

Bioaccumulation and Biota-Sediment Accumulation Factor of Metals and Metalloids in Edible Fish: A Systematic Review in Ethiopian Surface Waters

Authors: Melake, Bealemlay Abebe, Endalew, Salie Mulat, Alamirew, Tamagnu Sintie, and Temesegen, Liku Muche

Source: Environmental Health Insights, 17(1)

Published By: SAGE Publishing

URL: <https://doi.org/10.1177/11786302231159349>

The BioOne Digital Library (<https://bioone.org/>) provides worldwide distribution for more than 580 journals and eBooks from BioOne's community of over 150 nonprofit societies, research institutions, and university presses in the biological, ecological, and environmental sciences. The BioOne Digital Library encompasses the flagship aggregation BioOne Complete (<https://bioone.org/subscribe>), the BioOne Complete Archive (<https://bioone.org/archive>), and the BioOne eBooks program offerings ESA eBook Collection (<https://bioone.org/esa-ebooks>) and CSIRO Publishing BioSelect Collection (<https://bioone.org/csiro-ebooks>).

Your use of this PDF, the BioOne Digital Library, and all posted and associated content indicates your acceptance of BioOne's Terms of Use, available at www.bioone.org/terms-of-use.

Usage of BioOne Digital Library content is strictly limited to personal, educational, and non-commercial use. Commercial inquiries or rights and permissions requests should be directed to the individual publisher as copyright holder.

BioOne is an innovative nonprofit that sees sustainable scholarly publishing as an inherently collaborative enterprise connecting authors, nonprofit publishers, academic institutions, research libraries, and research funders in the common goal of maximizing access to critical research.

Bioaccumulation and Biota-Sediment Accumulation Factor of Metals and Metalloids in Edible Fish: A Systematic Review in Ethiopian Surface Waters

Environmental Health Insights
Volume 17: 1–10
© The Author(s) 2023
Article reuse guidelines:
sagepub.com/journals-permissions
DOI: 10.1177/11786302231159349



Bealemlay Abebe Melake^{id}, Salie Mulat Endalew,
Tamagnu Sintie Alamirew and Liku Muche Temesegen^{id}

School of Environmental Health Science, College of Health and Medical Science, Haramaya University, Harar, Ethiopia.

ABSTRACT: Metals and metalloids pollution of Ethiopian surface water is becoming an environmental issue. Bioaccumulation and Biota-Sediment Accumulation Factor (BAF and BSAF) are used to quantify the bioaccumulation of contaminants from water and sediment to biota. The present study aimed to determine the BAF and BSAF of metals and metalloids in different surface waters of Ethiopia. Furthermore, the ecological and human health risks were also examined. Generally, 902 peer-reviewed papers from 2005 to 2022 were searched using search engines. The most common types of edible fish species in studied surface waters of Ethiopia were *Oreochromis niloticus*, *Clarias gariepinus*, and *Barbus intermedius*. The concentration of metals and metalloids were higher in sediment than in water and in carnivorous fish than in herbivorous fish. The BSAF of Se in all fish species was greater than 1. *Oreochromis niloticus* was a bio-concentrator of As and Se. The dissolved concentration of Cu, Cd, Pb, and Ni were higher compared to the Ethiopian Environmental Protection Authority and the European Union; Organization of Economic and Co-Operation Development environmental water quality standard guidelines for inland surface freshwater bodies. Likewise, in sediment, the concentration of Cu, Pb, Ni, Zn, and Cr were above Tolerable Effect Concentration values and Cd, Ni, and Cr were above Probable Effect Concentration levels when compared to the United States Consensus-Based Sediment Quality Guidelines for freshwater which indicates that these metals may pose risk to aquatic organisms. Consumption of raw water and fish contaminated with the detected metals and metalloids is not associated with any diseases. However, local consumers who live close to each freshwater ecosystem may become more exposed to health risk hazards. The findings of this study will provide baseline information on BAF and BSAF of metals and metalloids in surface waters and will contribute to the effective monitoring of environmental quality.

KEYWORDS: Bioaccumulation, Ethiopia, freshwater ecosystem, environmental pollution, metal(loid)s

RECEIVED: September 22, 2022. **ACCEPTED:** February 6, 2023.

TYPE: Review

FUNDING: The author(s) received no financial support for the research, authorship, and/or publication of this article.

DECLARATION OF CONFLICTING INTERESTS: The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

CORRESPONDING AUTHOR: Bealemlay Abebe Melake, School of Environmental Health Science, College of Health and Medical Sciences, Haramaya University, P.O.BOX 238/235, Harar, Ethiopia. Email: bealemlayabebe@gmail.com

Introduction

Surface water has been exposed to numerous pollutants. Because of their persistence, non-biodegradability and bio-magnification potential, water pollution by metals and metalloids become a serious environmental problem worldwide.^{1,2} In the aquatic environment, metals and metalloids are partitioned among various media such as biota, water, and sediment.³ In the water phase, metals and metalloids are partitioned in dissolved form and adsorbed to suspended matter.⁴ However, they preferentially accumulate in sediments due to their adsorption capacity, from where due to desorption and remobilization processes, they are later retransferred to the water column and food chain.⁵⁻⁹

The main possible uptake routes of metals and metalloids for fish are through food ingestion and the permeable epidermis in the gills.¹⁰ Fish can accumulate metals and metalloids from their diet, water and sediment and these accumulated concentrations can be transferred to humans through fish consumption.¹¹ However, the toxicity of metals and metalloids to aquatic organisms is linked to the bioavailable fraction.¹² Metals and metalloids can magnify when they accumulate in aquatic biota via the food chain.¹³ Because of their relatively large body size, long life cycle, position in the aquatic food chain and value for human food, fish are involved as biological

indicators for the assessment of the effects of metals and metalloids and the quality of aquatic environment.¹⁴

Bioaccumulation factor (BAF) is used to quantify the bioaccumulation of metals and metalloids from water to biota due to uptake through all possible routes of exposure which is expressed as a quotient of the concentration of a specific metal or metalloid in biota and the concentration of that metal or metalloid in the water (ambient media).¹⁵ Likewise, Biota-Sediment Accumulation Factor (BSAF) quantifies the bioaccumulation of sediment-associated metal or metalloid into biota.¹⁶ In many Ethiopian freshwater ecosystems, metals and metalloids pollution is increasing.¹⁷ Metals and metalloids can originate from 2 main sources, that is natural causes such as weathering of the earth's crust or mineral ores weathering, soil runoff, soluble salts dissolution in water; and anthropogenic causes include withdrawing of minerals, wastewater, industrial processes, irrigation activities, runoff from urban areas, and pesticide spray.⁴ Moreover, most industries in Ethiopia are discharging their untreated water to the nearby surface waters.^{18,19}

Previous studies have explored higher levels of metals and metalloids in sediment than in water, high levels of Hg in carnivorous fish (*Barbus intermedius*),^{17,19,20} and none of the detected metals was hazardous to humans.^{17,21,22} These studies



Creative Commons Non Commercial CC BY-NC: This article is distributed under the terms of the Creative Commons Attribution-NonCommercial 4.0 License (<https://creativecommons.org/licenses/by-nc/4.0/>) which permits non-commercial use, reproduction and distribution of the work without further permission provided the original work is attributed as specified on the SAGE and Open Access pages (<https://us.sagepub.com/en-us/nam/open-access-at-sage>).

