Review Article

A Review on Effects of Heavy Metals on Aquatic Animals and Public Health Significance

Maria Al Mazed[1]*, Md. Ashikur Rahman[1] and Sk. Istiaque Ahmed[2]

[1]Freshwater Station, Bangladesh Fisheries Research Institute, Mymensingh, Bangladesh; [2]Department of Fisheries Resource Management, Chattogram Veterinary and Animal Sciences University, Bangladesh.

Abstract | Heavy metals such as As, Pb, Hg, Cd, Cr, Fe, Mn, Ni and Zn are usually toxic for the aquatic ecosystem. Exposure of heavy metals in the aquatic organisms is linked to the retardation of growth, lesions in liver and damages in kidney. They are also causing infertility in animals. Chronic exposure and excessive concentrations are also deleterious for the normal physiological functions of human. Consumption of fishes contaminated with toxic metals are neurotoxic and carcinogenic to blood, lungs, kidneys, bones, liver and other vital organs of human. The present review outlines the contamination of aquatic environment with heavy metals and their contagious effects on aquatic animals and their public health concerns.

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***Correspondence** | Maria Al-Mazed, Freshwater Station, Bangladesh Fisheries Research Institute, Mymensingh, Bangladesh; **Email:** mariaalmazed7379@gmail.com
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Introduction

Fish is considered as one of the most important protein sources for human (Balami *et al*., 2019; Karayakar *et al*., 2022). Fish may also concentrate large amounts of some metals from the water (Mansour and Sidky, 2002) and transfer throughout the web chain into human. Of late, aquatic environment is repetitively polluted through heavy metals (HMs) from a variety of sources and right now it has anticipated a dangerous scenario for aquatic life and fish species. HMs is usually available in natural waters and some are essential to living organisms even though they may become highly toxic when existing in high concentrations. U.S. Environmental Protection Agency listed metals of major interest in bioavailability studies, are Al, As, Be, Cd, Cr, Cu, Hg, Ni, Pb, Se and Sb (Abdel-Mohsien and Mahmoud, 2015). A number of health risks can expose because of excessive intake of these metals. For instance, fish consuming heavy metals can seriously lessen some essential nutrients in the body causing a decrease in immunological defenses, intrauterine growth retardation, impaired psycho social behaviors, disabilities associated with malnutrition and a high prevalence of upper gastrointestinal cancer (Arora *et al*., 2008). There is limited comprehensive information about effects of heavy metals on aquatic animals and public health significance in humans. In this review, we attempted to provide an updated and comprehensive knowledge on the heavy metals effects and human health hazards.

Sources of heavy metals

HMs is introduced into the aquatic environment by means of natural and anthropogenic sources. They are naturally found in the earth's crust, soil, air, water and all biological substances at various concentrations, from where they are being distributed widely through the anthropogenic activities such as rapid industrialization, overgrowing urbanization, globalization, intensive agricultural practices and environment manipulation (Gupta *et al*., 2009; Vaseem and Banerjee, 2016). Industrial sources of HMs pollution are refinery, smelter, lead-based paints, lead-soldered food cans, lead plumbing pipes, auto mobile exhaust (tetraethyl lead) refinery, plastic, paints, antiseptic, scientific instruments, photography, fuel combustion, tannery, smelter, mining, electroplating, pigments (Cadmium yellow), plastics, pesticides, land application of fertilizers, animal manures, sewage sludge, pesticides, waste water irrigation, spillage of petrochemicals and Uranium mining etc. (Verma *et al*., 2018). However, the most common source of HMs pollution in the aquatic environments is come from the mining companies. Residues of toxic metals may persist in the environment and can accumulates in higher concentrations ranging from hundreds to thousands times than their concentration of water and sediments (Goodwin *et al*., 2003; Osman *et al*., 2007). Toxic heavy metals are generally accumulates in fish body directly from the environment through the contact with water and diets of fish.

Toxic heavy metals

Toxic heavy metals are individual metals and metalloids that have negative effect on human health. Heavy metals are noteworthy environmental pollutants and their toxicity is a problem of increasing significance for ecological, evolutionary, nutritional and environmental reasons (Shah, 2017). Toxic effects of heavy metals include reduction in fitness, interference in reproduction leading to carcinoma and finally death. The toxic effects usually associated with chronic exposure by pollutant heavy metals are mutagenicity, carcinogenicity, teratogenicity, immunosuppression, poor body condition and impaired reproduction (Pandey and Madhuri, 2014). Toxicity of HMs can lower the energy levels and can damage the functioning of brain, lungs, kidney, liver and blood composition and other important organs (Shah, 2017). Long term exposure to the higher concentrations of HMs leads to the gradual and progressive physical, muscular and neurological degenerative processes that initiate disease like multiple sclerosis (Shah, 2017).

Commonly encountered toxic heavy metals

- Arsenic (As)
- Lead (Pb)
- Mercury (Hg)
- Cadmium (Cd)
- Chromium (Cr)
- Iron (Fe)
- Manganese (Mn)
- Nickel (Ni)
- Zinc (Zn)

Arsenic

Arsenic (As) is an ubiquitous element, released into the aquatic environment through anthropogenic activities such as metal smelting, chemical manufacturing, and agricultural runoff (Schlenk *et al*., 1997; