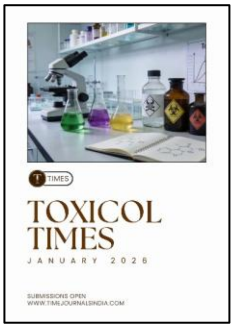
Review Article



Heavy Metals: A Desolation for Fishes

Samiksha Sharma* and Manik Sharma
Department of Zoology, University of Jammu, Jammu and Kashmir, India, 180006

check for updates

Received: January 27, 2026
Accepted: March 28, 2026
Published: March 29, 2026

***Corresponding author:**
Samiksha Sharma
E-mail:
samikshasharma6946@gmail.com

ABSTRACT
The review highlights the influences of heavy metals on fishes. Through bioaccumulation, these heavy metals get stored in different organs of the fishes and gets biomagnified at the higher trophic levels and eventually reach humans. Fishes are usually contemplated as the bioindicators of heavy metal contamination. Heavy metal also ensues the instability of the ecosystem, resulting in the deprivation of the biodiversity at all the levels. Heavy metals perturb various behavioural and physiological changes in the fishes, eventually leading to their death. Heavy metals also pose enormous health effects on humans including cancer.

KEYWORDS: Heavy metals, Fishes, Bioaccumulation, Effects, Toxicity

1. INTRODUCTION

Pollution of the aquatic environment by heavy metals can be contemplated as a prime commination to all the aquatic organisms including fishes (ECDG Report, 2000). Heavy metal contamination is usually the most treacherous chemical pollution in water (Sönmez et al., 2012a). Heavy metals have the potential to cause ecological and health concern by virtue of their toxicity, bioaccumulation and biomagnification at higher trophic levels. Heavy metal ensues the instability of the ecosystems and also influence human health (IARC, 1980).

Fishes, being the top carnivores in the aquatic environment, are badly influenced by the heavy metal contamination (Rashed, 2001). The past and present pollution load in the aquatic environment can be perceived by the concentrations of heavy metals in the fishes (Ravera et al., 2003). Thus, various fishes are reliable bioindicators of heavy metal contamination and assessing the changes in their surrounding habitats (Svobodova,2004). Freshwater fishes usually migrate to less contaminated areas or die off when their habitat is being tainted by heavy metals and this process muddle the food chains (Rashed, 2001). Heavy metals when present in elevated concentrations have both acute and chronic effects on fishes (Kotze et al., 1999). Five possible direct routes of heavy metal uptake in fishes were proposed by Nussey (2000) viz food, suspended particles, gills, integument, water intake and indirectly through consumption of other contaminated organisms such as small fishes, invertebrates, vegetation etc. After ingestion, these heavy metals enter their target organs for storage or excretion through body fluid of the fishes (Tarrio et al., 1991). Their reserves in the organs depend upon their way of exposure or their concentration levels in the surrounding water (Tarrio et al., 1991 & Alam et al., 2002). Several factors ascertain heavy metal accumulation in distinct parts of the fish body viz solubility of water, feeding behaviour, age, reproductive state, species, size, health of fish, habitat etc (Perguini et al.,2014 & Anand et al., 2017). Gills, liver and kidneys are the major repositories of heavy metal accumulation. Enormous amount of heavy metal accumulation takes place in the liver (Wepener et al., 2001). Fishes present in the aquatic environment with low concentration of heavy metals don't reflect any signs of disease, but even this small amount of pollution reduces the fecundity of the fish population and in long term, leads to their extinction (Sankar et al., 2007).

Several perilous effects on fishes due to heavy metal contamination on fishes include deformities in skeleton, problems in metabolism, kidney disorders, liver damage, infertility, behavioural and physiological changes (Fatima et al., 2020).

2. SOURCES OF HEAVY METALS INTO THE AQUATIC ENVIRONMENT

Heavy metals can enter into the aquatic environment through various sources, both anthropogenic and natural and gets bioaccumulated in the food chains of various plants and animals (Al-Yousuf et al., 2000).

Prominent sources are (ATSDR, 2007)

- Urban run- off
- Industrial waste waters
- Mining wastes
- Landfill leaches
- Municipal wastewater

2.1 Heavy Metal uptake by Fishes

Fishes or aquatic organisms uptake heavy metals in two phases: firstly through rapid adsorption and later on its entry into the cell occurs through slower transport, either by diffusion or by active transport (Crist et al., 1988 and Brezonik et al., 1991).

The route of heavy metals uptake and absorption is

FOOD/GILLS → **BLOOD** → **LIVER**

3. HEAVY METALS AND THEIR EFFECTS

Heavy metals are those chemical elements having high density and are toxic even when present at low concentrations and get accumulated in the soft tissues of the body without even getting metabolized (Baby et al., 2010).

Toxicity of the heavy metals in fishes depends upon many factors (Afshan et al., 2014):

- Sex
- Age
- Species
- Season
- Feeding behaviour
- Habitat
- Temperature
- pH
- Alkalinity of water

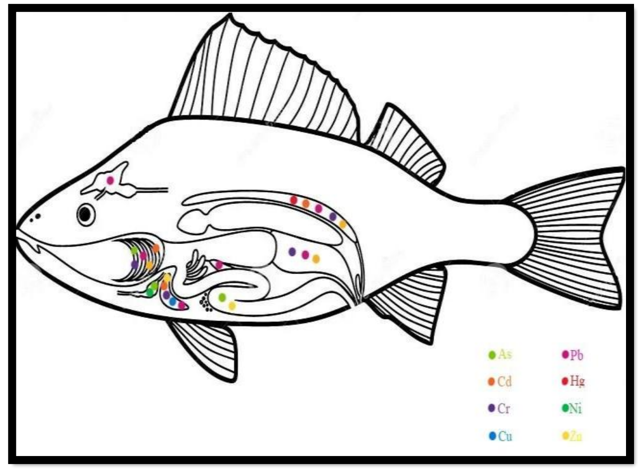
3.1 Effects of Heavy Metals on Fishes

U.S. "Environmental Protection Agency" (EPA) in cooperation with the 'Agency for Toxic Substances and Disease Registry' (ATSDR), Atlanta, Georgia has reported 'Top 20 Hazardous substances'. Among these, heavy metals like Arsenic (As), Lead (Pb) and Mercury (Hg) holds the 1st, 2nd and 3rd position in the study whereas Cadmium (Cd) is ranked at the 7th place.