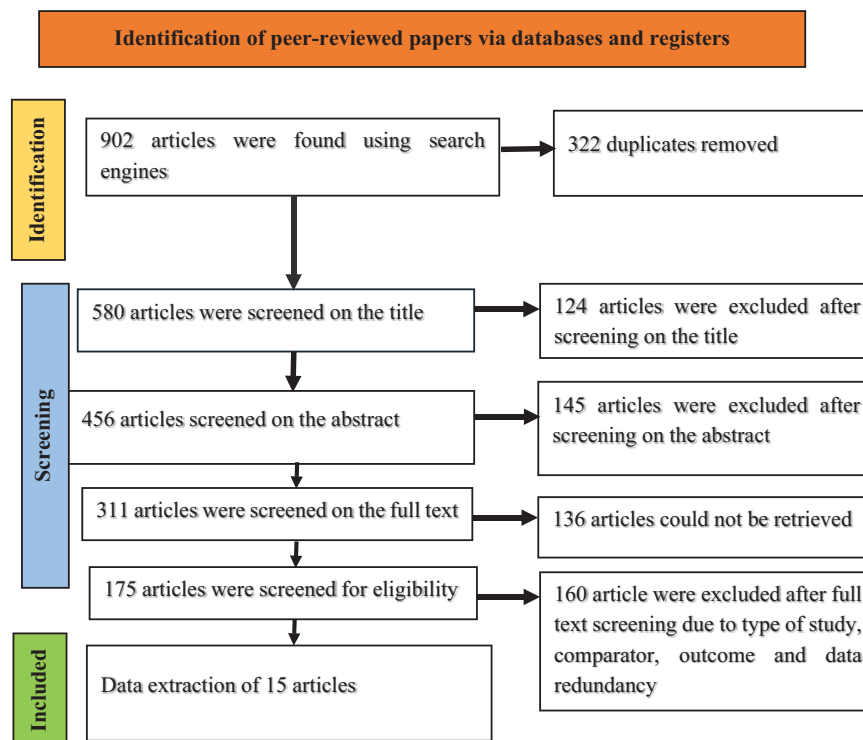


Figure 1. A personal creation shows the flowchart representing the methodology of the review.

also mostly determined the total concentrations of metals and metalloids in water, sediment and fish tissue. However, only one study¹⁷ has determined BAF and BSAF of metals and metalloids. Therefore, this study aims to determine BAF and BSAF of metals and metalloids in different surface waters of Ethiopia. Furthermore, the ecological and human health risks associated with metals and metalloids concentration were also examined. Hence, the findings of this study will provide baseline information on the levels of BAF and BSAF of metals and metalloids in Ethiopian surface waters, and will contribute to effective monitoring of environmental quality. Later, it will also enable the evaluation of future trends in surface water pollution by metals and metalloids.

Materials and Methods

Searching strategy and the study protocol

The study has been conducted between 19 March, 2022 and 23 August, 2022. Google Scholar, PubMed, Web of Science, Embase and SCOPUS were mainly used for web-searching of peer-reviewed articles focusing on the distribution and concentration of metals and metalloids in water, sediment and fish in surface waters of Ethiopia. Accordingly, 902 papers from 2005 to 2022 were searched and collected (Figure 1). Important key words mainly “metals,” “trace metals,” “heavy metals,” and “metals in water,” “metals in sediment,” “metals in fish tissue,” and “metals in the aquatic environment” were used in the search engine (databases). The study period of peer-reviewed articles was left closed-ended to search for updated papers.

Inclusion and exclusion criteria

For the inclusion of peer-reviewed papers in the study, basically, the following considerations were taken such as all factors related to metals and metalloids in surface water of Ethiopia. The focus of the study was on published and peer-reviewed papers. However, books, reviewed papers, conference articles, and master’s and PhD thesis were excluded from the study. Throughout the review, all searches may have a limitation according to the following considerations: (1) Published literatures may be omitted due to a lack of a linkage with the important keywords, (2) all used literatures were only in the English versions, (3) some may not available due to closed access, (4) others were not cataloged in the electronic databases, and (5) all included studies are cross-sectional studies.

Because of the variation of metals and metalloids concentration and their multitude in different surface water of the region, the collected data was analyzed from numerous points of view including the spatial distribution of metals and metalloids in the aquatic environment. All the units of concentration are expressed as $\mu\text{g/L}$ and mg/kg for metal and metalloid levels in water, sediment and fish tissue respectively. Concentrations that were below the limit of quantification (detection) ($<\text{LOQ}/\text{LOD}$), were substituted with a value of $\text{LOQ}/2$.^{23,24}

Bioaccumulation –and biota-sediment accumulation factor

The most common types of edible fish species found in many studies were Nile tilapia (*Oreochromis niloticus*), African sharp

tooth catfish (*Clarias gariepinus*), and African big barb (*Barbus intermedius*). Following, the bioaccumulation-and Biota-Sediment Accumulation factor (BAF and BSAF) of metals and metalloids were calculated as follows using equations.¹⁶

$$\text{BAF} = C_b / C_w$$

$$\text{BSAF} = C_b / C_s$$

Where: BAF= bioaccumulation factor (L/kg), BSAF= biota-sediment accumulation factor (mg/kg/dw), C_b = concentration of metal in fish ($\mu\text{g/g dw}$), C_s = concentration of metal in sediment ($\mu\text{g/g dw}$), and C_w = concentration of metal in water (mg/L).

Ecological risk assessment of metals and metalloids in water and sediment

To determine whether the measured dissolved metals and metalloids in the surface waters pose adverse effects on the benthic aquatic fauna, the average concentrations of metals and metalloids were compared to the water quality standards of the Ethiopian Environmental Protection Authority (EEPA)²⁵ and the European Union water quality standard guidelines for inland surface freshwater bodies.²⁶ Likewise, to determine whether the detected metals and metalloids in the lake sediment have potential adverse effects on the benthic fauna, the investigated concentrations were compared to the United States Consensus-Based Sediment Quality Guidelines (SQGs) for freshwater. These values represent Threshold/Tolerable Effect Concentration (TEC) and Probable Effect Concentration (PEC) values.²⁷

Human health risk assessment

To estimate the potential non-carcinogenic human health risk associated with metals and metalloids in the surface waters of Ethiopia, the detected metals and metalloids concentrations were compared with water quality standards for drinking water by the World Health Organization (WHO)²⁸. Likewise, to estimate human health risks associated with metal or metalloid contaminated fish consumption, estimated daily intake (EDI in mg/kg/day), average daily intake (ADI in mg/kg/day), and hazard quotient (HQ) values for metals and metalloids were calculated using the corresponding reference dose (RfD in mg/kg/day).²⁹ A 60 kg body weight person (ie, an average body weight of Ethiopian adults) and a national fish consumption of 0.19 kg/week (~ 0.027 kg/day)³⁰ were used for the calculations. The maximum edible amount (MEA in kg/day) of fish consumption per person per day, without causing a potential human health risk, was calculated using the reference dose (the maximum tolerable daily intake of a metal or metalloid that does not pose any adverse health effect) of metals and metalloids established by United States Environmental Protection Authority,³¹ Agency for Toxic Substances and

