



Bioaccumulation of Heavy Metals in Freshwater and Marine Fish Species of Pakistan

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ABSTRACT

Fish have a higher likelihood of surviving under hypo toxic conditions when exposed to heavy metals, but they can accumulate in humans' brain, liver, kidney, lungs, and muscles after consumption, posing a significant health risk. The fish meat quality is the biggest concern in the food chain of the present time. Both water and fish species are contaminated with heavy metals due to anthropogenic activities i.e., domestic, sewage, industrial and agricultural runoff. Heavy metals concentration in the seven fish species was analyzed from different riverine and marine sites of Pakistan. Freshwater fish were collected from Rawal Dam (Islamabad), Mini Dam at Fateh Jang (Attock) and Sulemanki Headworks at River Satluj, Head Sulemanki at River Satluj, River Jhelum, River Chenab and marine fish species were collected from Karachi coastal region. The concentrations of cadmium, chromium, nickel, lead and iron were analyzed in the fish muscles by Atomic Absorption Spectrophotometer. Among metals, the highest concentrations of Pb ($3.391 \pm 0.002 \mu\text{g/g}$) followed by Cr ($0.311 \pm 0.001 \mu\text{g/g}$) were estimated in the freshwater fish species *L. rohita* collected from Rawal Dam and *W. attu* from River Chenab, respectively. The maximum concentrations of Cr ($4.589 \pm 1.008 \mu\text{g/g}$) and Fe ($41.176 \pm 8.123 \mu\text{g/g}$) was observed in marine fish species *S. cavalla* and *Pampus* sp., while Cd showed the intermediate concentration throughout in all fish species. Results showed that the concentration of Pb and Fe exceeded the limit of WHO and FAO which is the potential threat specifically the marine species due to their high consumption rate.

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Authors' Contribution

HJ supervised the study. UI and AF detected metal concentration in the lab. AZA and JA collected fish samples and did statistical analysis. UI and KA wrote the paper.

Key words

Ecotoxicology, Bioaccumulation, Metal contamination, Fish muscles, Anthropogenic activities

INTRODUCTION

Fish play a substantial role within aquatic ecosystems and are recognized as an exceptional protein source for human dietary needs. Globally, fish contribute approximately a quarter of the animal-derived protein that people consume. With the global population on the rise and a growing demand for sustenance, the necessity for fish and related products is escalating (Bahnasawy *et al.*, 2009). As emphasized by the American Heart Association, consuming fish at least two times per week is a vital element in averting coronary heart diseases, ensuring an adequate intake of omega-3 fatty acids (Martin and Genner, 2009).

The accumulation of heavy metals in fish hinges on both the absorption rate of these metals by fish and the metabolic activity of the species. However, in aquatic

ecosystems, fish tend to occupy higher positions within the food chain, consequently resulting in elevated heavy metal concentrations within their bodies. The degree of this accumulation relies on the balance between the rate of intake and excretion within the fish's physiological system (Karadede *et al.*, 2004). Multiple research endeavors have unveiled a range of biotic and abiotic factors contributing to the accumulation of inorganic contaminants in fish tissues and organs. These factors encompass fish species diversity, the trophic level occupied by fish in the ecosystem, feeding patterns, fish age and size, species-specific variances in susceptibility to different metals, the concentration of heavy metals within water bodies, sediment concentrations in the environment, the composition of fish diets, water quality influenced by physical and chemical aspects, the intrinsic nature and chemical properties of heavy metals, and the availability of these metals for uptake (Griboff *et al.*, 2018; Moiseenko and Gashkina, 2020). Given their inherent toxicity, a heightened focus has been placed on the evaluation of heavy metal content in various food sources, particularly marine fish consumed as part of meals. Poultry chicken, owing to elevated arsenic levels in their diet, can harbor heavy metals within their meat (Nachman *et al.*, 2012). Inversely, heavy metals accumulation in fish may absorb into their systems through the aquatic environment, including water, sediments, and feeding intake (Pal and

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Maiti, 2018; Kumar *et al.*, 2020). Considering current resources, a consistent effort is required to understand how pollutants or metal contaminants invade through food chains in the complex consumption web. Abiotic factors like soil and water are being studied less frequently than live organisms due to the increased awareness of the importance of life (Tashla *et al.*, 2018; Fatima *et al.*, 2020). Furthermore, according to Abdel-Mohsien and Mahmoud (2015), cadmium (Cd) adversely affects kidneys and exerts a lasting toxic influence on reproductive functions, as well as renal and hepatic systems.

