	Al, As, Cd, Co, Cr, Cu, Fe, Hg, Mn, Ni, Pb, Zn	mg/kg ww	ICP-OES	Milošković et al. 2016
Danube River	Pb, Cd, Hg, Cu, Fe, Zn, As	mg/kg ww	AAS	Jovanović et al. 2017
Sava River	As, Zn, Cu, Cd, Cr, Pb, Ni, Hg	mg/kg dw	ICP-MS, AAS for Hg, AFS for MeHg	Zuliani et al. 2019
Garaši Reservoir	Ag, Al, As, B, Ba, Ca, Cd, Co, Cr, Cu, Fe, Hg, K, Li, Mg, Mn, Mo, Na, Ni, P, Pb, S, Se, Si, Sr, Zn	μg/g dw	ICP-OES	Nikolić et al. 2021
Zlatar Reservoir	Al, As, B, Ba, Ca, Cd, Co, Cr, Cu, Fe, Hg, K, Li, Mg, Mn, Mo, Na, Ni, P, Pb, S, Se, Si, Sr, Zn	μg/g dw	ICP-OES	Nikolić et al. 2022
Garaši Reservoir	Ca, K, Mg, P, S, B, Co, Cu, Fe, Mo, Mn, Se, Si, Zn, Ag,	μg/g dw	ICP-OES	Nikolić et al. 2023

	Al, As, Ba, Cd, Cr, Hg, Li, Ni, Pb, Sr			

When it comes to reservoirs, Nikolić et al. (2021, 2023) reported that in the Garaši Reservoir, concentrations of Hg and Cd exceeded the MPC.

Hg and Cd are the most found elements exceeding maximum permissible concentrations (MPC) in both rivers and reservoirs. Studies by Cerveny et al. (2014), Khemish et al. (2017), and Ivanović et al. (2016) indicate that toxic element accumulation, particularly Hg and Cd, can be two to four times higher in fish at higher trophic levels compared to omnivorous fish. This is especially true for Hg, as it biomagnifies through the food chain (Khemish et al., 2017). Pikeperch (*Sander lucioperca*) is considered an apex predator in both lakes and rivers, with an estimated trophic position between 4 and 5 (Kopp et al., 2009).

Conclusion

This review highlights significant progress in understanding PTEs contamination in pikeperch in Serbia. However, many knowledge gaps remain and need to be addressed in the future. In particular, numerous aquatic ecosystems, smaller rivers and reservoirs, have been overlooked in PTEs contamination studies and require greater attention. The importance of this review lies in its capacity to identify areas where PTE concentrations in pikeperch meat exceed MPCs, serving as an early warning system to mitigate health risks associated with fish consumption.

Acknowledgement

The research presented in this article is part of Grants No. 451-03-136/2025-03/200378 and 451-03-136/2025-03/200122 funded by the Serbian Ministry of Science, Technological Development, and Innovation.

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