



Effect of Bioaccumulation and Bioremediation of Heavy Metal in Fish Physiology- A Review

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Abstract

Heavy metals are one of the major parameters of concern for analysing pollution level in aquatic ecosystem. Contamination of heavy metal shows drastic degradation of health in fish and notably damages the water quality of rivers. Accumulation of heavy metal increases oxidative stress in fish and extreme effect of heavy metal act as carcinogenic element for fish. Histo-pathological alteration in fish also happens because of the exposure of heavy metal. Different haematological changes and biochemical alteration are introduced by heavy metal in fish. DNA and some genetic abnormalities also occur due to the over expression of heavy metal. Rapid urbanization and industrialization are considered to be the main reason for increasing pollution on riverine system. In this review paper, biochemistry of different heavy metals and effect of heavy metals in fish are analyzed. Main purpose of this study is to examine toxic forms and various toxic properties of heavy metals and how heavy metals harm physiological properties of living beings and what are the target organs in fish physiology for the effect of heavy metal contamination. In conclusion, it is clearly described the impact of heavy metal on fish health, reason behind the increase of heavy metals contamination and their preventive measure.

Keywords: Heavy metal, oxidative stress, genetic abnormality, urbanization.

Introduction

Among the five major elements on Earth, Water is one of the major elements for continuing life on Earth. Because of the urbanization and industrialization, water bodies face various disturbances and for that physical and chemical integrity of water undergo alteration and because of this instability, the life present in water bodies such as fish also experiences multiple disturbances.

Heavy metals are defined as such metals which have high atomic weight and high density and these are metallic chemical elements and metalloids act as very toxic elements and biochemical poison for environment. Some lighter metals such as selenium, arsenic and aluminium are very toxic but some heavier metals such as gold is typically not toxic for environment. Pollution related to heavy metal is under great concern because of growing industrial and agricultural phenomenon (Briffa *et al.*, 2020). Heavy metals are one of the most dangerous water pollutants because of their bio accumulating and biomagnifying abilities and it is very difficult to remove heavy metal from the body of living beings through metabolism. (Elbesht *et al.*, 2018). Heavy metal such as Arsenic (As), Cadmium (Cd), Chromium (Cr), Lead (Pb), Mercury (Hg), Nickel (Ni) and Zinc (Zn) act as persistent environmental pollutants (PEP) which can cause threat to life and may responsible for environmental degradation. Primary source of heavy metal contamination is industrial discharges, domestic sewage, agricultural runoff and mining activities. Concentration of Arsenic and Mercury are very high in marine fish and concentration of Lead and Cadmium are significantly high in fresh water fish. If those contaminated fishes are consumed by human, it may cause serious health problems like neurological disorders, kidney damage and different carcinogenic diseases also (Pandey *et al.*, 2024). Effect of heavy metal on juvenile period of a fish may alter both structural and functional aspects of different organ which are responsible for enzymatic and genetic functions and therefore innate immunity of suffered fishes may also be affected and so that different disease can easily harm those affected fish species. The increasing level of heavy metals in the environment is the alarming condition for researchers to analyze how to reduce the over spreading of heavy metal in the environment (Agbugui *et al.*, 2022). Heavy metals are also considered as nutrient because they show vital role by doing benefit on fish health but heavy metals turn into toxic product when their concentration rise and they become poisonous for both fish and human. One of the significant reasons behind the toxic effect of heavy metal is their non biodegradable nature. Heavy metals also show severe negative impact on fish development, swimming, reproductive health and spawning of fish. One of the major effect of heavy metal on fish health is the endocrine disruption of fish species (Wasif *et al.*, 2024).

Fish is one of the most important food sources for human because of their high nutritional values providing protein, omega-3-fatty acid with low cholesterol level and different vitamin as well as mineral. Heavy metals enter into the human body through fish by consuming fish as food by human and may show drastic degradation of human health with their various effects including carcinogenic effect. Specially Arsenic and Cadmium effect on human health severely. Effect of heavy metal is higher in *Clarias gariepinus* compared to *Oreochromis niloticus* and

Gill consumes very high level of heavy metal and muscle consume very low level of heavy metal (E.B. Ogbuene *et al.*, 2023).