Heavy Metals are present in the water bodies naturally at a level not toxic to the aquatic life (Fatima et al., 2020) [Table Number 1].

Heavy metals cause various adverse effects on fishes viz decrease in fitness level, starvation, shocks, hypoxic conditions, reproductive interference, cancer and finally death (Levesque et al., 2002; Arslan et al., 2006; Govind and Madhuri, 2014). By interfering with the metabolic, biochemical and physiological functions, heavy metal contamination affects growth, development and reproduction (Heath, 1995; Çiftçi et al., 2017). Despite being carcinogenic, heavy metal contamination also pose genotoxic effects on the fishes, directly or indirectly (Snow, 1992; Bolognesi et al., 1999). Both estrogenic and androgenic secretions are curtailed on exposure to heavy metals toxicity (Ebrahimi and Taherianfard, 2011). Enormous contagious diseases become prevalent in fishes due to immune system flaws caused by toxic nature of heavy metals. These changes bare fishes to the risk of mortality (Abel and Papoutsouglou, 1986; Çelik, 2006; Akgün et al.,2010; Larsson and Haux, 1985; Nemesok and Huphes,1988; Sehgal and Saxena, 1986; Al-Weher, 2008).

Figure shows various heavy metals affecting different organs of fish and are also discussed in following sections. Detrimental effects of these heavy metals along with some other contaminants on fish community can be demonstrated as:



Effects of Arsenic: Barnes et al., 2002 and Gornati et al., 2002 cited 'Arsenic' as a genotoxic agent. Arsenic intake in the fish occurs through gills as well as adulterated feeds (Ahmed et al., 2008). Sudden fish death occurs during acute exposure to arsenic because of increase in mucous secretion, altered structure of gill epithelium and suffocation whereas chronic exposure to arsenic may lead to several pathological changes and itself gets accumulated in various tissues of the fish body (Hughes et al., 2002).

Arsenic causes oedema in the gills of Odontesthes bonariensis (Puntorerio et al., 2018). Exposure to sodium arsenite in Channa punctata causes apoptosis of the heart muscle and intestinal mucosal and submucosal enlargement (Hossain, 2012). In Oryzias latipes, complete ceasation in development can be observed on exposure to arsenic toxicity (Ishaque et al., 2004).

Table 1. Showing the concentration of Heavy Metals in marine and freshwater

Heavy Metal	Marine Water [Concentration in µg/l]	Fresh Water [Concentration in µg/l]
Arsenic (As)	1.7	10
Cadmium (Cd)	0.1	0.1
Chromium (Cr)	0.3	1.0
Copper (Cu)	0.3	3
Lead (Pb)	0.03	3
Mercury (Hg)	0.03	0.1
Nickel (Ni)	0.6	0.5
Zinc (Zn)	5	15

Effects of Cadmium: Due to its high rate of bioaccumulation, cadmium is known to be one of the most toxic heavy metals for fishes (Garai et al., 2021). Cadmium is accumulated mostly in liver, kidney, gills and its accumulation is found to be lowest in the skin (Handy R, 1992). Fish can take cadmium directly through gills, skin as well as gastrointestinal tract (Zhang et al., 2017). Cadmium is known to cause severe toxicity in fishes by inhibiting the electron transport chain in mitochondria and reviving the production of reactive oxygen species (Wang et al., 2004).

Exposure of cadmium even at low level causes DNA damage in Cyprinus carpio (Jia et al., 2011). Cadmium works as an endocrine disrupter and it inhibits vitellogenesis in Oncorhynchus mykiss (Vettilard and Bailhache, 2005). Puntius conchonius shows the symptoms of hyperglycemia (on exposure to high cadmium concentrations) and hypoglycemia (when exposed to low cadmium concentrations) (Çelik et al., 2008). Haemoglobin and RBCs level decrease during cadmium toxicity in Oreochromis mossambicus (Ruparella et al., 1990; Çelik, 2006).

Effects of Chromium: Chromium exists in two forms, trivalent (Cr+3) which is a stable one and hexavalent (Cr+6), being the most toxic as it has the ability to cross the cell membranes (Ram et al., 2019). Chromium uptake by fishes is mainly through gills or gastrointestinal tract (Rashed,2001). Chromium toxicity in fishes is species specific and depends upon many factors such as age, phase of development, pH, temperature etc (Sekar et al., 2016).

Sublethal concentration of Cr+6 in Oreochromis massambicus causes histopathological changes in gills, gonads, kidneys and liver (Ackermann, 2008). Labeo rohita shows a decrease in protein content in many organs viz muscle, liver and gill on accumulation of chromium in the gills (Vutukuru SS, 2003). In Colisa fasciatus, liver glycogen gets depleted when exposed to chromium toxicity (Nath and Kumar, 1987).

Table 2. Showing some histopathological conditions caused due to Heavy Metal toxicity

Heavy Metals	Histopathological Conditions
Arsenic	Apoptosis
Cadmium	Inhibition of Vitellogenesis
Chromium	Changes in histology of gills, gonads, kidneys and liver
Copper	Apoptosis, Larval mortality
Lead	Lipid cholesterol decrease in brain and gonads
Mercury	Necrosis of kidney tubules, Decrease in fecundity
Nickel	Skin lesions
Zinc	Decrease in fecundity

Effects of Copper: Copper uptake by fish is through die or ambient exposure. Various environmental factors affect copper toxicity viz hardness of water, anions, pH etc (Dang et al., 2009). Reduced growth, life span shortening, lessen immune response etc are some of the effects caused by chronic exposure to copper in fishes.