Due to their elevated toxicity, enduring presence, and propensity to accumulate, heavy metals rank among the most perilous pollutants within aquatic environments, capturing worldwide attention (Ali *et al.*, 2016, 2018; Karunanidhi *et al.*, 2017; Lao *et al.*, 2019). Their capacity to inflict harm extends to aquatic ecosystems, affecting fish, sediments, and water (Agusa *et al.*, 2007; Hajebe *et al.*, 2009; Bhuyan and Bakar, 2017). These heavy metals accumulate within marine ecosystems, imparting detrimental impacts on both the environment and human well-being (Batvari *et al.*, 2015; Islam *et al.*, 2018). As indicated by several investigations (Terra *et al.*, 2008; Yi *et al.*, 2011; Islam *et al.*, 2016; 2017), the contamination of aquatic settings with these heavy metals raises potential concerns for human health, given that these contaminants enter the human food chain through the consumption of fish and other aquatic products. A prominent global challenge concerning the health risks associated with fish consumption pertains to the contamination of seafood. The nutritional and therapeutic benefits of fish consumption have driven a global surge in its intake in recent years. Fish are notably rich in protein content (accounting for 60% of daily protein requirements), essential minerals, and vitamins (Medeiros *et al.*, 2012; de Anda *et al.*, 2019; Hossein *et al.*, 2021). However, it has been revealed that the consumption of fish tainted with harmful metals has been linked to the emergence of various severe disorders. For instance, chromium (Cr) contamination in fish has been associated with kidney lesions, anuria, nephritis, and extensive lesions (Proshad *et al.*, 2018; Rahman *et al.*, 2012). Cadmium toxicity has been linked to compromised fertility, kidney dysfunction, tumors, hypertension, and hepatic malfunction (Al-Busaidi *et al.*, 2011; Rahman *et al.*, 2012), while lead poisoning is known to cause liver damage and renal failure (Lee and Hieu, 2011). It has been noted that fish gills and skin can be contributing factors to the accumulation of heavy metals in fish (Al-Busaidi *et al.*, 2011). Fish have become significantly contaminated by toxic metals within aquatic environments, primarily through consuming water and organisms like zooplankton and phytoplankton as direct sources of food. As inhabitants

of various trophic levels, spanning all age groups and sizes, and serving as a crucial food source for human populations (Burger, 2002; Kuklina *et al.*, 2014; Karunanidhi *et al.*, 2017; Svobodová *et al.*, 2017), fish are commonly employed as bio-indicators of hazardous metal pollution. The enduring, toxic, and accumulative properties of these metals can give rise to ecological challenges and detrimentally impact aquatic ecosystems (Rahman *et al.*, 2010; Islam *et al.*, 2017). Since fish inhabit and feed within aquatic habitats, they cannot evade the adverse effects of pollutants, rendering them particularly sensitive and susceptible to contamination (Saha and Zaman, 2013). The potential danger of heavy metal ingestion hinges on factors like the absorbed dosage, the mode of exposure, and the duration of exposure, whether it's acute or chronic, as explored in the study by Islam *et al.* (2016). Fish, due to their heightened vulnerability to diverse toxic substances, offer valuable insights as test subjects, aiding in the evaluation of ecosystem health.

Untreated industrial and domestic effluent negatively impacts ecosystems and people's health, affecting fishing, boating, and tourism. To prevent marine extinction and biodiversity loss, frequent monitoring is crucial. Preventing marine pollution along the Karachi Coast is essential for safety, health, and socioeconomic viability (Jilani, 2015). In River Satluj, anthropogenic activities such as dumping of domestic effluents, untreated industrial and sewage water have significantly contributed to the decline of aquatic fish species (Sharma and Singh, 2015). In Rawal Lake, pollutants enter the reservoir from a variety of sources, including garbage from nearby human settlements, car washes, and poultry farms (Malik and Maurya, 2014). Low-slung water quality effect directly affects the aquatic community (Qadir *et al.*, 2008) and humans due to their consumption of aquatic organisms specifically fishes which have pathological changes in their tissue (Ahmed *et al.*, 2014).

The aim of this study was to investigate the accumulation of heavy metals from muscle tissues of relevant marine and freshwater fish species across various regions of Pakistan.

MATERIALS AND METHODS

Sampling sites and collection

Seven fish species were collected from six different sites *Labeo rohita* from Mini Dam Fateh Jang (Attock), River Satluj, and Rawal Dam (Islamabad), *Cyprinus carpio* from River Satluj, *Wallago attu* from River Chenab, *Hypophthalmichthys molitrix* and *Xenentodon cancila* from River Jhelum, and *Scomberomorus cavalla* and *Pampus* sp. from Karachi coastal area in the post monsoon

season from September to November 2023. These samples were packed in thermo-cool boxes with ice packs and transported to the laboratory for further analysis.

