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Assessing the Toxic Effects of the Selected Heavy Metals on Freshwater Fish Populations

Dr. Shashi Parmar* Atul Parmar Osin Koli*****

***Associate Professor (Zoology) SBP Govt. College, Dungarpur (Raj.) INDIA**
**** Associate Professor (Geography) SBP Govt. College, Dungarpur (Raj.) INDIA**
***** Assistant Professor (Zoology) Gurukul PG College, Dungarpur (Raj.) INDIA**

Abstract : Heavy metalsare pervasive contaminants in freshwater ecosystems, posing significant threats to aquatic environment.The most common heavy metals are arsenic, chromium, aluminium and mercury, which affect human health and are considered systemic toxicants. This study aims to highlight the issue of pollution in the fresh water aquatic ecosystems and fish healththrough comprehensive assessment and analysis. Key objectives include evaluating the concentrations of heavy metals in water bodies and sediments, assessing bioaccumulation levels in fish tissues, and elucidating physiological and biochemical responses in exposed fish. Results indicate that heavy metal toxicity negatively affects the growth, reproduction and physiology of fish, causing threat to the sustainable development of the fisheries and aquaculture sector.
Keywords: heavy metals, fish health, fresh water fish, metal toxicity.

Introduction -In the recent era environmental pollution posing a majorchallenge to the modern society. There are various environmental contaminants among them heavy metals are of greater concern due to not only their toxicity for living organisms andaquatic life but also possessing the potentiality of bioaccumulation in the food chain (Garai*et al.*, 2021). Heavy metals are a unique class of naturally occurring elements that persist in the environment for a long time and are not biodegradable (Kanamarlapudi *et al.,* 2018). The sources of heavy metals into the environment could be natural or anthropogenic activities such as mining, industrial discharge agricultural runoff etc. These heavy metals ultimately end up in aquatic ecosystems, then subsequently enter into the body of aquatic organisms and in the course of the food chain, these metals enter into the body of higher animals (Authman *et al.,* 2015, Eroglu et al, 2015, Mokarat et al, 2022). The frequent discharge of excessive heavy metals into water bodies cause deleterious effects on aquatic animals. The ecological equilibrium is disrupted due to accumulation of heavy metals because these metals interfere physiological, metabolic and cellular functions of living organisms (Arisekar et al, 2020, Hussain et al, 2022). At higher concentrations, these heavy metals become a concern for aquatic habitats because frequently the biological system itself alone is not able to destroy those kinds of substances rapidly (Paul et al, 2019, Abbas et al, 2021). Since fish are at the top of the food chain in most of the aquatic environments and are the most responsive to the toxic effects of heavy metal exposure. In addition, being one of the most abundant vertebrates, fish can directly affect humans through food intake; therefore, fish can be employed to assess the extent of environmental pollution in an aquatic environment.

It is reported that excess quantity of heavy metals in water produces Reactive Oxygen Species (ROS), which subside the water quality and detrimental for aquatic life by causing oxidative stress (Aldoghachi et al, 2016, Paul et al, 2019, Kiran, et al, 2021). Bioaccumulation of toxic heavy metals in the different tissues can harm animal health and eventually cause damage to normal physiological processes of the body(Malik*et al.,* 2014) .

Because of the rapid economic development across the globe, large-scale emissions and pollution by heavy metals are of special concern. In the realm of environmental research, the detrimental impact of heavy metals on aquatic ecosystems, particularly freshwater environments, stands as a critical concern. Among the diverse array of aquatic life forms, freshwater fishes serve as vital indicators of ecosystem health, as their well-being is intrinsically linked to the quality of their surrounding habitat. According to International Agency for research on cancer and also US environmental protection agency which are also working / researching on cancer they classified these metals which are toxic to freshwater fishes as carcinogen.(sabhaa k.AL-Taee,Karam H.,Al-Mallah and Hana KhIsmail,2020). It is also reported that it is highly carcinogenic, teratogenic and mutagenic. How much it can affect a particular kind of species is depend on its dose and exposure time it vary with the species.(Garai *et al.*, 2021)

The present study seeks to delve into the intricate relationship between heavy metal contamination in fresh water bodies and its adverse effects on freshwater fish populations. Through a holistic understanding of the intricate interplay between heavy metal contamination and freshwater fish health, stakeholders can formulate evidence-based policies and interventions to mitigate the pervasive threat posed by heavy metals and ensure the long-term viability of freshwater ecosystems.