Teleost fish, Oreochromis niloticus, when exposed to copper, exhibited induction in apoptosis (Eyckmans et al., 2011). Liver tissues are found to be affected on exposure to copper sulfate (Gainey et al., 1990). Appetite, navigation and awareness of surroundings are likely to be affected by copper contamination as it affects the sense of olfaction in fishes (Solomon, 2009). Copper can cause larval mortality and deformities of the body in the goldfish Carassius auratus (Kong et al.,2013). Muscle and liver glycogen level decrease and serum glucose levels increase on exposure to copper toxicity in Oncorhynchus mykiss, Heteropneustes fossilis and Clarias lazera (Singh and Reddy, 1990; Dethloff et al., 1999; Arslan et al., 2006).

Effects of Lead: Lead enters the fish body through diet via gills causing two distinct responses. Chronic lead toxicity in Clarias gariepinus causes pathological effects viz epithelium damage, desquamation and aneurism (Olojo et al., 2005). Lead is bioaccumulated in the fish mainly in the liver, spleen, kidney and gills (Creti et al., 2010).

Exposure to lead nitrate in C. batrachus lessens the levels of lipid cholesterol in brain and gonadal organs (Ghosh et al., 2006). Çiftçi et al. (2017) conducted a study on Nile tilapia (Oreochromis niloticus) and concluded that lead decrease HSI (Hepatosomatic Index) in the same. Ovarian tissue showed some histological changes in Mastacembelus pancalus on exposure to lead toxicity (Biswas et al., 2016).

Effects of Mercury: The mercury uptake in fishes occurs through ingestion. Through circulation, mercury reaches its target organ i.e. liver. The site of deposition, detoxification and reproportionment of mercury is the fish liver (Hansen et al., 2011). Mercury shows high affinity to proteins, therefore, fish muscle accumulates the highest percentage (approximately 90%) of the total mercury in the fish body (Basu et al., 2017). The toxic form of mercury which affects the fishes is 'Methylmercury', an environmental contaminant which have known to cause Minamata Disease of waterways in Japan and human poisoning in Iraq (Bakir et al.,1973 and Tsubaki and Irudayaraj, 1977).

The kidney of Clarius batrachus shows the symptoms of kidney damage and necrosis of kidney tubules when exposed to mercurial compounds (Kirubagaran et al., 1988). Mercury toxicity is also shown to disrupt functions of male reproductive system in Gymnotus caropo viz germ cell reduction, proliferation of interstitial tissue, disorganization of seminiferous tubules etc (Vergilio et al., 2013).

Effects of Nickel: Nickel gets accumulated in the body of the fish without getting magnified along the trophic levels (Pandey et al., 2014). Abnormality in swimming behaviour, skin lesions, disorders in respiratory systems etc are observed on exposure of nickel to Nile Tilapia (Ibrahim et al., 2008).

Cyprinus carpio, on being exposed for a short term to nickel, causes stress reaction along with other behavioural changes (Al Ghanim, 2011). High amount of nickel gets bioaccumulated causing lymphopenia and leucopenia in Tilapia nilotica (Garai et al., 2021). Carassius auratus, Prochilodus lineatus and Fundulus heteroclitus undergo oxidative stress on exposure to nickel toxicity (Kubrak et al., 2013; Blewett and Wood, 2015; Palermo et al., 2015). Nickel contamination also affects locomotion in Carassius auratus and Neogobius melanostomus (Ellgaard et al., 1995; Leonard et al., 2014; Blewett and Leonard, 2017).

Effects of Zinc: Zinc intake by fish occurs through the gastrointestinal tract and gills (Gaw et al., 2016). Toxicity of zinc in fishes is found to be species specific and this differs among the distinct advancing stages of the fish. Various environmental factors viz temperature, water hardness, concentration of dissolved oxygen etc influence the toxic effect of zinc on fishes. Zinc, when present at an acute concentration, destroys tissues of the gill and eventually kills the fish and when present long-term leads to fish death due to chronic stress to the fish (Skidmore, 1964).

Table 3. Showing the effects of Heavy Metals on Fish species

Heavy Metal	Fish species affected
Arsenic	*Channa punctata* *Clarias batrachus* *Clupea sprattus* *Engraulis encrasicholus* *Merlangius merlangus* *Mugil cephalus* *Mullus barbatus* *Oreochromis niloticus* *Oreochromis massambicus* *Odontesthes bonariensis* *Oryzias latipes* *Pomatomus saltor* *Salmo gairdneri* *Sarda sarda* *Sprattus sprattus* *Trachurus trachurus*
Cadmium	*Anguilla rostrata* *Capoeta tinca* *Caranx rhoncus* *Chondrostoma regium* *Clarias gariepinus* *Clupea sprattus* *Cyprinus carpio* *Engraulis encrasicholus* *Epinephelus areolatus* *Galaxius fasciatus* *Glossogobius giuris* *Gobiocyprus rarus* *Labeo rohita* *Lepomis gibbosus* *Leuciscus cephalus* *Lutjanus russelli* *Merlangius merlangus* *Mugil cephalus* *Mullus barbatus* *Onchorhynchus mykiss* *Oreochromis niloticus* *Pegusa lascaris* *Perca flavescens* *Pimephales promelas* *Pleuronectes platessa* *Puntius chola* *Puntius sophore* *Puntius ticto* *Onchorhynchus mykiss* *Sarda sarda* *Saurida undosquamis* *Scomber japonicus* *Scomber scombrus* *Sparus aurata* *Sparus sarba* *Sprattus sprattus* *Trachurus trachurus*
Chromium	*Channa punctata* *Clarias gariepinus* *Clupea sprattus* *Colisa fasciatus* *Coregonus lavaretus* *Cyprinus carpio* *Epinephelus areolatus* *Engraulis encrasicholus* *Glossogobius giuris* *Labeo rohita* *Lutjanus russelli* *Merlangius merlangus* *Mugil cephalus* *Mullus barbatus* *Onchorhynchus mykiss* *Oncorhynchus tshawytscha* *Oreochromis massambicus* *Pomatomus saltor* *Puntius chola* *Puntius sophore* *Puntius ticto* *Salmo gairdneri* *Saurida undosquamis* *Scomber scombrus* *Sparus aurata* *Sparus sarba* *Sprattus sprattus* *Tilapia sparrmanii* *Trachurus trachurus*
Copper	*Capoeta tinca* *Caranx rhoncus* *Carassius auratus* *Chondrostoma regium* *Clupea sprattus* *Cyprinus carpio* *Epinephelus areolatus* *Fundulus heteroclitus* *Glossogobius giuris* *Gobiocyprus rarus* *Labeo rohita* *Lepomis gibbosus* *Leuciscus cephalus* *Lepomis macrochirus* *Lutjanus russelli* *Menidia menidia* *Merlangius merlangus* *Mugil cephalis* *Mullus barbatus* *Onchorhynchus mykiss* *Oreochromis niloticus* *Oreochromis massambicus* *Pegusa lascaris* *Pomatomus saltor* *Puntius chola* *Puntius sophore* *Puntius ticto* *Perca flavescens* *Sarda sarda* *Saurida undosquamis* *Scomber japonicus* *Scomber scombrus* *Sparus aurata* *Sparus sarba*