Concentration of heavy metal analysis

Dissection of the fish sample was done on the same day in the laboratory with the help of stainless steel and plastic-coated tweezers pretreated with the acetone and rinsed with D₃ water before taking samples from the fish. Fish muscles of 3g were taken in the Pyrex vessel which further pretreated with 8 ml of 65% HNO₃ and 1.5 ml of 30% H₂O₂ to digest the sample. Samples with chemical were kept in the water bath at 80°C for 24 h to get fully digested sample. After heating the samples were cooled down at room temperature and diluted with 7 ml of D₃ water and obtained filtrate was analyzed through atomic absorption spectrophotometer from the given method by Howell (1984).

Statistical analysis

The metal absorption in fish muscles was measured in µg/g (per wet weight). One way ANOVA was used to estimate the difference between metal concentrations by using SPSS version 2.0.

RESULTS AND DISCUSSION

Heavy metals are the major concern in the developed and developing countries because of their toxic nature, persistence and bioaccumulation which cannot be degraded especially in the aquatic environment

(Gerhardt and Fieldes, 1999; Adeyeye *et al.*, 2016). The concentration of these metals differs in different body parts of animals. Fish is widely consumed as food as a rich source of protein which is mostly captured from the riverine and marine waters which are polluted by heavy metals through different point sources. So, it is the most important topic to study heavy metals in the tissues of consumable fishes for formulating future strategies. With these objectives in mind present study was conducted to access the concentration of heavy metals like chromium, cadmium, nickel, lead and iron in seven main fish species which are commonly used to consume in Pakistan. A close assessment of the statistics suggested some significant trends which are discussed here.

The heavy metal concentration in muscles of fish species is given in Table I. All metal accumulation patterns were significantly different ($p < 0.001$) between different localities except for lead (Table I). There was not a consistent increase observed in metals across all the freshwater fish species except the fishes collected from marine waters (*Scomberomus cavalla* and *Pampus sp.*) for the concentration of chromium and iron, respectively (Table I).

The mean concentration of cadmium was showing the highest in the muscles of *Labeo rohita* collected from Fateh Jang (0.015 ± 0.001 µg/g) followed by *Cyprinus carpio* (0.014 ± 0.002 µg/g) and lowest in *Xenotodon cancila* (0.009 ± 0.001 µg/g). Chromium concentration was observed highest in marine water fishes

Table I. Mean concentrations of heavy metals (µg/g) in fish samples collected from different sites of Pakistan.

Species	Locality	Number of samples	Metal concentration $\pm$ SD (µg/g)				
			Cadmium (Cd)	Chromium (Cr)	Nickel (Ni)	Lead (Pb)	Iron (Fe)
<i>Labeo rohita</i>	Rawal Dam	4	0.011 ± 0.001	0.016 ± 0.003	0.017 ± 0.002	3.391 ± 0.002	-
	Fateh Jang	3	0.015 ± 0.001	0.005 ± 0.001	0.084 ± 0.003	0.029 ± 0.001	1.085 ± 0.007
	River Satluj	10	0.013 ± 0.002	0.007 ± 0.001	0.089 ± 0.003	0.056 ± 0.002	1.239 ± 0.143
<i>Cyprinus carpio</i>	River Satluj	10	0.014 ± 0.002	0.005 ± 0.001	0.026 ± 0.004	0.044 ± 0.005	1.822 ± 0.086
<i>Hypophthalmichthys molitrix</i>	River Jhelum	3	0.008 ± 0.001	0.007 ± 0.001	0.097 ± 0.001	0.042 ± 0.001	1.267 ± 0.002
<i>Xenotodon cancila</i>	River Jhelum	3	0.009 ± 0.001	0.008 ± 0.002	0.059 ± 0.004	0.017 ± 0.003	1.151 ± 0.008
<i>Wallago attu</i>	River Chenab	3	-	0.311 ± 0.001	0.133 ± 0.003	0.176 ± 0.003	2.786 ± 0.013
<i>Scomberomus cavalla</i>	Karachi coast	5	-	1.723 ± 0.260	0.409 ± 0.127	0.230 ± 0.071	41.176 ± 8.123
<i>Pampus sp.</i>	Karachi coast	5	-	4.589 ± 1.008	0.051 ± 0.006	0.185 ± 0.013	4.723 ± 1.339
One-way ANOVA							
df			11	20	20	20	20
F			15.667	767.522	219.095	0.912	139.439
P			<0.001	<0.001	<0.001	<0.05	<0.001