Disease Registry,³² World Health Organization,³³ and United States Food and Drug Administration.³⁴ The used concentrations of metals and metalloids in fish muscle were the average of the measured concentrations in each edible fish species in Ethiopia. EDI, HQ, and MEA were calculated using the following equations^{29,35}:

$$\text{EDI} = C * \text{DFC} / \text{BW}$$

$$\text{ADI} = [\text{EDI} * \text{ED} * \text{EF}] / (\text{AT}) * 10^{-3}$$

$$\text{HQ} = \text{ADI} / \text{RfD}$$

$$\text{MEA} = \text{RfD} * \text{BW} / C$$

With C is the concentration of metals or metalloids in $\mu\text{g/g ww}$, DFC is fish consumption in kg/day, BW is adult Ethiopian body weight (60 kg), ED is the exposure duration (30 years for an adult),³⁶ EF is the exposure frequency (365 days/year),³⁷ AT is the average exposure time for non-carcinogens (365 days/year \times ED),³⁷ and RfD is the reference dose for Cd (0.00001 mg/kg/day), Cu (0.01 mg/kg/day), Pb (0.004 mg/kg/day), Cr (0.0009 mg/kg/day), Co (0.01 mg/kg/day), As (0.00003 mg/kg/day),³² Ni (0.02 mg/kg/day), Zn (0.3 mg/kg/day),³¹ Se (0.17 mg/kg/day), and Hg (0.00023 mg/kg/day).³³ EDI, HQ, and MEA values were also calculated based on the maximum concentrations detected in each edible fish species in Ethiopia, to determine the worst-case scenario.

Result and Discussion

Data accessibility

After searching, 902 peer-reviewed articles focusing on the distribution and accumulation pattern of metals and metalloids; that is Arsenic (As), Cadmium (Cd), Chromium (Cr), Cobalt (Co), Copper (Cu), Mercury (Hg), Lead (Pb), Nickel (Ni), Selenium (Se), and Zinc (Zn) in water, sediment, and fish muscle from 2005 to 2022, 15 articles were used for the analysis of the result. After screening all the reports in the Ethiopian aquatic environment, a majority (73.68%) of reports were from the Rift Valley Lakes (RVLs). For instance, from the RVLs, more (47.37%) was done in Lake Hawassa followed by Lake Ziway (26.32%).

Detection method of metals and metalloids

Observing the collected data, different methods (instrumental analysis) were used for the detection of metals and metalloids in water, sediment and fish. The most frequently used detection method (Figure 2) for metals and metalloids analysis was Atomic Absorption Spectrophotometer (AAS=66.7%) followed by Inductively Coupled Plasma Mass Spectrometry (ICP-MS) (26.7%). However, this was unexpected, even though both are the most common detection methods of metals and metalloids, AAS detects metals and metalloids serially while ICP-MS did concurrently. Moreover, ICP-MS is faster and has cheaper processing costs and better detection limits (LOD) compared to ASS.³⁸

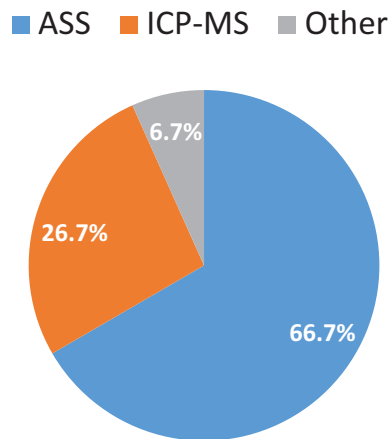


Figure 2. Instrumental analysis of metals and metalloids in water, sediment, and fish tissue in Ethiopian surface waters from 2005 to 2022.

Metals and metalloids in water, sediment, and fish muscle

The concentration of 10 metals and metalloids (ie, As, Cd, Cr, Co, Cu, Hg, Pb, Ni, Se, and Zn) were collected from previously done literatures. An overview of the concentration of metals and metalloids in water ($\mu\text{g/L}$), sediment (mg/kg dw), and fish muscle (mg/kg dw) of Ethiopian surface waters are presented in Table A1 to A3 (see in Appendix). Zn has the highest concentration ($575.90\mu\text{g/L}$) of metals and metalloids in water (Figure A1 in Appendix) which has shown a similar pattern as compared to previous studies.^{17,18,39-41} The average concentration of Cu, Cd, Pb, Ni, Cr, Co, Hg, As, and Se in water were 176.43, 66.60, 59.07, 191.84, 35.32, 109.04, 0.32, 2.10, and $0.82\mu\text{g/L}$. In terms of specific location, more data were collected from Rift Valley Lakes, Lake Hawassa, with the highest concentration of Zn $1059.76\mu\text{g/L}$ and was similar with other studies.^{17,18,39,41} In sediment, Figure A2 (see in Appendix) the concentration of Cr (4529.21mg/kg dw) and Ni (4422.56mg/kg dw) was higher when compared with other metals and metalloids which is similar compared to Kassaye et al⁴¹ in Lake Ziway and Hawassa. The concentration of Cu, Cd, Pb, Zn, Co, Hg, As, and Se were 32.93, 24.49, 16.10, 259.30, 23.17, 8.15, 2.08, and 0.18mg/kg dw . The highest concentration of Cr in sediment may be ingested by fish and later accumulated. Overall, the concentration of metals and metalloids in sediment was higher than in water.

Analysis of the results also revealed metals and metalloids levels in fish muscle (Table A3). For instance, in all fish species, the concentration of Zn was highest which was 15.40, 18.48, and 31.00mg/kg dw in *C. gariepinus*, *O. niloticus*, and *B. intermedius* respectively. This shows a similar pattern with previous studies,^{17,19,22} which may be due to the essentiality of Zn for physiological role and uptake from the aquatic environment by fish preferentially. Overall, similar to previous studies,^{17,19,22} the finding of this study also revealed that the concentration of most metals and metalloids were relatively higher in carnivorous fish than in herbivorous fish.