	Sprattus sprattus *Trachrus trachurus*
Lead	*Acipenser sinesis* *Caranx rhoncus* *Capoeta tinca* *Chondrostoma regium* *Clupea sprattus* *Cyprinus carpio* *Engraulis encrasicholus* *Epinephelus areolatus* *Glossogobius giuris* *Pegusa lascaris* *Pimephales promelas* *Clarius batrachus* *Clarias gariepinus* *Labeo rohita* *Lepomis gibbosus* *Leuciscus cephalus* *Lutjanus russelli* *Mastacembelus pancalus* *Merlangius merlangus* *Mugil cephalus* *Mullus barbatus* *Onchorhynchus mykiss* *Oreochromis niloticus* *Pomatomus saltor* *Puntius chola* *Puntius sophore* *Puntius ticto* *Sarda sarda* *Saurida undosquamis* *Scomber japonicus* *Scomber scombrus* *Sparus aurata* *Sparus sarba* *Sprattus sprattus* *Tinca tinca* *Trachurus trachurus*
Mercury	*Clupea sprattus* *Cyprinus carpio* *Engraulis encrasicholus* *Gambusia affinis* *Fundulus heteroclitus* *Merlangius merlangus* *Mugil cephalus* *Mullus barbatus* *Notemigonus crysoleucas* *Oreochromis niloticus* *Pimephales promelas* *Pomatomus saltor* *Sarda sarda* *Scomber scombrus* *Trachurus trachurus*

Nickel	*Capoeta tinca* *Channa punctatus* *Chondrostoma regium* *Clarias batrachus* *Clarias gariepinus* *Clupea sprattus* *Cyprinus carpio* *Danio rerio* *Epinephelus areolatus* *Engraulis encrasicholus* *Glossogobius giuris* *Gymnotus carapo* *Labeo rohita* *Lepomis gibbosus* *Leuciscus cephalus* *Lutjanus russelli* *Merlangius merlangus* *Mugil cephalus* *Mullus barbatus* *Onchorhynchus mykiss* *Pomatomus saltor* *Puntius chola* *Puntius sophore* *Puntius ticto* *Poecilia reticulata* *Oreochromis niloticus* *Sarda sarda* *Saurida undosquamis* *Scomer scombrus* *Sparus aurata* *Sparus sarba* *Sprattus sprattus*
Zinc	*Capoeta tinca* *Caranx rhoncus* *Channa punctatus* *Chondrostoma regium* *Cyprinus carpio* *Clupea sprattus* *Epinephelus areolatus Engraulis encrasicholus Gobiocyprus rarus* *Glossogobius giuris* *Fundulus heteroclitus* *Labeo rohita* *Lepomis gibbosus* *Leuciscus cephalus* *Lutjanus russelli* *Merlangius merlangus* *Mugil cephalus* *Onchorhynchus mykiss* *Pegusa lascaris* *Puntius chola* *Puntius sophore* *Puntius ticto* *Mullus barbatus* *Saurida undosquamis* *Sarda sarda* *Scomber japonicus* *Sparus aurata* *Sparus sarba* *Sprattus sprattus* *Tilapia nilotica* *Trachurus trachurus*

Murugan et al., 2008 reported in Channa punctatus the sequence of zinc deposit in different organs of fish as: Liver>Kidney>Intestine>Gill>Muscle. Zinc chloride is known to cause hatching delay, defect in growth and malformation of the skeleton in Zebrafish embryos (Salvaggio et al., 2016).

Behavioural changes along with changes in movement pattern viz less activity, easily frightened etc can be seen in exposure of zinc to Phoxinus phoxinus (Bengtsson,1974).

Table 4. Showing the effects of Heavy metals on Behaviour and Physiology of some Fish species

Heavy Metal	Behaviour affected	Fish Species	Source
Arsenic	Learning	*Carassius auratus*	Sarasamma et al., 2018
Cadmium	Food and foraging	*Abramis brama* *Cyprinus carpio*	Gerasimov et al., 1991 Kasumyan & Morsi, 1998
	Neurology Musculature	*Danio rerio*	Sarasamma et al., 2018
Copper	Locomotion	*Carassius auratus* *Cyprinus carpio* *Danio rerio* *Onchorhynchus mykiss* *Salmo trutta*	Beaumont et al., 1955; De Boeck et al., 2006
	Avoidance	*Carassius auratus* *Onchorhynchus tshawytscha* *Salmo salar*	Kleerekoper et al., 1972 Hansen et al., 1999 Sprague, 1964
	Olfaction	*Fundulus heteroclitus* *Menidia menidia*	Gardener & Roche, 1973
Lead	Learning	*Carassius auratus*	Sarasamma et al., 2018
	Neurology Musculature	*Danio rerio*	Sarasamma et al., 2018
Mercury	Food and Foraging	*Cyprinus carpio*	Kasumyan & Morsi, 1998
	Learning	*Carassius auratus*	Sarasamma et al., 2018
Nickel	Neurology Musculature	*Chrysichthys nigrodigitatus* *Tilapia zilli*	Olowu et al., 2010
Zinc	Food and foraging	*Cyprinus carpio* *Gambusia holbrooki* *Onchorhynchus kisutch*	Kasumyan & Morsi, 1998 Falcão et al., 2019 Bowen et al., 2006
	Neurology Musculature	*Clarias gariepinus* *Danio rerio*	Farombi et al., 2007 Sarasamma et al., 2018
	Olfaction	*Poecilia vivipara*	Leitemperger et al., 2019

4. EFFECTS OF BIOACCUMULATION OF HEAVY METALS IN HUMANS

Fishes accumulate enormous amounts of heavy metals within themselves. Humans, being the top carnivores amass heavy metals when consume fishes. Health issues of some of the heavy metals on humans are described as follows- (Afshan et al., 2014 & Pandey et al., 2014 & Isangedighi et al., 2019 & Catalano et al., 2020).