SOURCES OF HEAVY METALS

Natural Activities

Heavy metals are present naturally on Earth crust since Earth formation and heavy metals are also important for environment but in very less amount. Excessive amount of heavy metals act as life threatening elements for all. Forest fire, soil erosion, volcanic eruption, geological weathering and disintegrating rocks can increase the amount of heavy metal to the ecosystem are contribute to disrupt the environment severely (Kumar and Raju, 2025). Severe air pollution, soil pollution and river sediments also increase the heavy metal in the ecosystem and these toxic substances enter into the food chain and cause drastic abnormalities in different living beings (Zwolak *et al.*, 2019).

Anthropogenic activities

In the agricultural sector, different pesticides and different fertilizers are used to inhibit herbicide, insecticides, rodenticides, fungicides, nematocides. Pesticides and fertilizers are generally composed of some dangerous heavy metals such as Zink, Cadmium, and Chromium. These heavy metals are released into aquatic environment through pesticides and fertilizers used in the paddy fields and cause adverse effect on aquatic animals such as fish and human beings (Agbugui, 2013).

Industrial activities such as coal mining industries, mineral processing, thermal generation, battery manufacturing industries, chip manufacturing, metal coating industries, fertilizer industries, hard metal sectors, electrical and electronic equipments, dyes industries, wood production materials, textile industries, metal planting and electronic manufacturing, smelting, plastic industries, printing industries, nuclear reactor shielding, radioactive substances vessel manufacturing, metallurgical industries, chemical production metal coating mineral extraction processes, fluorescent light lamps fungicides and different environmental wastage activities such as drainage system, garbage dumps release different poisonous substances such as Arsenic, Cadmium, Chromium, Lead, Murcury, Nickel and Zinc (Angon *et al.*, 2024).

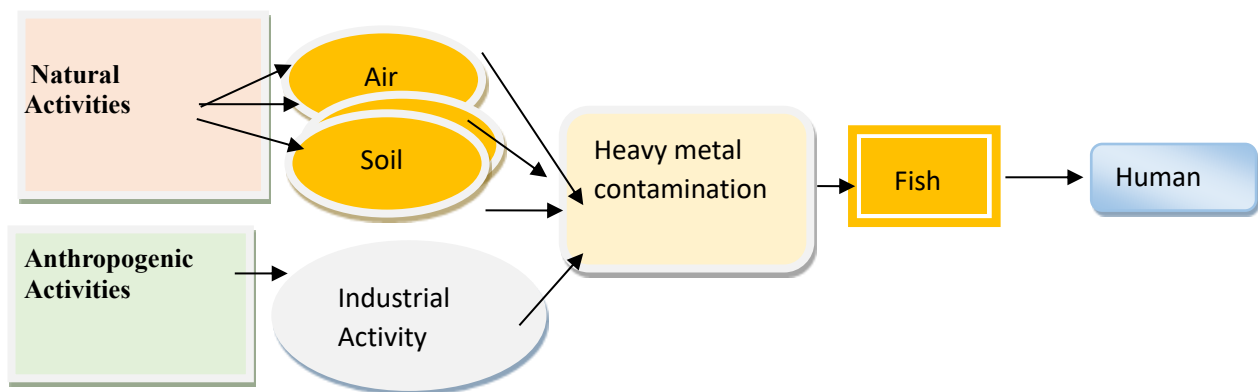


Figure 1: Accumulation of heavy metal in living beings through food chain

PROPERTIES OF HEAVY METALS

Arsenic (As): Arsenic is extremely toxic non essential heavy metal with atomic number 33. Generally As is present in two forms, As(III) and As(V) but in ecosystem, As has four different forms such as Arsine Gas (AsH_3), metalloid form (As^0), organic (As^{3+}) and inorganic form (As^{5+}) (Jadaa and Mohammad, 2023). AsH_3 (Arsine Gas) is the most toxic form of arsenic and inorganic form of arsenic is more toxic as compared to organic form (Gomaa and Rahman, 2022).