Bioaccumulation-and biota sediment accumulation factors

The average concentration of detected metals and metalloids in water ($\mu\text{g/L}$), sediment (mg/kg dw), fish muscle (mg/kg dw), and their BAF and BSAF are summarized in Table 1. For instance, the BAF of Hg in *O. niloticus* and *B. intermedius* and As in *O. niloticus* was greater than 1. The BSAF of Se in all fish species and As for *O. niloticus* and Co for *B. intermedius* was also greater than 1. Moreover, BSAF of As and Se for *O. niloticus* was greater than 2. In contrast, previous studies have shown a higher BAF for Cd⁴⁰ and Cr and Hg¹⁷ and BSAF of all metals or metalloids was also less than 1.¹⁷ Overall, BAF and BSAF value greater than 1 indicates that metal or metalloid may be accumulated in fish muscle, while a value less than 1 indicates that a metal or metalloid is not accumulated in fish tissue directly from water and is associated with sediment respectively.⁴² In addition, an organism tissue with $\text{BSAF} > 2$, $1 < \text{BSAF} < 2$, and $\text{BSAF} < 1$ can be considered as a macro-concentrator, micro-concentrator, and de-concentrator respectively.⁴³ Therefore, the results of this study illustrated that *O. niloticus* is a bio-concentrator of As and Se. While, authors like Arnot and Gobas⁴⁴ suggest that BAF values < 1000 , $1000 < \text{BAF} < 5000$, and > 5000 are also considered as having no probability of accumulation, bio-accumulative, and extremely accumulative respectively.

Ecological risk assessment

Based on data analysis, in surface waters of Ethiopia, the dissolved concentration of Cu, Cd, Pb, and Ni were higher compared to the water quality standards of the Ethiopian Environmental Protection Authority²⁵ and the European Union water quality standard guidelines for inland surface freshwater bodies²⁶ (Table A1). Likewise, in sediment of surface waters (Table A2), Cu, Pb, Ni, Zn, and Cr were above TEC values and Cd, Ni, and Cr were above PEC levels when compared to the United States Consensus-Based Sediment Quality Guidelines (SQGs) for freshwater which represent Threshold/Tolerable Effect Concentration (TEC) and Probable Effect Concentration (PEC) values,²⁷ and this was similar to a previous study¹⁷ in Lake Hawassa. This indicates that these detected metals in water and sediment may pose risk to aquatic organisms or benthic fauna.

Human health risk assessment

The concentration of detected metals and metalloids in water is not associated with any disease. Fish muscle is consumed by people in most countries.^{17,45} Analysis of human health risk (hazard quotient of metals and metalloids) associated with metal or metalloid-contaminated fish consumption (Table A4), HQ for all metals and metalloids for all edible fish species

Table 1. The average concentration of detected metals and metalloids in water ($\mu\text{g/L}$), sediment (mg/kg dw), fish tissue (*O. niloticus*, *C. gariepinus*, and *B. intermedius*) (mg/kg dw), and respective BAF and BSAF values.

VARIABLE	DETECTED METALS AND METALLOIDS									
	CU	CD	PB	NI	ZN	CR	CO	HG	AS	SE
Water	176.43	66.60	59.07	191.84	575.90	35.32	109.04	0.32	2.10	0.82
<i>O. niloticus</i>	0.72	0.50	0.71	1.16	0.51	3.18	18.48	0.79	14.47	0.49
BAF	0.004	0.008	0.012	0.006	0.001	0.090	0.169	2.450	6.901	0.60
<i>C. gariepinus</i>	0.73	0.32	2.64	1.10	0.73	2.31	15.40	0.22	1.29	0.29
BAF	0.004	0.005	0.045	0.006	0.001	0.07	0.14	0.68	0.62	0.35
<i>B. intermedius</i>	0.03	1.39	1.01	0.31	0.08	0.86	31.00	0.48	1.51	0.28
BAF	0.0002	0.021	0.017	0.002	0.0001	0.02	0.28	1.49	0.72	0.34
Sediment	32.93	24.49	16.10	4422.56	259.30	4529.21	23.17	8.15	2.08	0.18
<i>O. niloticus</i>	0.72	0.50	0.71	1.16	0.51	3.18	18.48	0.79	14.47	0.49
BSAF	0.02	0.02	0.04	0.0003	0.002	0.001	0.80	0.10	6.97	2.82
<i>C. gariepinus</i>	0.73	0.32	2.64	1.10	0.73	2.31	15.40	0.22	1.29	0.29
BSAF	0.02	0.01	0.16	0.0002	0.003	0.001	0.66	0.03	0.62	1.66
<i>B. intermedius</i>	0.03	1.39	1.01	0.31	0.08	0.86	31.00	0.48	1.51	0.28
BSAF	0.001	0.06	0.06	0.0001	0.0003	0.0002	1.34	0.06	0.73	1.60

was <1 . This was as expected because previous studies found, except Hg, metals, and metalloids were not hazardous to human consumers.^{17,21,22} A $HQ > 1$ is considered to be hazardous and a $HQ < 1$ is non-hazardous.^{29,46,47} Similarly, the MEA of most metals and metalloids in all edible fish species was higher than the average daily national fish consumption of Ethiopians. This indicates that a consumer (a 60 kg body weight person) is not at risk or will not be poisoned by the measured metals or metalloids. Accordingly to Dsikowitzky et al,²² a regional fish consumption of 1.05 kg/week was recorded. Therefore, local consumers who live close to each freshwater ecosystem may be more exposed to health hazards.

Recommendations

Consumption of raw water and fish contaminated with the detected metals and metalloids is not associated with any diseases. However, to give a comprehensive inference, analysis of metals and metalloids in other organs of the fish like kidney, gills, intestine, bone, and heart is required. It is highly recommended to characterize some physicochemical parameters of water (pH, temperature, conductivity, redox potential, hardness, divalent cations (eg, Mg^{2+} and Ca^{2+}), metal and metalloid chemical speciation, total alkalinity, total suspended, and dissolved solids) to investigate their effect in the distribution, bioavailability and bioaccumulation of metals and metalloids in the aquatic environment. Further investigators should also detect the effect of seasonal variation on BAF and BSAF of metals and metalloids.

Conclusion

Metals and metalloids have been detected in different surface water ecosystems of Ethiopia. Data on metals and metalloids in water, sediment and fish muscle were collected. The most used detection method for metals and metalloids analysis was Atomic Absorption Spectrophotometer (AAS). The average concentration of metal and metalloids in sediment were higher than in water. The average concentration of Zn was highest in all fish species muscle. The results of the study reveal that the concentration of most metals and metalloids were relatively higher in carnivorous fish than in herbivorous fish. BAF of Hg in *O. niloticus* and *B. intermedius* and As in *O. niloticus* was greater than 1. Likewise, BSAF of Se in all fish species was greater than 1. *O. niloticus* is considered as a bio-concentrator of AS and Se. Cu, Cd, Pb, and Ni in water and Cd, Ni, and Cr in sediment may pose risk to aquatic organisms. Consumption of raw water contaminated with the measured metals and metalloids is not associated with any disease. Similarly, eating fish contaminated with the measured metals and metalloids may not pose risk to consumers. The results of this study may also be a good database for government, risk managers, and researchers on metals and metalloids pollution of an aquatic environment. It will also enable the evaluation of future trends in surface water pollution.

Author Contributions

Conceptualization: BAM. **Developing methods:** BAM, SME, TSA. **Data analysis:** BAM, SME, TSA. **Writing and editing:** BAM, SME, TSA.