Pampus sp. ($4.589 \pm 1.008 \mu\text{g/g}$) and *Scomberomus cavalla* ($1.723 \pm 0.260 \mu\text{g/g}$), and lowest similar concentrations observed in the *L. rohita* collected from Fateh Jang and *C. carpio* ($0.005 \pm 0.001 \mu\text{g/g}$), respectively. The concentration of nickel was observed highest in the marine fishes *S. cavalla* ($0.409 \pm 0.127 \mu\text{g/g}$) and freshwater fish species *Wallago attu* ($0.133 \pm 0.003 \mu\text{g/g}$) while lowest concentration was observed in *L. rohita* collected from Rawal dam ($0.017 \pm 0.002 \mu\text{g/g}$). Similar pattern was observed for iron concentration which was highest in marine fishes *S. cavalla* ($41.176 \pm 8.123 \mu\text{g/g}$), *Pampus* sp. ($4.723 \pm 1.339 \mu\text{g/g}$) and in freshwater species *W. attu* ($2.786 \pm 0.013 \mu\text{g/g}$) while lowest in *L. rohita* collected from Fateh Jang ($1.085 \pm 0.007 \mu\text{g/g}$). Lead mean concentration was ranged from $0.017 \pm 0.003 \mu\text{g/g}$ in *X. cancila* to $3.391 \pm 0.002 \mu\text{g/g}$ in *L. rohita* collected from the Rawal Dam (Table I). The statistical estimations presented in Table I shows that there is a significant greater accumulation of lead in muscle tissues ($p < 0.05$).

Amongst the studied fish species, cadmium showed intermediate muscle concentrations in all, displaying a similar pattern for chromium. Conversely, *Labeo rohita* exhibited a higher chromium accumulation in Rawal Dam compared to other locations. Nickel distribution diverse, with intermediate levels in muscle of *L. rohita* showed slightly low concentration except *Scomberomus cavalla* which showed maximum concentration level. Chromium exhibits a high bonding for sediments due to its low water solubility and sturdy binding to particulate matter. These results in considerably elevated concentrations in sediments compared to the overlying water column. As a result, direct bioaccumulation of chromium by fish from the water phase is limited. Instead, chronic contact primarily occurs through the food chain via eating of impure benthic organisms and their associated detritus. This biomagnifications effect has been documented by Adeniyi *et al.* (2008) and Gupta *et al.* (2009) observed higher chromium levels in fish tissues when compared to water, often surpassed only by lead.

Metal uptake by fish also depends upon the zone of the water body occupied by fish. Kilgour (1991) has indicated that animals which have proximity with sediment show relatively high accumulation of metals while cadmium contamination exhibits negligible presence in fish tissues. This examination aligns with earlier studies by Has-Schön *et al.* (2008) and Öztürk *et al.* (2009) consistently identified cadmium as the metal with the lowest accumulation. Nickel deviated from this pattern, displaying a unique distribution. While its concentration remained lesser than lead and chromium in water and fish, it pointed high in sediments. This suggests low water retention, active sediment sequestration, and minimal uptake by benthic organisms

from both water and sediment. These findings concur with the notion that, although nickel can accumulate in aquatic life, it does not experience biomagnifications through the food chain. Furthermore, nickel mainly exhibits partial mobility, except under acidic conditions, as noted by Mahmood (2003).

Inter-site difference revealed a noticeable spatial variation in nickel (Ni) tissue concentrations in different fish species. Notably, at Head Sulemanki Headworks of River Satluj, Ni levels were constantly at upper point across all studied tissues, while at Rawal Dam exhibited the lowest mean values in *L. rohita*. Further, within Rawal Dam and Head Sulemanki, *L. rohita* depicted higher Pb concentrations compared to other species. This observation hinted potential species-specific factors influencing Pb bioaccumulation patterns, even within a seemingly less contaminated environment. Notably, the less Pb level in water at both sites implies limited direct uptake from this medium in *C. carpio*. This shows the food web may play a more significant role in Pb bioaccumulation for these fishes. Toxicological effects of industrial effluents deposited in River Chenab on *Wallago attu* in Muzaffargarh region, contrast with this one. The observations demonstrate that a larger concentration of tendency of bioaccumulation of metals in *W. attu* due to the fact that fish's physiology is vulnerable to a particular kind of metal (Yousafzai *et al.*, 2010). In this study, Fe was the maximum in the tissues of analyzed marine species (*Scomberomus cavalla* and *Pampus* sp.) at Karachi coast, followed by Cr, Ni and Pb. Similar data patterns were found by other researchers (Tepe *et al.*, 2008; Türkmen *et al.*, 2009). The calculated averages and standard deviations provided valuable insights into the dispersion and variability of heavy metals in *S. cavalla*.