Cadmium (Cd): Cadmium is one of the extremely toxic heavy metal with atomic number 48 and atomic weight 112.41 and it is one of the transition element in group 12 of the periodic table. Melting point and boiling point of Cd is 321°C and 767°C respectively. Cd produce bright light by forming Cadmium Oxide (CdO) when it burns in air (Mustapha *et al.*, 2023). Solubility of Cd and its ions in water are very high thus Cd can easily travel in water and soil and their bioaccumulation tendency is also very high (Sarma *et al.*, 2015).

Chromium (Cr): Chromium is an essential micro nutrient with atomic number 24. Chromium has various forms on the basis of its valence states but most stable form Chromium is the trivalent Chromium i.e. Cr(III) and hexavalent Chromium i.e. Cr(VI) (Barnhart, 1997). Cr(III) is harmless because it has very low membrane permeability into the cell but Cr(VI) can easily penetrate the plasma membrane of a cell, so Cr(VI) is highly toxic and act as strong oxidizing agent. Cr(VI) is highly mutagenic and it belongs to group I carcinogenic metal (Rajeswari and Sailaja 2014).

Lead (Ld): Lead is an extremely toxic non essential and non degradable heavy metal with atomic number 82 in the periodic table (Steinnes, 2013). Lead is a soft and malleable and the melting point is also very low. Colour of lead is a silvery bluish like but it turns into gray when it is exposed with air. When oxide of lead is in contact with acid and bases, it can form covalent bond (Boldyrev *et al.*, 2018). Lead in soil is mostly present in +2 oxidation state but its solubility become decreased by increasing pH in soil solution because of its complex chemical condition with organic matters. When soil becomes alkaline, the solubility within the soil drastically decreases which makes the lead as a non-biodegradable toxic chemical. (Han *et al.*, 2023).

Mercury (Hg): Mercury is highly toxic non essential metal with atomic number 80 present naturally in two forms, element and sulphide (Si and Ariya, 2018). Density and conductivity of mercury have very high due to which Hg becomes valuable for various industrial and scientific uses. Mercury is the only metal that available in liquid form at room temperature and so that it evaporates easily. If the vaporized form of Hg comes in contact with human, it may cause dangerous effect on human health (Qadiri and Ijet, 2025). Toxicity of mercury varies according to its form whether it is elementary mercury, inorganic mercury and organic mercury. Methyl mercury i.e. the simplest form of mercury is considered possibly carcinogenic according to International Agency for Research on Cancer (Mahurpawar, 2015).

Nickel (Ni): Nickel is an essential micronutrient with atomic number 28 and it appears as silvery - whitish in coloration. Though Ni mostly expressed as Ni^{2+} but its valence state is ranging in between -1 to +4. Ni exists in solid phase in pH 6.7 or above (Gench *et.al.*, 2020). For producing thin films, Nickel electro-deposition is widely used (Zelleet *et.al.*, 2024). Ni is extracted by heating it to Nickel oxide and then reducing with carbon. Ni is also a carcinogenic and allergen product (Anand, 2012).

Zinc (Zn): Zinc is an essential multivalent metal with atomic number 30. Zinc is a stable metal in the atmosphere which makes the Zn one of the most energy storage materials (Shin and Pharr, 2024). Vegetables, beef, dairy products are good source of Zn for safe consumption but Zn becomes toxic through the over dosage of Zn supplements. Zn toxicity in human being can easily be treated (Hussain *et.al.*, 2022). In biological and geological system, Zn is found in Zn(II) form. Though Zn is not redox sensitive metal but it may reduced to Zn(0) after Zn got exposure of high temperature with industrial high temperature. Zn is used to produce fertilizer, pesticides and electro-planting and released to environment through mining smelting process (Junqueira *et.al.*, 2024).

EFFECT OF HEAVY METAL IN FISH HEALTH

Heavy metals are non-biodegradable in nature make them highly toxic for fishes and other living beings. Through the production of oxidizing radical, heavy metals produce high amount of reactive oxygen species (ROS) which destroy several physiological functions such as haemato-biological, histopathological and immunological parameters and can cause different disease (Md. Shahjahan *et.al.*, 2022).

Effect of Arsenic (As) in Fish: Arsenic is naturally occurring poison metalloids available in Earth's crust in soil, water and air. Arsenic presents in both organic and inorganic forms and inorganic Arsenic is more toxic than organic form.