Table 5. Showing various health issues in Humans due to the following Heavy Metals

Heavy Metals	Health Issues in Humans
Arsenic	Hyperkeratosis Pigmentation Skin lesions Diabetes Cardiovascular diseases Cancer
Cadmium	Osteoporosis Osteomalacia Kidney dysfunction Hypertension Weaken immune system Infertility Hepatic cancer
Chromium	Allergic reactions Ulcers Respiratory and Circulatory problems Weaken immune system Genetic problems Hepatic cancer
Copper	Anaemia Liver disorders Kidney damage Stomach irritation Cramps High cholesterol
Lead	Constipation Memory Depression loss High blood pressure Infertility Cancer
Mercury	Abortion Tremors Damage to brain and CNS Contact dermatitis Stroke Autoimmune diseases

Nickel	Skin irritation Lung fibrosis Nose and sinus irritation Contact dermatitis Asthma Respiratory tract cancer
Zinc	Birth defects Loss of appetite Skin annoyances Stomach cramps Arteriosclerosis Anaemia

4. CONCLUSION

The heavy metals are toxic not only to the aquatic organisms like fishes but also to the humans. These are toxic even when present at their lower concentrations. Both point and non-point sources add enormous amount of heavy metals into the aquatic environment. Heavy metals plunge into the biogeochemical cycle which leads to toxicity among the animals and the human beings. These not only affect the fishes in many ways but also poses various health risks to humans including cancer.

Heavy metal pollution has created a havoc in the aquatic life around the world. Different measures should be taken to lessen the entry as well as leakage of the heavy metals in water, this includes pollution control boards to take strict actions when violated and policies need to be updated time to time. Moreover, chemical and biological indicators must be used regularly to put a check on the water pollution. By taking all the necessary measures, we can restore a better and safe environment now and sustain clean water bodies for the future.

5. REFERENCES

Abel PD, Papoutsoglou SE (1986) Lethal toxicity of cadmium to Cyprinus carpio and Tilapia aurea. Bulletin of Environmental Contamination and Toxicology 37:26-33.

Ackermann C (2008) A quantitative and qualitative histological assessment of selected organs of Oreochromis mossambicus after acute exposure to cadmium, chromium and nickel. Master's thesis, University of Johannesburg.

Afshan S, Ali S, Ameen US, Farid M, Bharwana SA, Ahmad R, Hannan F (2014) Effect of different heavy metal pollution on fish. Research Journal of Chemical and Environmental Sciences 2:35-40.

Ahmed K, Akhan A, Hasan M, Islam M, Hasan A (2008) Toxicity of arsenic (sodium arsenite) to freshwater spotted snakehead Channa punctatus (Bloch) on cellular death and DNA content. American-Eurasian Journal of Agricultural and Environmental Sciences 4:18-22.

Al-Ghanim K (2011) Impact of nickel (Ni) on hematological parameters and behavioural changes in Cyprinus carpio (common carp). African Journal of Biotechnology 10:13860-13866.

Akgün M, Kaya H, Celik E et al (2010) Assessment of surface water quality in the Atikhisar Reservoir and Saricay Creek (Canakkale, Turkey). Ecology 19:25-30.

Alam M, Tanaka A, Allinson G et al (2002) A comparison of trace element concentrations in cultured and wild carp (Cyprinus carpio) of Lake Kasumigaura, Japan. Ecotoxicology and Environmental Safety 53:348-354.

Al-Yousuf M, El-Shahawi MS, Al-Ghais SM (2000) Trace metals in liver, skin and muscle of Lethrinus lentjan fish species in relation to body length and sex. Science of the Total Environment 256:87-94.

Anandkumar A, Nagarajan A, Prabakaran K, Raja Ram R (2017) Trace metals dynamics and risk assessment in the commercially important marine shrimp species collected from the Miri coast, Sarawak, East Malaysia. Regional Studies in Marine Science 19:50-55.

Arslan M, Karaytug S, Cicik B (2006) Effects of copper on tissue glycogen and glucose levels in Clarias lazera (Valenciennes). European Journal of Aquatic Sciences 23:41-46.

Baby J, Raj JR, Biby ET, Sankarganesh P, Jeevitha MV, Ajisha SU, Rajan SS (2010) Toxic effects of heavy metals on aquatic environment. International Journal of Biological and Chemical Sciences 4:939-952.

Bakir F, Damluji SF, Amin-Zaki L, Murtadha M, Khalidi A, Al-Rawi NY, Doherty RE (1973) Methylmercury poisoning in Iraq. Science 181:230-241.

Barnes CA, Vazdarjanova A, McNaughton BL, Worley PF, Guzowski JF (2002) Experience-dependent coincident expression of the effector immediate-early genes Arc and Homer 1a in hippocampal and neocortical neuronal networks. Journal of Neuroscience 22:10067-10071.

Basu N, Bradley MA, Barst BD (2017) A review of mercury bioavailability in humans and fish. International Journal of Environmental Research and Public Health 14:169.

Bengtsson B (1974) Effect of zinc on the movement pattern of the minnow, Phoxinus phoxinus. Water Research 8:829-833.

Beaumont M, Butler P, Taylor E (1987) Exposure of brown trout, Salmo trutta, to sub-lethal copper concentrations in soft acidic water and its effect upon sustained swimming performance. Aquatic Toxicology 7:91-106.