ORCID iDs

Bealemlay Abebe Melake  <https://orcid.org/0000-0003-1661-6961>

Liku Muche Temesegen  <https://orcid.org/0000-0002-1292-0125>

REFERENCES

- Williams RJ, Johnson AC, Smith JJ, Kanda R. Steroid estrogens profiles along river stretches arising from sewage treatment works discharges. *J Environ Sci Technol.* 2003;37:1744-1750.
- Edem CA, Akpan SB, Dosunmu MI. A comparative assessment of heavy metals and hydrocarbon accumulation in *Sphyrna afra*, *Oreochromis niloticus* and *Elops lacerta* from Anantigha Beach Market in Calabar-Nigeria. *Afr J Environ Pollut Health.* 2008;6:61-64.
- Förstner U, Ahlf W, Calmano W. Studies on the transfer of heavy metals between sedimentary phases with a multi-chamber device: *Combined effects of salinity and redox variation.* *Mar Chem.* 1989;28:145-158.
- Prego R, Cobelo-García A. Twentieth century overview of heavy metals in the Galician Rias (NW Iberian Peninsula). *Environ Pollut.* 2003;121:425-452.
- Hasan MR, Khan MZH, Khan M, et al. Heavy metals distribution and contamination in surface water of the Bay of Bengal coast. *Cogent Environ Sci.* 2016;2:1-12.
- Ekeanyanwu CR, Ogbuinyi CA, Etienajirhevwe OF. Trace metals distribution in fish tissues, bottom sediments and water from Okumeshi River in delta State, Nigeria. *Ethiop J Environ Stud Manag.* 2011;3:6-10.
- Ramessur RT, Ramjeawon T. Determination of lead, chromium and zinc in sediments from an urbanized river in Mauritius. *Environ Int.* 2002;28:315-324.
- Awofolu OR, Mbolekwa Z, Mtshemla V, Fatoki OS. Levels of trace metals in water and sediment from Tyume River and its effects on an irrigated farmland. *Water SA.* 2005;31:87-94.
- Yilmaz AB, Doğan M. Heavy metals in water and in tissues of himri (*Carasobarbus luteus*) from Orontes (Asi) River, Turkey. *Environ Monit Assess.* 2008;144:437-444.
- Bonnail E, Sarmiento AM, DelValls TA, Nieto JM, Riba I. Assessment of metal contamination, bioavailability, toxicity and bioaccumulation in extreme metallic environments (Iberian pyrite belt) using *Corbicula fluminea*. *Sci Total Environ.* 2016;544:1031-1044.
- Zhao S, Feng C, Quan W, Chen X, Niu J, Shen Z. Role of living environments in the accumulation characteristics of heavy metals in fishes and crabs in the Yangtze River estuary, China. *Mar Pollut Bull.* 2012;64:1163-1171.
- Wang Z, Huang S, Liu Q. Use of anodic stripping voltammetry in predicting toxicity of copper in river water. *Toxicol Chem.* 2002;21:1788-1795.
- Krivokapić M. Study on the evaluation of (Heavy) metals in water and sediment of Skadar Lake (Montenegro), with BCF assessment and translocation ability (TA) by *Traça natans* and a review of SDGs. *Water.* 2021;13:876.
- Zhou Q, Zhang J, Fu J, Shi J, Jiang G. Biomonitoring: an appealing tool for assessment of metal pollution in the aquatic ecosystem. *Anal Chim Acta.* 2008;606:135-150.
- DeForest DK, Brix KV, Adams WJ. Assessing metal bioaccumulation in aquatic environments: the inverse relationship between bioaccumulation factors, trophic transfer factors and exposure concentration. *Aquat Toxicol.* 2007;84:236-246.
- Djikanović V, Skorić S, Spasić S, Naunovic Z, Lenhardt M. Ecological risk assessment for different macrophytes and fish species in reservoirs using biota-sediment accumulation factors as a useful tool. *Environ Pollut.* 2018;241:1167-1174.
- Melake BA, Nkuba B, Groffen T, De Boeck G, Bervoets L. Distribution of metals in water, sediment and fish tissue. Consequences for human health risks due to fish consumption in Lake Hawassa, Ethiopia. *Ethiopia. Sci. Total Environ.* 2022;843:156968.
- Amare TA, Yimer GT, Workagegn KB. Assessment of metals concentration in water, sediment and macrophyte plant collected from Lake Hawassa, Ethiopia. *J Environ Anal Toxicol.* 2014;5:1-7.
- Desta Z, Borgström R, Rosseland BO, Gebre-Mariam Z. Major difference in mercury concentrations of the African big barb, *Barbus intermedius* (R.) due to shifts in trophic position. *Ecol Freshw Fish.* 2006;15:532-543.
- Desta Z, Borgström R, Gebre-Mariam Z, et al. Habitat use and trophic position determine mercury concentration in the straight fin barb *Barbus paludinosus*, a small fish species in Lake Hawassa, Ethiopia. *J Fish Biol.* 2008;73:477-497.
- Asefa W, Beranu T. Levels of some trace metals in fishes tissues, water and sediment at Tendaho Water Reservoir, Afar Region, Ethiopia. *J Aquat Res Dev.* 2016;7:1-6.
- Disikowitzky L, Mengesha M, Dadebo E, de Carvalho CE, Sindern S. Assessment of heavy metals in water samples and tissues of edible fish species from awassa and Koka Rift Valley Lakes, Ethiopia. *Environ Monit Assess.* 2013;185:3117-3131.
- Bervoets L, Voets J, Chu S, Covaci A, Schepens P, Blust R. Comparison of accumulation of micropollutants between indigenous and transplanted zebra mussels (*Dreissena polymorpha*). *Environ Toxicol Chem.* 2004;23:1973-1983.
- Custer TW, Custer CM, Hines RK, Sparks DW. Trace elements, organochlorines, polycyclic aromatic hydrocarbons, dioxins, and furans in lesser scaup wintering on the Indiana Harbor Canal. *Environ Pollut.* 2000;110:469-482.
- Ethiopian Environmental Protection Authority (EEPA). *Guideline Ambient Environment Standards for Ethiopia.* Environmental Protection Authority and United Nations Industrial Development Organization; 2003.
- Organisation for Economic Co-Operation and Development OECD/EAP Task Force. *Proposed System of Surface Water Quality Standards for Moldova.* Technical Report Moldova. 2007.
- MacDonald DD, Ingersoll CG, Berger TA. Development and evaluation of consensus-based sediment quality guidelines for freshwater ecosystems. *Arch Environ Contam Toxicol.* 2000;39:20-31.
- World Health Organization (WHO). *Guidelines for drinking-water quality, volume 2: Health criteria and other supporting information.* *Sci Total Environ.* 1987;61:274.
- Pinzón-Bedoya CH, Pinzón-Bedoya ML, Pinedo-Hernández J, Urango-Cárdenas I, Marrugo-Negrete J. Assessment of potential health risks associated with the intake of heavy metals in fish harvested from the largest estuary in Colombia. *Int J Environ Res Public Health.* 2020;17:2921.
- World Health Organization (WHO). *Evaluation of Certain Food Additives and Contaminants: Seventy-third Report of the Joint FAO/WHO Expert Committee on Food Additives.* WHO Technical Report Series 960. 2011.
- United States Environmental Protection Authority (USEPA). *A Review of the Reference Dose and Reference Concentration Processes.* U.S. Environmental Protection Agency, Risk Assessment Forum, Washington, DC, EPA/630/P-02/002F. 2003.
- Agency for Toxic Substances and Disease Registry (ATSDR). 2013. Minimum risk levels (MRLs). <https://www.atsdr.cdc.gov/mrls/index.html>
- World Health Organization (WHO). *Evaluation of Certain Food Additives and Contaminants: Sixty-Seventh Report of the Joint FAO/WHO Expert Committee on Food Additives.* WHO Technical Report Series 940. 2007.
- United States Food and Drug Administration (USFDA). *Packaging & food contact substances (FCS).* 2013. <http://www.fda.gov/Food/IngredientsPackagingLabeling/PackagingFCS/default.htm>
- Hajduga G, Generowicz A, Kryłow M. Human health risk assessment of heavy metals in road dust collected in Cracow. *E3S Web Conf.* 2019;100:00026.
- United States Environmental Protection Agency (USEPA). *Exposure Factors Handbook 2011 Edition (Final Report).* U.S. Environmental Protection Agency, Washington, DC, EPA/600/R-09/052F, 2011.
- United States Department of Energy (USDOE). *The Risk Assessment Information System (RAIS).* U.S. Department of Energy's Oak Ridge Operations Office (ORO). 2011.
- Jarošová M, Milde D, Kuba M. Elemental analysis of coffee: A comparison of ICP-MS and AAS methods. *Czech J Food Sci.* 2014;32:354-359.
- Nigusie K, Chandravanshi BS, Wondimu T. Correlation among trace metals in Tilapia (*Oreochromis niloticus*), sediment and water samples of lakes Awassa and Ziway, Ethiopia. *Int J Biol Chem Sci.* 2011;4:1641-1656.
- Gebrekidan Asgedom A, Berhe Desta M, Weldegebriel Gebremedh Y. Bioaccumulation of heavy metals in fishes of hashenge lake, Tigray, Northern Highlands of Ethiopia. *Am J Chem.* 2013;2:326-334.
- Kassaye YA, Skipperud L, Einset J, Salbu B. Aquatic macrophytes in Ethiopian Rift Valley lakes; their trace elements concentration and use as pollution indicators. *Aquat Bot.* 2016;134:18-25.
- Salam MA, Paul SC, Zain RAMM, et al. Trace metals contamination potential and health risk assessment of commonly consumed fish of Perak River, Malaysia. *PLoS One.* 2020;15:e0241320.
- Dallinger R. Strategies of metal detoxification in terrestrial invertebrates. In: Dallinger R, Rainbow PS, eds. *Ecotoxicology of Metals in Invertebrates.* Lewis Publisher; 1993, pp. 291-313.
- Arnot JA, Gobas FA. A review of bioconcentration factor (BCF) and bioaccumulation factor (BAF) assessments for organic chemicals in aquatic organisms. *Environ Rev.* 2006;14:257-297.
- Ataro A, Wondimu A, Chandravanshi BS. Trace metals in selected fish species from lakes Awassa and Ziway, Ethiopia. *Sinet Ethiop J Sci.* 2005;26:103-114.
- Lemly AD. Evaluation of the hazard quotient method for risk assessment of selenium. *Ecotoxicol Environ Saf.* 1996;35:156-162.
- Onsanit S, Ke C, Wang X, Wang KJ, Wang WX. Trace elements in two marine fish cultured in fish cages in Fujian province, China. *Environ Pollut.* 2010;158:1334-1342.
- Teklay A, Amare M. Water quality characteristics and pollution levels of heavy metals in Lake Haiq, Ethiopia. *Ethiop J Sci Technol.* 2015;8:15.