Very high Arsenic concentration in groundwater shows concerning effect on the health of living beings in recent period. When *Channa punctatus* is exposed with sodium arsenite ($NaAsO_2$) with very high concentration, then *C. punctatus* experienced death and when $NaAsO_2$ effected on Liver of *Channa punctata*, then fragmentation of liver chromosomal DNA was observed (Das *et.al.*, 2012). Due to the harsh exposure of As(III), fish species like Crucian carp experienced tissue damage, unbalanced body movement, mucus shedding, open gill cover, white gill filament and after death of fishes, they were floated on the water surface (Tang *et.al.*, 2024). When *Heteropneustes fossilis* was highly exposed to Arsenic, then hexokinase in muscle was decreased and glycogen granules in liver were shown in depleted concentration. Carbohydrate metabolism was also altered due to the toxic effect of Arsenic (Tariang *et.al.*, 2019). Severe exposure of Arsenic contaminated water easily entered into the body of fish through gill, buccal cavity and skin. Intestine, gill, liver, muscle and kidney tissue were highly affected through high level of Arsenic exposure (Garai *et.al.*, 2021). In intestine, bioaccumulation of Arsenic was in high concentration and consumption of As(V) was relatively higher than As(III) (Pei *et.al.*, 2019). Aspartate amino transferase and alanine amino transferase were primarily found in liver but when Arsenic showed severe impact on liver, then these enzymes released into the blood from liver and increased the hepato-toxicity (Gaimet *et.al.*, 2015). Arsenic was responsible for inducing hyperglycemia and increased the acute, chronic toxicity and abnormalities in immune system in fish physiology. Arsenic also decreased the enzymatic activities of liver enzyme (Kumari *et.al.*, 2017). In *C. batrachus*, arsenic toxicity gradually decreased the haemoglobin content which induced anemia condition (Kumar and Banerjee, 2016). Arsenic contamination changed foraging and aggressive behaviour in fish physiology (Magellan *et.al.*, 2014).

Effect of Cadmium (Cd) in Fish: Cadmium is a naturally occurring metal in Earth's crust but Cadmium induces major threat to freshwater ecosystem due to their rising amount, elevated stability, biomagnifications and bioaccumulation quality. Accumulation of Cadmium is varying in species to species.

In *Carassius auratus*, Cadmium was in highest concentration in gill and in minimum concentration in bones. Concentration of WBC, RBC, platelets and values of haemoglobin and hematocrit were significantly decreased in *C. auratus* and mean corpuscular volume (MCV), mean corpuscular haemoglobin (MCH) and mean corpuscular haemoglobin concentration (MCHC) increased in *C. auratus* during the cruel exposure of Cadmium. Different biochemical enzymes such as serum glutamic pyruvic transaminase (SGPT), blood urea, serum triglycerides, high density lipoprotein, serum albumin, serum uric acid and serum alkaline PO_4 were tremendously increased to uppermost limit in *C. auratus* due to extreme exposure of Cadmium (Ali *et.al.*, 2025). When *Paralichthys olivaceus* exposed to waterborne Cadmium, hematocrit, haemoglobin concentration and plasma calcium were decreased significantly on the otherhand, plasma glucose and plasma cholesterol were significantly increased but there was no effect on plasma protein. Concentration of Plasma GOT and GPT were increased but Plasma ALP enzyme did not show any alteration in their concentration. Different antioxidant enzymes such as SOD, CAT and GST in *P. olivaceus* were extensively increased and AChE in *P. olivaceus* was inhibited due to extreme exposure of Cadmium. Liver HSP70 level in *P. olivaceus* was surprisingly increases after the exposure of Cadmium concentration (Lee *et.al.*, 2022). Cadmium primarily effect on the gill of fish and changes the structural and

functional appearance of gill and basically induces apoptosis, necrosis and inflammation on fish's gill. Cell proliferation, gill lamella bending, swelling of mitochondria, oxidative damage are caused because of the toxic effect of Cadmium. High level of Cadmium concentration alters the structural organization of Liver through endoplasmic reticulum expansion, nuclear deformation, nuclear membrane and mitochondrial swelling and so on. Cadmium contamination alter the reduction related hormonal regulation and damage the ovarian tissues and sperm tissues which may decreases the reductive ability of a fish species(Liu *et.al.*, 2022). Higher level of Cadmium contamination causes behavioural alteration such as changes in swimming pattern, irregular fin movement, trouble in breathing and also effect on genotoxicity level such as DNA damage and chromosomal abnormalities (Jayasvalet.*al.*, 2025).Cadmium breaks the immune and anti oxidant system which cause cancerthrough DNA mutation and damage (Lee *et.al.*, 2024).