Biswas S, Ghosh A (2016) Lead induced histological alterations in ovarian tissue of freshwater teleost Mastacembelus pancalus (Hamilton). International Journal of Advanced Science and Research 1:1-7.

Blewett T, Leonard E (2017) Mechanisms of nickel toxicity to fish and invertebrates in marine and estuarine waters. Environmental Pollution 230:206-214.

Blewett T, Wood C (2015) Salinity-dependent nickel accumulation and oxidative stress responses in the euryhaline killifish (Fundulus heteroclitus). Archives of Environmental Contamination and Toxicology 69:207-218.

Bolognesi C, Landini E, Roggieri P, Fabbri R, Viarengo A (1999) Genotoxicity biomarkers in the assessment of heavy metal effects in mussels: experimental studies. Environmental and Molecular Mutagenesis 33:50-58.

Bowen L, Werner I, Johnson M (2006) Physiological and behavioral effects of zinc and temperature on Coho salmon (Oncorhynchus kisutch). Hydrobiologia 560:451-458.

Brezonik P, King S, Mach C (1991) The influence of water chemistry on trace metal bioavailability and toxicity to aquatic organisms. In: Metal Ecotoxicology: Concepts and Applications. Newman MC, McIntosh AW (eds). Lewis Publishers, Michigan.

Catalano A, Genchi G, Carocci A, Sinicropi MS, Lauria G (2020) Nickel: human health and environmental toxicology. International Journal of Environmental Research and Public Health 17:7852.

Celik E (2006) Effect of heavy metals on blood parameters of fish. Journal of Fish Biology 23:67-76.

Celik E, Aslan A, Alparslan M (2008) Major factors affecting blood glucose in fish. Erciyes University Journal of the Institute of Science and Technology 24:9-15.

Creti P, Trinchella F, Scudiero R (2010) Heavy metal bioaccumulation and metallothionein content in tissues of the sea bream Sparus aurata from three different fish farming systems. Environmental Monitoring and Assessment 165:463-472.

Ciftci N, Korkmaz C, Karayakar A, Cicik B (2017) Copper and lead in Oreochromis niloticus: effects on hepatosomatic index, gonadosomatic index and condition factor. Solomon Journal 12:12-18.

Crist R, Oberholser K, Schwartz D, Marzoff J, Ryder D, Crist D (1988) Interactions of metals and protons with algae. Environmental Science and Technology 22:1213-1218.

Dang F, Zhong H, Wang W-X (2009) Copper uptake kinetics and regulation in a marine fish after waterborne copper acclimation. Aquatic Toxicology 94:267-273.

De Boeck G, Van der Ven K, Hattink J, Blust R (2006) Swimming performance and energy metabolism of rainbow trout, common carp and gibel carp respond differently to sublethal copper exposure. Aquatic Toxicology 79:391-400.

Dethloff G, Schlenk D, Khan S, Bailey H (1999) The effects of copper on blood and biochemical parameters of rainbow trout (Oncorhynchus mykiss). Archives of Environmental Contamination and Toxicology 36:115-120.

ECDG (2000) Heavy metals in waste. European Commission DG.

Ebrahimi M, Taherianfard M (2011) The effect of heavy metals exposure on reproductive systems of cyprinid fish from Kor River. Iranian Journal of Fisheries Sciences 10:197-210.

Eyckmans M, Celis N, Horemans N, Blust R, De Boeck G (2011) Exposure to waterborne copper reveals differences in oxidative stress response in three freshwater fish species. Aquatic Toxicology 103:112-120.

Ellgaard E, Ashley S, Langford A, Harlin D (1995) Kinetic analysis of the swimming behavior of the goldfish, Carassius auratus, exposed to nickel: hypoactivity induced by sublethal concentrations. Bulletin of Environmental Contamination and Toxicology 55:682-688.

Falcao B, Marques M, Nunes B (2019) Behavioral and biochemical effects of the antifouler and antidandruff zinc pyrithione on the freshwater fish Gambusia holbrooki. Fish Physiology and Biochemistry 45:101-113.

Farombi E, Adelowo O, Ajimoko Y (2007) Biomarkers of oxidative stress and heavy metal levels as indicators of environmental pollution in African catfish (Clarias gariepinus) from Nigeria Ogun River. International Journal of Environmental Research and Public Health 4:158-165.

Fatima S, Muzammal M, Rehman A, Rustam SA, Shehzadi Z, Mehmood A, Waqar M (2020) Water pollution of heavy metals and its effects on fishes. International Journal of Fisheries and Aquatic Studies 8:6-14.

Gainey L, Kenyon J (1990) The effects of reserpine on copper induced cardiac inhibition in Mytilus edulis. Comparative Biochemistry and Physiology Part C: Comparative Pharmacology 97:357-362.

Garai P, Banerjee P, Mondal P, Saha NC (2021) Effect of heavy metals on fishes: toxicity and bioaccumulation. Journal of Clinical Toxicology 11:1-8.

Gardner GR, LaRoche G (1973) Copper induced lesions in estuarine teleosts. Journal of the Fisheries Research Board of Canada 30:1295-1301.

Gaw S, McRae N, Glover C (2016) Mechanisms of zinc toxicity in the galaxiid fish, Galaxias maculatus. Comparative Biochemistry and Physiology Part C: Toxicology & Pharmacology 188:12-20.

Gerasimov Y, Pavlov D, Chuiko G (1991) Foraging behavior and some biochemical parameters of the bream brain in chronic action of cadmium. Proceedings of the All-Union Conference on Fish Behavior, Moscow.

Ghosh D, Bhattacharya S, Mazumder S (2006) Perturbations in the catfish immune responses by arsenic: organ and cell specific effects. Comparative Biochemistry and Physiology Part A: Molecular & Integrative Physiology 143:135-142.

Gornati R, Monetti C, Prati M (2002) Arsenic toxicity and

HSP70 expression in Xenopus laevis embryos. Toxicology and Industrial Health 18:479-483.