CONCLUSION

The findings underscored the spatial and species-specific variations in heavy metal bioaccumulation, highlighting the need for continued monitoring and assessment of riverine and marine ecosystems. The concentration was largely detected in marine fish species than freshwater species. Overall, the metal concentration was estimated from high to low in the following order:

$$\text{Fe} > \text{Pd} > \text{Ni} > \text{Cr} > \text{Cd}$$

Additionally, the calculated averages and standard deviations offered crucial information for understanding the potential environmental impact and guiding future conservation efforts in the freshwater reservoirs and coastal regions of Pakistan.

DECLARATIONS

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Statement of conflict of interest

The authors have declared no conflict of interest.

REFERENCES

- Abdel-Mohsien, H.S. and Mahmoud, M.A., 2015. Accumulation of some heavy metals in *Oreochromis niloticus* from the Nile in Egypt: Potential hazards to fish and consumers. *J. environ. Prot.*, **6**: 1003. <https://doi.org/10.4236/jep.2015.69089>
- Adeniyi, A.A., Yusuf, K.A. and Okedeyi, O.O., 2008. Assessment of the exposure of two fish species to metals pollution in the Ogun River catchments, Ketu, Lagos, Nigeria. *Environ. Monit. Assess.*, **137**: 451-458. <https://doi.org/10.1007/s10661-007-9780-5>
- Adeyeye, S.A.O., Oyewole, O.B., Obadina, O., Adeniran, O.E., Oyedele, H.A., Olugbile, A. and Omemu, A.M., 2016. Effect of smoking methods on microbial safety, polycyclic aromatic hydrocarbon, and heavy metal concentrations of traditional smoked fish from Lagos State, Nigeria. *J. Culin. Sci. Technol.*, **14**: 91-106. <https://doi.org/10.1080/15428052.2015.1080644>
- Agusa, T., Kunito, T., Sudaryanto, A., Monirith, I., Kan-Atireklap, S., Iwata, H. and Tanabe, S., 2007. Exposure assessment for trace elements from consumption of marine fish in Southeast Asia. *Environ. Pollut.*, **145**: 766-777. <https://doi.org/10.1016/j.envpol.2006.04.034>
- Ahmed, Q., Khan, D. and Elahi, N., 2014. Concentrations of heavy metals (Fe, Mn, Zn, Cd, Pb, and Cu) in muscles, liver and gills of adult *Sardinella albella* (Valenciennes, 1847) from Gwadar water of Balochistan, Pakistan. *FUUAST J. Biol.*, **4**: 195-204.
- Al-Busaidi, M., Yesudhasan, P., Al-Mughairi, S., Al-Rahbi, W.A.K., Al-Harthy, K.S., Al-Mazrooei, N.A., Al-Habsi, S.H., 2011. Toxic metals in commercial marine fish in Oman with reference to national and international standards. *Chemosphere*, **85**: 67-73. <https://doi.org/10.1016/j.chemosphere.2011.05.057>
- Ali, M.M., Ali, M.L., Islam, M.S. and Rahman, M.Z., 2018. Assessment of toxic metals in water and sediment of Pasur River in Bangladesh. *Water Sci. Technol.*, **77**: 1418-1430. <https://doi.org/10.2166/wst.2018.016>
- Ali, M.M., Ali, M.L., Islam, M.S. and Rahman, M.Z., 2016. Preliminary assessment of heavy metals in water and sediment of Karnaphuli River, Bangladesh. *Environ. Nanotechnol. Monit. Manag.*, **5**: 27-35. <https://doi.org/10.1016/j.enmm.2016.01.002>
- Bahnasawy, M., Khidr, A.A. and Dheina, N., 2009. Seasonal variations of heavy metals concentrations in mullet, *Mugil cephalus* and *Liza ramada* (Mugilidae) from Lake Manzala, Egypt. *Egypt. J. aquat. Biol. Fish.*, **13**: 81-100. <https://doi.org/10.21608/ejabf.2009.2034>
- Batvari, B., Prabhu, D., Kamalakannan, S. and Krishnamurthy, R.R., 2015. Heavy metals accumulation in two fish species (*Labeo rohita* and *Cirrhina mrigala*) from Pulicat Lake, North of Chennai, Southeast Coast of India. *J. Chem. Pharm. Res.*, **7**: 951-956.
- Bhuyan, M.S. and Bakar, M.A., 2017. Seasonal variation of heavy metals in water and sediments in the Halda River, Chittagong, Bangladesh. *Environ. Sci. Pollut. Res.*, **24**: 27587-27600. <https://doi.org/10.1007/s11356-017-0204-y>
- Burger, J., 2002. Food chain differences affect heavy metals in bird eggs in Barnegat Bay, New Jersey. *Environ. Res.*, **90**: 33-39. <https://doi.org/10.1006/enrs.2002.4381>
- de Anda, J., Gradilla-Hernández, M.S., Díaz-Torres, O., de Jesús Díaz-Torres, J. and de la Torre-Castro, L.M., 2019. Assessment of heavy metals in the surface sediments and sediment-water interface of Lake Cajititlán, Mexico. *Environ. Monit. Assess.*, **191**: 1-13. <https://doi.org/10.1007/s10661-019-7524-y>
- Fatima, S., Muzammal, M., Rehman, A., Rustam, S.A., Shehzadi, Z., Mehmood, A. and Waqar, M., 2020. Water pollution on heavy metals and its effects on fishes. *Int. J. Fish. aquat. Stud.*, **8**: 6-14.
- Gerhardt, K.E. and Fieldes, M.A., 1999. Charge and molecular weight differences for fourteen guaiacol peroxidase isozymes in flax indicate that most are encoded by different structural genes. *Electrophoresis*, **20**: 1939-1945. <https://doi.org/10.1002/>