Effect of Chromium (Cr) in Fish:Chromium is one of the important metals for physiology to maintain the physiological homeostasis. Deficiency of Chromium can cause diabetic like symptoms in health but over exposure of Chromium is also not good for health.

Over expression of Chromium causesbehavioural, physiological, immunological, morphological and genetic change in fish. Very high exposure of chromium causes erratic swimming, swollen of gill filament, lamellar fusion, epithelial lifting, thickening of gill rakers, accelerated operculum, slow motility, abnormalities in fin and scale structure (Biswas *et.al.*, 2023).Glycogen level, protein content, cholesterol level of liver, muscle, kidney and gill of *Labio rohita* were tremendously decreased with increased time period of Cadmium exposure(Dhanalakshmi *et.al.*,2012). Due to the severe exposure of Chromium in *Channa striatus* fish, Protein level in gill, liver and kidney was drastically decreased but Amino acid level in gill, liver and kidneylevel was significantly increased (Palaniappan *et.al.*,2016). Haemoglobin, nuclear structure of erythrocyte and number of RBC decrease during strong exposure of Chromium which cause anaemia, erythropenia, leucopoiesis etc in fishes (Islam *et.al.*, 2020).Chromium increases DNA damage that initiate decrease of growth and survival rate of fishes. Function associated with lactate dehydrogenase reduces drastically with increasing concentration of Chromium(Ghosh and Saha, 2022).Glomerular shrinkage, degradation of renal tubule, epithelial necrosis of kidney, hepatocellular vacuolization, cytoplasmic degeneration, nuclear pyknosis in liver are main symptoms occur because of extreme exposure of Chromium (Mahapatra and Dixit, 2025). Excessive concentration of Chromium(VI) induceshypoxia with very low level of oxygen, decreases glycogen level in liver increases the glycemic concentration in blood of fish and modify the enzymatic activities like succinate dehydrogenase, latate dehydrogenase and pyruvate dehydrogenase in brain, liver and kidney of fishes etc.(Aslam and Yousafzai, 2017).In *P. hypophthalmus*, when treated with potassium dichromate ($K_2Cr_2O_7$), different abnormalities in blood were observed. Nucleus with elongated, twin, fusion, teardrop and echinocytic structure were examined. Erythrocytic nuclear abnormalities (ENA) and erythrocytic cellular abnormalities significantly increased due to the exposure of Chromium in *P. hypophthalmus*(Islam *et.al.*, 2020).

Effect of Lead in Fish: Lead is generally available in Earth's crust through various natural substances such as plant, rocks, air, water and soil. Lead is not an essential nutrient instead of lead causes hazardous effect in fish physiology.

Very high exposure of lead showed genotoxic effects such as DNA damage, DNA fragmentation in*Cyprinus carpio*. When lead nitrate effected onthe gill of*Cyprinus carpio*, shortening of secondary filaments and fusion of adjacent lamellae were observed (Sarma *et.al.*, 2024). Over expression of lead causes death of fishes. Over expression of lead decreases the Na^+ influx rate into the cells. Excessive expression of lead initiates histopathological alteration in gill of fishes such as lamellar aneurism, hyperplasmia, epithelial lifting and hyperglycemia condition with low lipid and protein level is also occurred with hyper expression of lead (Martinez *et.al.*, 2003). Erratic swimming, hyper secretion of mucus, heavy breathing, strong movement of operculum etc are also observed because of extreme secretion of lead and fish lost their equilibrium through over expression of lead (Kim *et.al.*, 2019). Lead also decreases the haemoglobin level in fish which may cause anaemia condition and lead causes cardiovascular disease in fish that severely affect the growth and development of fish. Liver and kidney are also effected when lead crosses its threshold point during expression(Lohar *et.al.*, 2025).Nuclear rupture, necrosis, cell rupture, liver damage with formation of large vacuole and alter the secretion of liver enzymes etc are also observed in fish due to the acute exposure of lead(Mahi *et.al.*, 2022).In *Heteropneustesfossilis*, Plasma calcium level and plasma phosphate level decreased progressively when lead nitrate showed significant exposure on it (Srivastav *et.al.*, 2013).In *Nile tilapia*, serum estradiol level, serum FSH level, serum prolactin level, serum cortisol level, and serum thyroid level were increased significantly serum progesterone level, serum testosterone level and serum LH level decreased noticeably due to very high exposure of lead(Sayed *et.al.*, 2013).