Govind P, Madhuri S (2014) Heavy metals causing toxicity in animals and fishes. Research Journal of Animal, Veterinary and Fishery Sciences 2:10-18.

Hansen B, Stafford CP, Stanford JA (2011) Mercury in fishes and their diet items from Flathead Lake, Montana. Transactions of the American Fisheries Society 140:1512-1525.

Hansen J, Marr J, Lipton J, Cacela D, Bergman H (1999) Differences in neurobehavioral responses of chinook salmon (Oncorhynchus tshawytscha) and rainbow trout (Oncorhynchus mykiss) exposed to copper and cobalt: behavioral avoidance. Environmental Toxicology and Chemistry 18:1972-1978.

Handy R (1992) The assessment of episodic metal pollution. 1. Uses and limitations of tissue contaminant analysis in rainbow trout (Oncorhynchus mykiss) after short waterborne exposure to cadmium or copper. Archives of Environmental Contamination and Toxicology 23:74-81.

Heath A (1995) Water pollution and fish physiology. CRC Press.

Hossain M (2012) Effect of arsenic (NaAsO2) on the histological change of snake head fish Channa punctatus. Journal of Life and Earth Sciences 7:67-70.

Hughes MF (2002) Arsenic toxicity and potential mechanisms of action. Toxicology Letters 133:1-16.

Ibrahim K, Hadeed A, El-Sharkawy N, Saleh Sakr F, El-Hamed SA (2008) Experimental studies on nickel toxicity in Nile tilapia health. [Journal details approximated from context].

International Agency for Research on Cancer (1980) Some metals and metallic compounds: arsenic. IARC Monographs 23:251-305.

Isangedighi IA, David GS (2019) Heavy metal contamination in fish: effects on human health. Journal of Aquatic Science and Marine Biology 7:39-54.

Ishaque A, Tchounwou P, Wilson B, Washington T (2004) Developmental arrest in Japanese medaka (Oryzias latipes) embryos exposed to sublethal concentrations of atrazine and arsenic trioxide. Journal of Environmental Biology 25:291-299.

Jia X, Zhang H, Liu X (2011) Low levels of cadmium exposure induce DNA damage and oxidative stress in the liver of Oujiang colored common carp Cyprinus carpio var. color. Fish Physiology and Biochemistry 37:97-103.

JC N, Sekar R, Chandran R (2016) Acute effect of chromium toxicity on the behavioural response of zebra fish Danio rerio. International Journal of Plant, Animal and Environmental Sciences 6:1-6.

Kasumyan A, Morsi A (1998) A high sensitivity of Cyprinus carpio to free amino acids. Journal of Ichthyology 38:129-136.

Kirubagaran R, Joy KP (1988) Toxic effects of three mercurial compounds on survival, and histology of the kidney of the catfish Clarias batrachus (L.). Ecotoxicology and Environmental Safety 16:146-151.

Kleerekoper H, Westlake G, Matis J, Gensler P (1972) Orientation of goldfish (Carassius auratus) in response to a shallow gradient of a sublethal concentration of copper in an open field. Journal of the Fisheries Research Board of Canada 29:1721-1726.

Kong X, Jiang H, Wang S, Wu X, Fei W, Li L (2013) Effects of copper exposure on the hatching status and antioxidant defense at different developmental stages of embryos and larvae of goldfish Carassius auratus. Chemosphere 92:1458-1464.

Kotze P, du Preez HH, van Vuren JHJ (1999) Bioaccumulation of copper and zinc in Oreochromis mossambicus and Clarias gariepinus, from the Olifants River, Mpumalanga, South Africa. Water SA 25:99-110.

Kubrak OI, Husak VV, Rovenko BM et al. (2013) Antioxidant system efficiently protects goldfish gills from Ni^{2+} induced oxidative stress. Chemosphere 92:668-677.

Larsson A, Haux C (1985) Fish physiology and metal pollution: results and experiences from laboratory and field studies. Ecotoxicology and Environmental Safety 10:314-325.

Leitemperger J, Müller T, Cerezer C et al. (2019) Behavioural and biochemical parameters in guppy (Poecilia vivipara) following exposure to waterborne zinc in salt or hard water. Molecular Biology Reports 46:1385-1396.

Leonard EM, Marentette JR, Balshine S, Wood CM (2014) Critical body residues, Michaelis-Menten analysis of bioaccumulation, lethality and behaviour as endpoints of waterborne Ni toxicity in two teleosts. Aquatic Toxicology 153:79-86.

Levesque HM, Moon TW, Campbell PG, Hontela A (2002) Seasonal variation in carbohydrate and lipid metabolism of yellow perch (Perca flavescens) chronically exposed to metals in the field. Aquatic Toxicology 60:257-267.

Murugan S, Karuppasamy R, Poongodi K, Puvaneswari S (2008) Bioaccumulation pattern of zinc in freshwater fish Channa punctatus (Bloch.) after chronic exposure. Turkish Journal of Fisheries and Aquatic Sciences 8:55-59.

Nath K, Kumar N (1987) Toxicity of manganese and its impact on some aspects of carbohydrate metabolism of a freshwater teleost, Colisa fasciatus. Science of the Total Environment 68:257-262.

Nemesok J, Hughes Z (1988) The effects of copper sulphate on some biochemical parameters of rainbow trout. Environmental Pollution Series A, Ecological and Biological 52:29-40.

Nussey G (2000) Bioaccumulation of chromium, manganese, nickel and lead in the tissues of the moggel, Labeo umbratus (Cyprinidae), from Witbank Dam, Mpumalanga. Water SA 26:269-284.

Olojo EAA, Olurin KO, Mbaka GO, Oluwemimo A (2005) Histopathology of the gill and liver tissues of the African catfish Clarias gariepinus exposed to lead. African Journal of Biotechnology 4:23-28.

Olowu RA, Ayejuyo OO, Adewuyi GO et al. (2010) Determination of heavy metals in fish tissues, water and sediment from Epe and Badagry Lagoons, Lagos, Nigeria. E-Journal of Chemistry 7:S311-S319.