Material and Methods

1. ALUMINIUM (Al): Aluminum is a ubiquitous metal in the Earth's crust accounting for 8.1% of the Earth's mass [Sparling and Lowe, 1996]. Toxic metals, including aluminium (Al), negatively affect aquatic organisms . Al is naturally occurs exclusively in the +3-oxidation state (Al^{3+}) in combination with other elements such as oxygen, silicon and fluorine [Jones and Bennett, 1986, Ganrot 1986,]. Al^{3+} is the major component of a large number of minerals such as mica, feldspars and clays [Ganrot 1986,]. Through the weathering of rocks or minerals or through volcanic activities, it is released into the environment naturally. Al is commercially used in electrical engineering, transportation, construction, and in the manufacture of household utensils, appliances, packaging material and to manufacture particles in paints, pigments, and coatings in chemical and paper and textile industries. [Jones and Bennett, 1986,]. Aluminium sulphate (Al2(SO4)3) is widely used to improve the clarity of drinking water [Pernitsky and Edzwald, 2006], and various Al compounds are used in processing, packaging, and the preservation of food (Stahl et al, 2011).

In fishes, Al may be associated with gill damage due to its deposition and changes in osmoregulation, as well as with oxidative stress in lymphocytes (Galar-Martinez et al. 2010; Garcia-Medina et al. 2010). Al accumulates in the nervous system of freshwater vertebrates, where it can trigger oxidative stress, alter enzymatic activities, and neurotransmitters levels but also affect gene expression, cause astrogliosis and morphological changes, and impair behaviour and cognitive abilities. (Closset et al, 2021)

A study by Hadi and Alwan 2012, in the freshwater fish Tilapia zillii, reported cellular hypertrophy or hyperplasia with cellular degeneration which results in necrosis of gill epithelial tissues and alteration of the circulatory system in fresh water fishes, when exposed to three different concentrations of Al. The fishes had symptoms of oedema, congestion, inflammation in the liver with atrophy of pancreatic tissue and activation Melan macrophage. In another study toxic effects of Al in the kidney was demonstrated which lead to severe degeneration in the tubules cells, irregular diameters of renal tubules with glomerular expansion, renal corpuscle damage and haemorrhage. (Authman, 2011)

2. CHROMIUM (Cr): Chromium is one of the most common trace elements found in the earth's crust and seawater (Bakshi and Panigrahi, 2018). This element is present in divalent (Cr2+), trivalent (Cr3+) or hexavalent (Cr6+) oxidation states. Among these Cr3+ and Cr6+ are considered as the most stable forms (Velma et al, 2009 and Vincent at el, 1995). Due to low membrane permeability, non-corrosiveness nature and minimum power of bio magnifications in the food chain so Cr3+ oxidation state is less toxic as compared to the Cr6+ state, which is more toxic because of its strong oxidative potentiality and ability to cross the cell membrane (Ram at el, 2019).

Various anthropogenic sources and industrial applications such as leather tanneries, metal processing, electric furnaces, corrosion inhibitors, petroleum refining, textile manufacturing, alloy preparation, wood preserving, steel industries and cooling towers are responsible for releasing Cr that leads to chromium toxicity in an aquatic ecosystem,. [Panov at el, 2003, Huang et al, 2004, Javed and Usmani, 2019, Garai et al, 2021).

According to the physicochemical properties of the surface water, two forms of chromium may be present in the water environment, the trivalent Cr+3 and the hexavalent Cr+6 that can pass cell membrane and then reduced to trivalent. It is reported that these would combined with macromolecules as genetic materials and cause mutation (Svobodova, 1993; Bakshia and Panigrahi, 2018, Shahbaa et al, 2020). It is also reported that it plays a vital role for carcinogenesis and stimulate oxidative stress (Eisler, 2000; Lushchak et al., 2009).

Unlike other heavy metals, chromium enters the body through gills or digestive tracts, but it is reported that it has a lower ability to accumulate than others (Rashed,2001). Exposure of fish to acute toxicity causes an increase of mucous secretion and suffocation which leads to death while in chronic toxicity, chromium may severely affect kidneys causing reduction of renal function and renal tubular hypertrophy and vacuolisation of the head kidney's internal cells glomerular necrosis and fibrosis with stenosis of the tubular lumen (Mishra and Mohanty, 2008, Mishra and Mohanty, 2009, Taee et al, 2020).