- (SICI)1522-2683(19990701)20:10<1939::AID-ELPS1939>3.3.CO;2-9
- Griboff, J., Horacek, M., Wunderlin, D.A. and Monferran, M.V., 2018. Bioaccumulation and trophic transfer of metals, As and Se through a freshwater food web affected by anthropic pollution in Córdoba, Argentina. *Ecotoxicol. Environ. Saf.*, **148**: 275-284. <https://doi.org/10.1016/j.ecoenv.2017.10.028>
- Gupta, A., Rai, D.K., Pandey, R.S. and Sharma, B., 2009. Analysis of some heavy metals in the riverine water, sediments and fish from river Ganges at Allahabad. *Environ. Monit. Assess.*, **157**: 449-458. <https://doi.org/10.1007/s10661-008-0547-4>
- Hajeb, P., Christianus, A., Ismail, A., Zadeh, S.S. and Saad, C.R., 2009. Heavy metal concentration in horseshoe crab (*Carcinoscorpius rotundicauda* and *Tachypileus gigas*) eggs from Malaysian coastline. In: *Biology and conservation of horseshoe crabs*. pp. 455-463. https://doi.org/10.1007/978-0-387-89959-6_28
- Has-Schön, E., Bogut, I., Kralik, G., Bogut, S., Horvatić, J. and Čačić, I., 2008. Heavy metal concentration in fish tissues inhabiting waters of "Buško Blato" reservoir (Bosnia and Herzegovina). *Environ. Monit. Assess.*, **144**: 15-22. <https://doi.org/10.1007/s10661-007-9627-0>
- Hossen, M.A., Chowdhury, A.I.H., Mullick, M.R.A. and Hoque, A., 2021. Heavy metal pollution status and health risk assessment vicinity to Barapukuria coal mine area of Bangladesh. *Environ. Nanotechnol. Monit. Manage.*, **16**: 100469. <https://doi.org/10.1016/j.enmm.2021.100469>
- Howell, R., 1984. Manual of methods in aquatic environment research. Part 9. Analyses of metals and organochlorines in fish. FAO/SIDA, 1983. FAO Fish. Tech. Pap., (212): 33 pp. (Obtainable from FAO, Via dello Terme di caracalla, Rome, Italy). *Mar. Pollut. Bull.*, **15**: 235-235. [https://doi.org/10.1016/0025-326X\(84\)90298-4](https://doi.org/10.1016/0025-326X(84)90298-4)
- Islam, M.S., Ahmed, M.K. and Habibullah-Al-Mamun, M., 2017. Heavy metals in sediment and their accumulation in commonly consumed fish species in Bangladesh. *Arch. Environ. Occup. Hlth.*, **72**: 26-38. <https://doi.org/10.1080/19338244.2016.1152946>
- Islam, M.S., Ahmed, M.K., Habibullah-Al-Mamun, M., Raknuzzaman, M., Ali, M.M. and Eaton, D.W., 2016. Health risk assessment due to heavy metal exposure from commonly consumed fish and vegetables. *Environ. Syst. Decis.*, **36**: 253-265. <https://doi.org/10.1007/s10669-016-9592-7>