Palermo FF, Risso WE, Simonato JD, Martinez CBR (2015) Bioaccumulation of nickel and its biochemical and genotoxic effects on juveniles of the neotropical fish Prochilodus lineatus. Ecotoxicology and Environmental Safety 119:125-132.

Pandey G, Madhuri S, Shrivastava A (2014) Fish cancer by environmental pollutants, 1st Edn. Narendra Publishing House, Delhi, India.

Pergalini M, Visciano P, Manera M et al. (2014) Heavy metals (As, Cd, Hg, Cu, Zn, Se) concentrations in muscle and bone of four commercial fish caught in the central Adriatic Sea, Italy. Environmental Monitoring and Assessment 186:5397-5407.

Puntoriero ML, Cirelli AF, Volpedo AV (2018) Histopathological changes in liver and gills of Odontesthes bonariensis inhabiting a lake with high concentrations of arsenic and fluoride (Chascomús lake, Buenos Aires Province). International Journal of Environmental Pollution 64:1-12.

Ram B, Han Y, Yang G, Ling Q, Dong F (2019) Effect of hexavalent chromium [Cr(VI)] on phytoremediation potential and biochemical response of hybrid napier grass with and without EDTA application. Plants 8:439.

Rashed MN (2001) Monitoring of environmental heavy metals in fish from Nasser Lake. Environment International 27:27-33.

Ravera O, Boene G, Dantas M, Lodigiani P (2003) Trace element concentrations in freshwater mussels and macrophytes as related to those in their environment. Journal of Limnology 62:61-70.

Ruparelia SS, Verma Y, Saiyed SN, Rawal UM (1990) Effect of cadmium on blood of tilapia Oreochromis mossambicus (Peters) during prolonged exposure. Bulletin of Environmental Contamination and Toxicology 44:525-531.

Salvaggio A, Marino F, Albano M et al. (2016) Toxic effects of zinc chloride on the bone development in Danio rerio (Hamilton, 1822). Frontiers in Physiology 7:502.

Sankar TV, Sivaperumal P, Nair PGV (2006) Heavy metal concentrations in fish, shellfish and fish products from internal markets of India vis-a-vis international standards. Food Chemistry 102:612-620.

Sarasamma S, Audira G, Juniardi S et al. (2018) Zinc chloride exposure inhibits brain acetylcholine levels, produces neurotoxic signatures, and diminishes memory and motor activities in adult zebrafish. International Journal of Molecular Sciences 19:3680.

Sehgal R, Saxena A (1986) Toxicity of zinc to a viviparous fish Lebistes reticulatus (Peters). Bulletin of Environmental Contamination and Toxicology 37:225-230.

Singh H, Reddy TV (1990) Effect of copper sulfate on hematology, blood chemistry and hepatosomatic index of Indian catfish, Heteropneustes fossilis (Bloch), and its recovery. Ecotoxicology and Environmental Safety 20:29-41.

Skidmore JF (1970) Toxicity of zinc compounds to aquatic animals, with special reference to fish. Reviews in Fish Biology and Fisheries (historical reference; modern equiv. Water Research 4:227-253).

Snow ET (1992) Metal carcinogenesis: mechanistic implications. Pharmacology & Therapeutics 53:31-65.

Solomon F (2009) Impacts of copper on aquatic ecosystems and human health. Environmental Communities 1:53-59.

Sonmez AY, Hisar O, Yanik T (2012) Detection of heavy metal pollution in Karasu River and classification according to water quality. Faculty of Agriculture Journal 23:69-77.

Sprague JB (1964) Lethal concentrations of copper and zinc for young Atlantic salmon. Journal of the Fisheries Research Board of Canada 21:1183-1218.

Svobodova Z, Celechovska O, Kolora J, Randak T, Zlabek V (2004) Assessment of metal contamination in the upper reaches of the Ticha Orlice River. Czech Journal of Animal Science 49:57-65.

Tarrio JT, Jaffor MF, Ashraf M (1991) Levels of selected heavy metals in commercial fish from five freshwater lakes in Pakistan. Toxicological & Environmental Chemistry 33:133-140.

Agency for Toxic Substances and Disease Registry (2007) Toxicological profile for lead. US Department of Health and Human Services, Atlanta, GA.

Tsubaki T, Irukayama K (1977) Minamata disease: methyl mercury poisoning in Minamata and Niigata, Japan. Elsevier Scientific Publications.

Vergilio CS, Moreira RV, Carvalho CEM, Melo E (2013) Effects of mercury on male gonad and sperm of tropical fish Gymnotus carapo in vitro. E3S Web of Conferences 1:13004.

Vetillard A, Bailhache T (2005) Cadmium: an endocrine disrupter that affects gene expression in the liver and brain of juvenile rainbow trout. Biology of Reproduction 72:37-41.

Vutukuru SS (2003) Chromium induced alterations in some biochemical profiles of the Indian major carp, Labeo rohita (Hamilton). Bulletin of Environmental Contamination and Toxicology 70:118-123.

Wang Y, Fang J, Leonard SS, Rao KM (2004) Cadmium inhibits the electron transfer chain and induces reactive oxygen species. Free Radical Biology & Medicine 36:1434-1443.

Wepener V, van Vuren JHJ, du Preez HH (2001) Uptake and distribution of a copper, iron and zinc mixture in gill, liver and plasma of a freshwater teleost, Tilapia sparrmanii. Water SA

27:99-108.

Zhang Z, Shen Q, Xu S et al. (2017) Effects of cadmium on respiratory burst, intracellular Ca^{2+}, and DNA damage in the white shrimp Litopenaeus vannamei. Aquatic Toxicology 198:1-10.

Author Contributions
All the authors conceived the concept, wrote and approved the manuscript.

Acknowledgements
Not applicable.

Funding
Not applicable.

Availability of data and materials
Not applicable.

Competing interest
The authors declare no competing interests.

Ethics approval
Not applicable.

Citation: Samiksha Sharma and Manik Sharma (2026) Heavy Metals: A Desolation for Fishes. Toxicol TIMES 1 (1): 21-31.