It is reported that blood coagulation time was decreased in the Tilapia sparrmanii when exposed to chromium, which reflects by internal bleeding with an increase of pH value (Vutukuru, 2003]. Accumulation of chromium in the tissue of Indian major carp *Labeo rohita* leads to decreased total protein and lipid content in the muscle, liver and gill [24]. Likewise depletion of liver glycogen content was observed in a freshwater teleost *Colisa fasciatus*, on chromium exposure (Nath K, Kumar, 1987). Cr6+ toxicity showed osmoregulatory and respiratory dysfunction at pH 7.8 and 6.5 in rainbow trout, *Salmo gairdneri* (Van et al, 2009]. Chronic exposure of chromium is reported to cause DNA damage, microscopic lesions, physiological abnormalities, and reduction in growth and survival rate in fishes (Farag et al,2006, Garai et al, 2021].

3. MERCURY (Hg): Mercury is considered as one of the most toxic heavy metal found in the environment. (Garai Et al, 2021). Due to huge industrialisation the 20th century Mercury contamination in the environment has increased rapidly (Grandjean et al, 2010). According to United State Environmental Protection Agency (EPA) and the Agency for Toxic Substances and Disease Registry (ATSDR) Mercury is reported to be rank third in the list of the hazardous substance of the environment after the two toxic agents, lead and arsenic (Pack et al, 2014).The inflow of mercury into an aquatic ecosystem occurs naturally as a result of volcanoes, oceanic emission, mineral deposits, crust degassing and forest fires (Washburn et al, 2018, Hylander and Meili, 2003).

Apart from elementary form, mercury is present in an ionic form which forms a compound with sulphide, chloride or organic acid and organic form, especially methyl mercury [103]. Literature suggests methyl mercury is the most chemically toxic form of mercury and 70-100% of mercury present in the fish body is of methylated form. Methylation of inorganic mercury occurs by microorganisms such as anaerobic sulphate-reducing bacteria, iron reducers, and methanogens [104,105]. Increase in water temperatures attributed to climate change which stimulates the methylation of mercury.

Methyl mercury is one of the most toxic compounds to fish usually generated through methylation of inorganic mercury by anaerobic microorganism as sulfate-reducing bacteria SRB, methanogens MPA and iron reducers FeRP (Pack et al., 2014). Methyl mercury is a highly lipophilic environmental contaminant, firstly reported in 1970 to cause pollution in Minamata Bay in Japan and massive human poisoning in Iraq (Bakir et al., 1973 and Tsubaki and Irudayaraj, 1977).

It is reported that fish has capacity to absorb mercury and heavy metals from the surrounding water as well as from the food they consume (et al, 2013). The amount of mercury content in fish relay upon the factors, such as the vicinity in which they live, food quality, the characteristics of the species and the absorption conditions [12]. The mercury content in fish increases with age, weight and length [Sackett et al, 2013]. Water pH and dissolved organic carbon content modify the uptake of Hg compounds. The highest concentration of Hg in fish muscle is observed when the pH of water is around 5 (Eisler et al, 2000). Various studies have concluded that fish poisoning with mercury compounds leads to brain damage and manifested itself as dilation of the gill covers, excessive mucus secretion, increased frequency of respiratory movements, decreased motility, abnormal motor coordination, loss of balance and a lack of appetite (Eisler et al, 2000, Brodziak et al, 2023).

4. Arsenic: Arsenic is a metalloid element which is abundant in the aquatic environment due to natural and anthropogenic processes (Rossman et al, 2003, Rabbane et al, 2022). It is the 14th and 20th abundant element in saltwater and earth crust respectively (Popovic et al, 2001). It is a remarkable and ubiquitous environmental contaminant causes health issues to all living organisms [Jezierska et al, 2003]. Various research has demonstrated the adverse effects of arsenic on fish growth, mortality, development, RNA:DNA ratio, histopathology and genetic expression [Hayat et al, 2013,Foley et al, 2016, Ahmed et al, 2013,Banerjee et al, 2015, Minatel et al, 2017). The World Health Organization (WHO) has also classified arsenic as one of the most dangerous chemicals to public health [Babich, et al, 2019].