- Islam, M.S., Hossain, M.B., Matin, A. and Sarker, M.S.I., 2018. Assessment of heavy metal pollution, distribution and source apportionment in the sediment from Feni River estuary, Bangladesh. *Chemosphere*, **202**: 25-32. <https://doi.org/10.1016/j.chemosphere.2018.03.077>
- Jilani, S., 2015. Assessment of heavy metal pollution in Lyari river and adjoining coastal areas of Karachi. *J. Biodivers. Env. Sci.*, **6**: 208-214.
- Karadede, H., Oymak, S.A. and Ünlü, E., 2004. Heavy metals in mullet, *Liza abu*, and catfish, *Silurus triostegus*, from the Atatürk Dam Lake (Euphrates), Turkey. *Environ. Int.*, **30**: 183-188. [https://doi.org/10.1016/S0160-4120\(03\)00169-7](https://doi.org/10.1016/S0160-4120(03)00169-7)
- Karunanidhi, K., Rajendran, R., Pandurangan, D. and Arumugam, G., 2017. First report on distribution of heavy metals and proximate analysis in marine edible puffer fishes collected from Gulf of Mannar Marine Biosphere Reserve, South India. *Toxic. Rep.*, **4**: 319-327. <https://doi.org/10.1016/j.toxrep.2017.06.004>
- Kilgour, B.W., 1991. Cadmium uptake from cadmium-spiked sediments by four freshwater invertebrates. *Bull. environ. Contam. Toxicol. (US)*, **47**. <https://doi.org/10.1007/BF01689455>
- Kuklina, I., Kouba, A., Buřič, M., Horká, I., Ďuriš, Z. and Kozák, P., 2014. Accumulation of heavy metals in crayfish and fish from selected Czech reservoirs. *BioMed. Res. Int.*, <https://doi.org/10.1155/2014/306103>
- Kumar, V., Sharma, A., Pandita, S., Bhardwaj, R., Thukral, A.K. and Cerda, A., 2020. A review of ecological risk assessment and associated health risks with heavy metals in sediment from India. *Int. J. Sediment Res.*, **35**: 516-526. <https://doi.org/10.1016/j.ijsrc.2020.03.012>
- Lao, Q., Su, Q., Liu, G., Shen, Y., Chen, F., Lei, X. and Gao, J., 2019. Spatial distribution of and historical changes in heavy metals in the surface seawater and sediments of the Beibu Gulf, China. *Mar. Pollut. Bull.*, **146**: 427-434. <https://doi.org/10.1016/j.marpolbul.2019.06.080>
- Lee, B.K. and Hieu, N.T., 2011. Seasonal variation and sources of heavy metals in atmospheric aerosols in a residential area of Ulsan, Korea. *Aerosol Air Qual. Res.*, **11**: 679-688. <https://doi.org/10.4209/aaqr.2010.10.0089>
- Mahmood, G., 2003. Lead and nickel concentrations in fish and water of River Ravi (Pakistan). *Pak. J. Biol. Sci.*, **6**. <https://doi.org/10.3923/pjbs.2003.1027.1029>
- Malik, D.S. and Maurya, P.K., 2014. Heavy metal concentration in water, sediment, and tissues of fish