Effect of Mercury in Fish:Mercury isahighly toxic substance and it doesn't have any positive impacts for living beings. Very less quantity of Mercury can cause severe and irreversible negative impacts on human health such as it damages nervous system, digestive system, immune system, brain and kidney. Mercury is strictly regulated worldwide after Minamata convention.

Contamination of mercury penetrates plasma membrane of cells which show negative impact on cellular metabolism and physiological system by altering the enzymatic reactions.Bioaccumulation of mercury into nervous system and kidney cause organ damage in fish. Excessive exposure of mercury increases the production of oxidative stress by synthesizing reactive oxygen specieslike hydrogen peroxide and superoxide anion which results in DNA damage, chromosomal alteration, nitric oxide production, enzymatic degradation in blood(Kumar *et.al.*, 2025).Histo-pathological changes in gill, liver, and hepato- pancrease such as pale gills, depletion in gaseous

exchange, lamellar fusion, necrosis, cell lysis, liver hepatocytes and morphological changes such as whitish body color, anemic eyes etc are observed in fish due to accumulation of mercury in fish. Effect of mercury varies in different organs in the order Muscle > eye > bone > head > gill (Suhendrayatna *et al.*, 2019). When gill, liver and stomach of *Clarias batrachus* exposed to mercury chloride, gill tissue showed rupture in epithelial layer, club shaped gill filaments, broken gill lamellae, hyperplasia of interlamellar epithelium and deletion of some secondary lamellae, vacuoles formation, blood conjugation, necrosis in gill filament, simultaneously, liver tissue showed hepato-cellular dissociation some inflamed hepatocytes, cloudy swelling, vacuole formation and hydropic degeneration, necrosis, vacuolization and demolition of portal vein continuing with stomach tissue, thinner serosa, vacuolization in circular muscle layer, cellular dissociation in mucus and submucosa, vacuolization in sub mucosa, muscle damage in a circular muscle layer and necrosis (Mishra and behera, 2023). Enlargement of nucleus, lateral nuclei, nuclear degradation, vacuolation of nucleus and brain dysfunction occur in the cells because of the bioaccumulation of Mercury into the fish (Thangam and Manju, 2015). Over expression of mercury alter the genes related with hypothalamic-pituitary-gonadal axis and modify the level of sexual hormone which show severe impact on reproductive health of fish. Initial stage of fish is very sensitive for mercury effect. Accumulation of mercury damage the nervous system by altering the central nervous system, numbers of neurotransmitter and neuroglia which may change the pattern of swimming of fish and other physiological changes (Omachet *et al.*, 2023).