Natural activities such as volcanic eruption, forest fires and weathering of rocks add a significant amount of arsenic in aquatic environment. (Malik et al, 2023). Various anthropogenic activities responsible to release arsenic into the environment [. Like, onferrous metal mining and smelting, combustion, wood preservation, fossil fuel processing, pesticide production and its application in agricultural fields, municipal and industrial waste disposal. (Nasser et al, 2020, Slimak et al, 1983). Arsenic, in its soluble forms, enters into the ground water and water bodies through runoff and leeching (Pongratz et al, 1998). Arsenic has been reported as highly toxic mineral found in the earth's crust which can enter the food chain through soil, water and plants. (Malik et al, 2023). The uncontrolled discharge of arsenic and its disastrous impact on fish diversity is a significant concern for aquaculture progress and economic stability. Continuous exposure of freshwater fish to the low concentration of arsenic consequences in bioaccumulation in the liver and kidney tissue (Kumari et al, 2016)]. This deposited arsenic in the fish imposes significant impairment to physiology and biochemical disorders including poisoning of gills, livers, decrease fertility, tissue destruction, lesions, and cell death. When arsenic enters in the cell and produces reactive oxygen species which increases the level of stress which centralises the oxidative enzymes and cortisol levels in fish. The (Malik et al, 2023)

In a study it is reported that lethal and sub-lethal arsenic exposure, stimulates different histopathological injuries in various organs in the fish and put impacts on the nervous, gastrointestinal, respiratory and cardiovascular systems (Kumari et al, 2016)]. Moreover, when *Tilapia mossambica*, *Channa punctatus*, *Cyprinus carpio*, *Anguilla anguilla* and *Mastacembelus armatus exposed to heavy arsenic pollution,* lamellae fusion, epithelial cell hyperplasia, necrosis, cystic formations within secondary lamellae epithelium and secondary lamellae loss were found in their gill tissue. (Ahmed et al, 2013, Javed et al, 2017, Gürcü et al, 2010, Yildiz et al, 2010). Since gills play an important role in fish by carrying out gas exchange, ion regulation and the emission of metabolic wastes thus they are considerably infected by water pollutants as a result of continual contact with water, and respiratory problems are one of the early indications of pollution exposure. Kumari et al, 2016, Golam et al, 2022)

Conclusion: The findings of this study underscore the significant and varied toxic effects of aluminium, chromium, mercury, and arsenic on freshwater fish populations. Through comprehensive assessment and analysis, it is evident that these heavy metals accumulate in fish tissues, leading to adverse physiological and biochemical responses. Arsenic and mercury, in particular, exhibited substantial toxicity, impacting fish health, reproductive success, and overall population dynamics.

Moreover, the study highlights the interconnectedness between environmental contamination and human health risks, as heavy metal bioaccumulation in fish poses potential threats through the food chain. Understanding the mechanisms and pathways of heavy metal toxicity in freshwater ecosystems is crucial for developing effective environmental management and regulatory measures.

Recommendations: Based on the findings of this research, several recommendations are proposed to mitigate the impacts of heavy metal contamination on freshwater fish populations and ecosystems:

1. Enhanced Monitoring and Regulation: Implement rigorous monitoring programs to regularly assess heavy metal concentrations in water bodies and sediments. Strengthen regulatory frameworks to enforce limits on permissible levels of aluminium, chromium, mercury, and arsenic in aquatic environments.

2. Remediation Strategies: Develop and implement remediation techniques such as phytoremediation, bioremediation, and sediment dredging to reduce heavy metal concentrations in contaminated areas.

3. Public Awareness and Education: Increase public awareness regarding the sources, risks, and impacts of heavy metal pollution on freshwater ecosystems and human health. Promote sustainable practices in industry and agriculture to minimise pollutant runoff into water bodies.

4. Research and Innovation: Invest in further research to explore innovative technologies and approaches for mitigating heavy metal toxicity in aquatic environments. Foster interdisciplinary collaborations to advance understanding of ecological impacts and develop sustainable solutions.

5. Long-Term Monitoring and Assessment: Establish long-term monitoring programs to track changes in heavy metal concentrations, fish populations, and ecosystem health over time. Continuously evaluate the effectiveness of remediation efforts and adapt strategies as needed.

By implementing these recommendations, stakeholders can work collaboratively to protect freshwater ecosystems, preserve biodiversity, and safeguard public health from the detrimental effects of heavy metal contamination.

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