49. Haile E, Tadesse S, Babu NS, Endale M. Analysis of selected metals in edible fish and bottom sediment from Lake Hawassa, Ethiopia. *Elixir J Appl Chem.* 2015;82:32610-32616.
50. Kebede A, Wondimu T. Distribution of trace elements in muscle and organs of Tilapia, *Oreochromis niloticus*, from Lakes Awassa and Ziway, Ethiopia. *Bull Chem Soc Ethiop.* 2004;18:119-130.
51. Tadiso TM, Borgström R, Rosseland BO. Mercury concentrations are low in commercial fish species of lake ziway, Ethiopia, but stable isotope data indicated biomagnification. *Ecotoxicol Environ Saf.* 2011;74:953-959.
52. Reda AH, Ayu AA. Accumulation and distribution of some selected heavy metals in both water and some vital tissues of two fish species (*Oreochromis niloticus* and *Clarias gariepinus*) from Lake Chamo Ethiopia. *Int J Fish Aquat Stud.* 2016;4:6-12.

Appendix

Table A1. The average concentration of metals and metalloids ($\mu\text{g/L}$) in water of Ethiopian surface waters from 2005 to 2022.

STUDY AREA	CONCENTRATIONS OF METALS AND METALLOIDS ($\mu\text{G/L}$)										REFERENCES
	CU	CD	PB	NI	ZN	CR	CO	HG	AS	SE	
Lake Hawassa	4.03	0.30	0.84	0.66	50.8	3.05	0.96	0.09	1.68	2.66	Melake et al ¹⁷
Lake Hawassa	3	0.01	0.2	0.7	3	1	0.1	-	2	0.7	Kassaye et al ⁴¹
Lake Hawassa	35	1.2	140	55	245	70	50	-	-	-	Nigussie et al ³⁹
Lake Hawassa	-	1.55	1.3	-	-	1.5	-	0.1	1.6	0.05	Dsikowitzky et al ²²
Lake Hawassa	-	5	10	-	5000	60	-	1	-	-	Amare et al ¹⁸
Lake Hashenge	2	9	3	2	938	3	4	-	-	-	Gebrekidan Asgedom et al ⁴⁰
Lake Ziway	5	0.02	2	8	25	9	1.3	-	2.5	0.8	Kassaye et al ⁴¹
Koka Reservoir	16	0.04	5	22	48	28	5	-	3	0.6	
Koka Reservoir	-	0.1	0.6	-	-	3	-	0.1	1.8	0.1	Dsikowitzky et al ²²
Lake Ziway	35	5	110	40	235	60	57	-	-	-	Nigussie et al ³⁹
Lake Haiq	1100	0.1	84	-	75	-	-	-	-	-	Teklay and Amare ⁴⁸
Lake Chamo	740	910	210	840	40	-	740	-	-	-	{Formatting Citation}
Tendaho Reservoir	530	0.1	260	950	251	150	123	-	-	-	Asefa and Beranu ²¹
Standards for drinking water (WHO) and environmental quality (EEPA and OECD)	2000	3	10	70	3000	50	-	6	10	10	WHO ²⁸
	20	5	50	20	1000	-	-	-	-	-	Ethiopian Environmental Protection Authority (EEPA) ²⁵
	20.0	-	2.50	8.0	70.0	50.0	-	-	50	-	Organisation for Economic Co-Operation and Development OECD/EAP Task Force ²⁶

Table A2. The average concentration of metals and metalloids (mg/kg dw) in sediment of Ethiopian surface waters from 2005 to 2022.