Effect of Nickel in Fish: Nickel is one of the essential elements for living beings though severe exposure of nickel can affect health of animals but less amount of nickel is crucial for functioning of various enzymes such as nickel is essential for the formation and functioning of cGMP and nickel is also essential for the activation of calcineurin. Nickel toxicity in fish induces reactive oxygen species (ROS) cause oxidative damage and hypoxia condition in fish. Ca^{+} and Mg^{+} homeostasis disruption are occurred due to contamination of toxic Nickel into the cells of fish (Brix *et al.*, 2016). In *Oreochromis niloticus*, serum sodium, chloride and osmolality were noticeably decreased but serum glucose, cholesterol, total protein, albumin and the activities of amylase, lipase, ALT, and AST were significantly increased with exposure of nickel. With severe exposure of Nickel, the gill of *O. niloticus* faced drastic changes such as hyperplasia, increased proliferation of cells, hypertrophy, shortening of secondary lamellae, fusion of adjacent lamellae and adjacent filaments because of severe exposure of Nickel (Attar, 2007). Severe exposure of Nickel decrease the serum sodium, chloride and osmolarity in fish and increase the blood glucose level in the blood of fish. Histo-pathological alteration is also observed in gill such as shortening of secondary lamella, hyperplasia, hypertrophy hyper-fusion of adjacent lamella, some stress hormones such as adrenalin and cortisol show hyper-secretion of blood and blood glucose level is significantly increase due to excessive accumulation of Nickel in fish. Significant alterations of liver enzymes indicate tremendous hepato-cellular damage in fish liver (Ali, 2024). Nickel contamination induces oxidative damage to DNA and protein which inhibit the cellular antioxidant resistance of cells in fish. Bioaccumulation of excessive nickel also effect on opercular movement, gaseous exchange and loss of equilibrium in fish. Concentration of glycogen decreases in muscle and liver with increase of lactic acid in blood which occurs due to the heavy accumulation of Nickel in fish (Svecevicus, 2009). Dissolved oxygen level is decreased and Carbon-di-oxide level is increased and blood parameters such as erythrocytes, leucocyte, and haemoglobin count decrease drastically with extreme contamination of Nickel. Several stress responses also initiate in fish with the short term exposure of Nickel in the fish (Ghanim, 2011).

Effect of Zinc in Fish: Zinc is one of the essential micronutrient which play significant role for various physiological activities such as survival, growth and reproduction. Zinc is an important cofactor for DNA polymerase as well as RNA polymerase. Overall, zinc has multiple roles in molecular biology. But overexposure of Zinc can change physiological activities of living beings.

Zinc primarily effect in liver, kidney, gill, scales, skin and muscle but liver is the organ which show tremendous degradation after accumulating Zinc (Javed, 2012). Indeposition of Zinc through diet causes damage in anti-oxidation capacity by inhibiting antioxidant enzyme and gene expression in the intestine. Stress in endoplasmic reticulum and enzymatic alteration of tight junction happen due to the exposure of Zinc into fish (Xu *et al.*, 2023). Extreme accumulation of Zinc increases the mortality of fish and zinc affects the brain tissues severely (Saddicket *et al.*, 2015). Zinc contamination causes hypoxia condition by reducing respiratory surface of gill, over secretion of mucus by inter lamellar space in gill, fusion of secondary lamellae, reduction in length, swelling and bulging of epithelial cells of secondary lamellae, cytoplasmic vacuolation necrosis in the tip of secondary gill lamellae and gill ray degradation are happen because of very high exposure of Zinc in the gill of fish. Interstitial edema is one of the most common lesions experienced in the gill epithelia because of the bioaccumulation of Zinc in the fish. Liver is another organ which shows drastic changes due to the exposure of Zinc. Vacuolation, dilated blood capillary and loose arrangement of hepatocyte in liver are the main symptoms occur due to the exposure of Zinc in fish. Thick lining in Bowman's capsule, degenerated glomerulucs, capsular space increase with swelling and necrosis in renal tubules occurs in kidney due to the acute exposure of Zinc in fish (Srivastava and Prakash, 2019).