- species (*Heteropneustis fossilis* and *Puntius ticto*) from Kali River, India. *Toxicol. environ. Chem.*, **96**: 1195-1206. <https://doi.org/10.1080/02772248.2015.1015296>
- Martin, C.H. and Genner, M.J., 2009. High niche overlap between two successfully coexisting pairs of Lake Malawi cichlid fishes. *Can. J. Fish. aquat. Sci.*, **66**: 579-588. <https://doi.org/10.1139/F09-023>
- Medeiros, R.J., dos Santos, L.M.G., Freire, A.S., Santelli, R.E., Braga, A.M.C., Krauss, T.M. and Jacob, S.D.C., 2012. Determination of inorganic trace elements in edible marine fish from Rio de Janeiro State, Brazil. *Fd. Contr.*, **23**: 535-541. <https://doi.org/10.1016/j.foodcont.2011.08.027>
- Moiseenko, T.I. and Gashkina, N.A., 2020. Distribution and bioaccumulation of heavy metals (Hg, Cd and Pb) in fish: Influence of the aquatic environment and climate. *Environ. Res. Lett.*, **15**: 115013. <https://doi.org/10.1088/1748-9326/abbf7c>
- Nachman, K.E., Raber, G., Francesconi, K.A., Navas-Acien, A. and Love, D.C., 2012. Arsenic species in poultry feather meal. *Sci. Total Environ.*, **417**: 183-188. <https://doi.org/10.1016/j.scitotenv.2011.12.022>
- Öztürk, M., Özözen, G., Minareci, O. and Minareci, E., 2009. Determination of heavy metals in fish, water and sediments of Avsar Dam Lake in Turkey. *J. Environ. Hlth. Sci. Eng.*, **6**: 73-80.
- Pal, D. and Maiti, S.K., 2018. Heavy metal speciation, leaching and toxicity status of a tropical rain-fed river Damodar, India. *Environ. Geochem. Hlth.*, **40**: 2303-2324. <https://doi.org/10.1007/s10653-018-0097-9>
- Proshad, R., Kormoker, T., Mursheed, N., Islam, M.M., Bhuyan, M.I., Islam, M.S. and Mithu, T.N., 2018. Heavy metal toxicity in agricultural soil due to rapid industrialization in Bangladesh: A review. *Int. J. Adv. Geosci.*, **6**: 83-88. <https://doi.org/10.14419/ijag.v6i1.9174>
- Qadir, A., Malik, R.N. and Husain, S.Z., 2008. Spatio-temporal variations in water quality of Nullah Aik-tributary of the river Chenab, Pakistan. *Environ. Monit. Assess.*, **140**: 43-59. <https://doi.org/10.1007/s10661-007-9846-4>
- Rahman, M., Molla, A. and Arafat, S., 2010. Status of pollution around Dhaka export processing zone and its impact on Bangshi River water. *Bangladesh J. Nat. Sci. Sustain. Tech.*, **4**: 91-110.
- Rahman, M.S., Molla, A.H., Saha, N. and Rahman, A., 2012. Study on heavy metals levels and its risk assessment in some edible fishes from Bangshi River, Savar, Dhaka, Bangladesh. *Fd. Chem.*, **134**: 1847-1854. <https://doi.org/10.1016/j.foodchem.2012.03.099>
- Saha, N. and Zaman, M.R., 2013. Evaluation of possible health risks of heavy metals by consumption of foodstuffs available in the central market of Rajshahi City, Bangladesh. *Environ. Monit. Assess.*, **185**: 3867-3878. <https://doi.org/10.1007/s10661-012-2835-2>
- Sharma, V. and Singh, P., 2015. Heavy metals pollution and it's effect on environment and human health. *Int. J. Rec. Sci. Res.*, **6**: 7752-7755.
- Svobodová, J., Douda, K., Fischer, D., Lapšanská, N. and Vlach, P., 2017. Toxic and heavy metals as a cause of crayfish mass mortality from acidified headwater streams. *Ecotoxicology*, **26**: 261-270. <https://doi.org/10.1007/s10646-017-1760-0>
- Tashla, T., Žuža, M., Kenjveš, T., Prodanović, R., Soleša, D., Bursić, V. and Puvača, N., 2018. Fish as an important bio-indicator of environmental pollution with persistent organic pollutants and heavy metals. *J. Agron.*, **28**: 52-56.
- Tepe, Y., Türkmen, M. and Türkmen, A., 2008. Assessment of heavy metals in two commercial fish species of four Turkish seas. *Environ. Monit. Assess.*, **146**: 277-284. <https://doi.org/10.1007/s10661-007-0079-3>
- Terra, B.F., Araújo, F.G., Calza, C.F., Lopes, R.T. and Teixeira, T.P., 2008. Heavy metal in tissues of three fish species from different trophic levels in a tropical Brazilian river. *Water Air Soil Pollut.*, **187**: 275-284. <https://doi.org/10.1007/s11270-007-9515-9>
- Türkmen, A., Tepe, Y., Türkmen, M. and Mutlu, E., 2009. Heavy metal contaminants in tissues of the Garfish, *Belone belone* L., 1761, and the Bluefish, *Pomatomus saltatrix* L., 1766, from Turkey waters. *Bull. environ. Contam. Toxicol.*, **82**: 70-74. <https://doi.org/10.1007/s00128-008-9553-z>
- Yi, Y., Yang, Z. and Zhang, S., 2011. Ecological risk assessment of heavy metals in sediment and human health risk assessment of heavy metals in fishes in the middle and lower reaches of the Yangtze River basin. *Environ. Pollut.*, **159**: 2575-2585. <https://doi.org/10.1016/j.envpol.2011.06.011>
- Yousafzai, A.M., Chivers, D.P., Khan, A.R., Ahmad, I. and Siraj, M., 2010. Comparison of heavy metals burden in two freshwater fishes *Wallago attu* and *Labeo dyocheilus* with regard to their feeding habits in natural ecosystem. *Pakistan J. Zool.*, **42**: 537-544.