STUDY AREA	CONCENTRATION OF METALS AND METALLOIDS (MG/KG DW)										REFERENCE
	CU	CD	PB	NI	ZN	CR	CO	AS	SE	HG	
Lake Hawassa, Ethiopia	71.9	0.7	59.9	230	664	397	68	21	7.3	0.3	Melake et al ¹⁷
Lake Hawassa, Ethiopia	5	0.2	11	11	1.5	13	6	4	0.1	-	Kassaye et al ⁴¹
Lake Ziway, Ethiopia	13	0.3	14	15	166	21	5.5	2.8	0.6	-	
Koka Reservoir, Ethiopia	37	0.1	17	67	161	95	18	4.8	0.3	-	
Lake Hawassa, Ethiopia	34.5	8.5	19	17.5	184	9.5	28.5	-	-	-	Haile et al ⁴⁹

(Continued)

Table A2. (Continued)

STUDY AREA	CONCENTRATION OF METALS AND METALLOIDS (MG/KG DW)										REFERENCE
	CU	CD	PB	NI	ZN	CR	CO	AS	SE	HG	
Lake Hawassa, Ethiopia	32.5	6	14.5	14	119.5	4-9	25.5	-	-	-	Nigussie et al ³⁹
Lake Ziway, Ethiopia	36.5	20	15.5	19.5	142.5	6.5	20	-	-	-	
Lake Hashenge, Ethiopia	56	208	3	39424	1129	87	34	-	-	-	Gebrekitan Asgedom et al ⁴⁰
Lake Hawassa, Ethiopia	-	0.1	1.1	-	3.5	0.55	-	-	-	0.05	Amare et al ¹⁸
Tendaho Reservoir, Ethiopia	10	1	6	5	22	2.5	3	-	-	-	Asefa and Beranu ²¹
TEC values	31.6	0.99	35.8	22.7	121	43.4	-	9.8	-	0.18	MacDonald et al ²⁷
PEC values	150	5	130	49	460	110	-	33	-	1.1	

Table A3. The average concentration of metals and metalloids (mg/kg dw) in 3 edible fish species (*O. niloticus*, *C. gariepinus*, and *B. intermedius*) muscle of Ethiopian surface waters from 2005 to 2022.

LOCATION		METALS AND METALLOIDS CONCENTRATION (MG/KG DW)										REFERENCES
		CD	PB	CR	CO	NI	CU	ZN	AS	SE	HG	
Lake Hawassa, Ethiopia	<i>O. niloticus</i>	0.01	0.03	1.90	0.06	0.31	1.18	29.7	0.37	1.91	0.08	Melake et al ¹⁷
	<i>C. gariepinus</i>	0.02	0.03	3.22	0.34	0.51	1.47	30.5	0.22	1.29	0.29	
	<i>B. intermedius</i>	0.01	0.03	1.83	0.03	0.22	1.16	31.0	0.48	1.51	0.28	
Lake Hawassa, Ethiopia	<i>O. niloticus</i>	0.5	0.15	0.4	1.5	0.01	0.17	8	1	10.5	0.7	Ataro et al ⁴⁵ ; Dsikowitzky et al ²² ; Haile et al ⁴⁹ ; Kebede and Wondimu ⁵⁰
	<i>C. gariepinus</i>	0.2	0.45	2.05	0.16	0.065	0.05	-	-	-	-	
	<i>B. intermedius</i>	0.07	3.05	0.65	0.31	0.007	0.1-0.2	-	-	-	-	
Koka Reservoir, Ethiopia	<i>O. niloticus</i>	0.005	0.7	0.15	0.25	0.0008	0.65	-	-	-	-	Dsikowitzky et al ²²
Lake Hashenge, Ethiopia	<i>O. niloticus</i>	0.6	1.24	0.4	1.61	0.41	3.4	25	-	-	-	Gebrekitan Asgedom et al ⁴⁰
Lake Ziway, Ethiopia	<i>O. niloticus</i>	0.7	0.6	-	1.85	-	-	28	1.0	31.0	0.7	Ataro et al ⁴⁵ ; Kebede and Wondimu ⁵⁰ ; Tadiso et al ⁵¹
Lake Ziway, Ethiopia	<i>C. gariepinus</i>	0.2	0.3	-	1.7	-	-	-	-	-	-	Ataro et al ⁴⁵ ; Tadiso et al ⁵¹
Koka Reservoir	<i>B. intermedius</i>	0.01	1.1	0.55	0.6	0.0008	0.56	-	-	-	-	Dsikowitzky et al ²²
Lake Chamo, Ethiopia	<i>O. niloticus</i>	2.5	0.3	-	1.7	1.83	10.5	1.7	-	-	-	Reda and Ayu ⁵²
	<i>C. gariepinus</i>	2.5	0.5	-	2.2	1.6	5.4	0.3	-	-	-	

Table A4. Estimated Daily Intake (EDI in mg/Kg/day) levels, the average daily intake (ADI in mg/Kg/day), Hazard Quotient (HQ), and Maximum Edible Amount (MEA in mg/Kg/day) of metals and metalloids when consuming the 3 commercially important fish species muscle (*O. niloticus*, *C. gariepinus*, and *B. intermedius*) from 2005 to 2022.