Table 1. Summary of the effects of different heavy metals on fish physiology

Heavy Metals	Toxic Forms	Effects on Fish Health

Arsenic	AsH ₃ (Arsine gas)	Tissue damage, unbalanced body movement, mucus shedding, open gill cover, white gill filament, hyperglycemia, chronic toxicity, abnormalities in immune system, decreases the enzymatic activities of liver enzyme.
Cadmium	Cd ²⁺ (Cadmium ion)	WBC, RBC, platelets and values of haemoglobin and hematocrit are decrease, MCH, MCH and MCHC increase, hematocrit, haemoglobin concentration and plasma calcium were decreased, plasma glucose and plasma cholesterol were increased, apoptosis, necrosis, cell proliferation, gill lamella bending, swelling of mitochondria, oxidative damage are caused
Chromium	Cr(VI) (Hexavalent Chromium)	Erratic swimming, swollen of gill filament, lamellar fusion, epithelial lifting, thickening of gill rakers, accelerated operculum, slow motility, abnormalities in fin and scale structure, anaemia, erythropenia, leucopoiesis, DNA damage
Lead	Pb ²⁺ (Lead ion)	DNA damage, DNA fragmentation, toxic central nervous system, neurotoxicity, neurotransmitter malfunction and synaptic damage, imbalance immune system, anaemia condition and lead causes cardiovascular disease.
Mercury	Hg ⁺ (Mercury ion)	Organ damage, oxidative stress, pale gills, depletion in gaseous exchange, lamellar fusion, necrosis, cell lysis, liver hepatocytes, morphological alteration, Enlargement of nucleus, lateral nuclei, nuclear degradation, vacuolation of nucleus and brain dysfunction
Nickel	Ni ⁺ (Nickel ion)	Oxidative damage and hypoxia condition, Ca ⁺ and Mg ⁺ homeostasis disruption, hyperplasia, increased proliferation of cells, lamellar shortening of secondary lamellae, fusion of adjacent lamellae and adjacent filaments in gill, hypersecretion of adrenalin and cortisol, opercular movement, gaseous exchange and loss of equilibrium, Dissolved oxygen level is decreased and Carbon-di-oxide level is increased and erythrocytes, leucocyte, and haemoglobin count decrease.
Zinc	Zn ⁺ (Zinc ion)	Damage in anti-oxidation capacity, hypoxia condition, inter lamellar space in gill, fusion of secondary lamellae, reduction in length, swelling and bulging of epithelial cells of secondary lamellae, cytoplasmic vacuolation necrosis

Discussion

As India is a developing country, most of the water bodies serve as the main source for conducting different industrial, agricultural, household activities. So different pollutants easily deposit and threaten the aquatic ecosystem of water bodies (Zahran *et.al.*, 2025). Heavy metals easily transfer into water bodies from various sources and accumulate into living beings through food chain and effect on health. Fishes are exposed to heavy metal through gill and skin rapidly. Within the fish, heavy metals are metabolized, excreted, stored, bio accumulated (Kumar *et.al.*, 2024).

Bioaccumulation of heavy metals varies among species to species of fishes. Carnivorous fishes accumulate more toxicity through contamination of heavy metals than omnivorous and herbivorous fish (Khan *et.al.*, 2020). Bioaccumulation of heavy metals is also on the basis of size, gender, body weight, sexual maturity and food sources of fishes (Sharma *et.al.*, 2024).

As some metals are essential micronutrient and some are highly toxic. Availability of these toxic metals make the water highly toxic. The toxicity of aquatic ecosystem basically depends on the types of metal, their capacity of contamination on fishes and other aquatic life. Fish are often mostly vulnerable to heavy metal because their feeding habit is primarily depend on aquatic ecosystem, therefore constantly exposed to pesticides and various pollutants like heavy metal (Emon *et.al.*, 2023). Effect of heavy metal on fish mainly depends on concentration and exposure duration of metals on fish. Small or juvenile fish species are highly affected than large fish and penetration of heavy metal on fresh water fish is more as compared to salt water fish species (Singh *et. al.*, 2024). Heavy metals destroy different organs of fishes; especially gill, liver and kidney are mostly affected because heavy metal are easily exposed through gill, digested through liver and excrete through kidney. Whole physiology can change after the toxicity of heavy metal on fish (Rosada *et.al.*, 2024).

Conclusion

Heavy metals are important metals for health but excessive consumption of these metals act as one of the major environmental pollutants. Contamination of heavy metal in fish cause severe physiological alteration in fish. Bioaccumulation, biomagnifications and toxic effects of heavy metals in fish are discussed in the present study. Bioaccumulation of heavy metal and their effect gain considerable attention in recent years because of their extreme effect in living beings. Industrial and natural sources easily increase the heavy metal concentration in the Environment. Analyzing how to reduce heavy metal contamination and identifying the source of heavy metals are crucial for effective environmental management. Lead, Arsenic and Cadmium are the most dangerous metal for living beings with their prominent possible health risks. Agriculture also increases the amount of heavy metal in Environment therefore it is very important to implement well designed sustainable agricultural plan for preventing the increase of heavy metal contamination. Even though heavy metal poisoning can be treated, the best choice is to prevent pollution associated with heavy metal. Researchers should study the effects of heavy metals and mechanisms to control the extreme effect of heavy metal in fish.

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