VARIABLES	EDI AND HQ FOR MEAN CONCENTRATION OF METALS AND METALLOIDS IN FISH MUSCLE									
	CD	PB	CR	CO	NI	CU	ZN	AS	SE	HG
RfD	0.00001	0.0040	0.0009	0.0100	0.0200	0.0100	0.3000	0.00003	0.1700	0.0002
<i>O. niloticus</i>	0.7192	0.5033	0.7125	1.1617	0.5122	3.1800	18.4800	0.7900	14.4700	0.4933
EDI	0.0003	0.0002	0.0003	0.0005	0.0002	0.0014	0.0083	0.0004	0.0065	0.0002
ADI	0.0000003	0.0000002	0.0000003	0.0000005	0.0000002	0.000001	0.000008	0.0000004	0.000007	0.0000002
HQ	0.03	0.0001	0.0004	0.0001	0.0001	0.0001	0.0003	0.01	0.00004	0.001
<i>C. gariepinus</i>	0.7300	0.3200	2.6350	1.1000	0.7250	2.3067	15.4000	0.2200	1.2900	0.2900
EDI	0.0003	0.0001	0.0012	0.0005	0.0003	0.0010	0.0069	0.0001	0.0006	0.0001
ADI	0.0000003	0.0000001	0.000001	0.0000005	0.0000003	0.000001	0.000007	0.0000001	0.0000006	0.0000001
HQ	0.03	0.0004	0.001	0.0005	0.0002	0.0001	0.0002	0.003	0.000003	0.0006
<i>B. intermedius</i>	0.0300	1.3933	1.0100	0.3133	0.0759	0.8600	31.0000	0.4800	1.5100	0.2800
EDI	0.00001	0.0006	0.0005	0.0001	0.0000	0.0004	0.0140	0.0002	0.0007	0.0001
ADI	0.00000001	0.0000006	0.0000005	0.0000001	0.00000003	0.0000004	0.00001	0.0000002	0.0000007	0.0000001
HQ	0.001	0.0002	0.0005	0.00001	0.000002	0.00004	0.00005	0.007	0.000004	0.0005
EDI and MEA for maximum concentration of metals and metalloids in fish muscle										
<i>O. niloticus</i>	2.5000	1.2400	1.9000	1.8500	1.8300	10.5000	29.7000	1.0000	31.0000	0.7000
EDI	0.0011	0.0006	0.0009	0.0008	0.0008	0.0047	0.0134	0.0005	0.0140	0.0003
MEA	0.0002	0.0960	0.0216	0.2400	0.4800	0.2400	7.2000	0.0007	4.0800	0.0055
<i>C. gariepinus</i>	2.5000	0.5000	3.2200	2.2000	1.6000	5.4000	30.5000	0.2200	1.2900	0.2900
EDI	0.0011	0.0002	0.0014	0.0010	0.0007	0.0024	0.0137	0.0001	0.0006	0.0001
MEA	0.0002	0.0960	0.0216	0.2400	0.4800	0.2400	7.2000	0.0007	4.0800	0.0055
<i>B. intermedius</i>	0.0700	3.0500	1.8300	0.6000	0.2200	1.1600	31.0000	0.4800	1.5100	0.2800
EDI	0.00003	0.0014	0.0008	0.0003	0.0001	0.0005	0.0140	0.0002	0.0007	0.0001
MEA	0.0086	3.4286	0.7714	8.5714	17.1429	8.5714	257.1429	0.0257	145.7143	0.1971

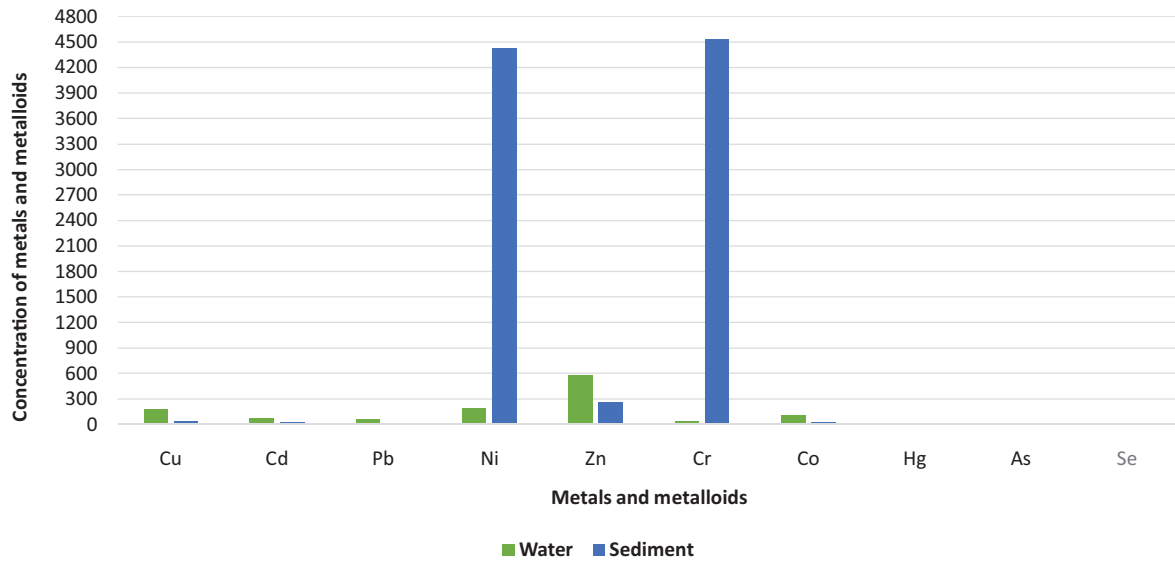


Figure A1. The average concentration of metals and metalloids in water (µg/L) and sediment (mg/kg dw) in Ethiopian surface waters.

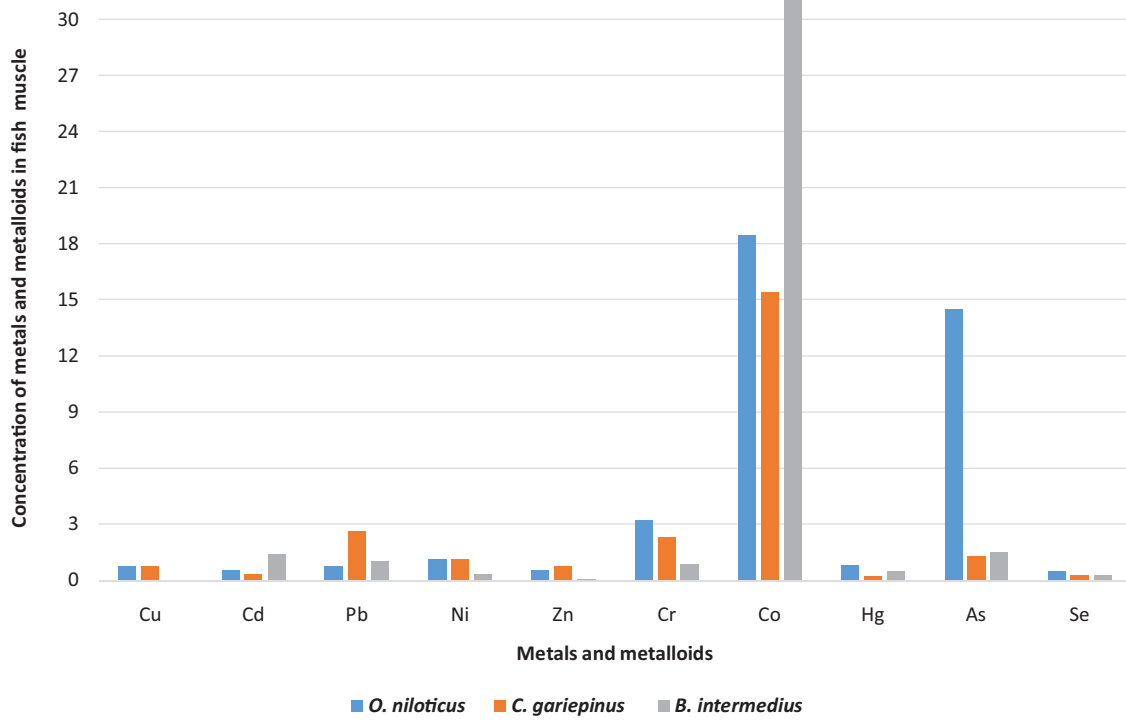


Figure A2. The average concentration of metals and metalloids in 3 edible fish species muscle (mg/kg dw) in Ethiopian surface waters.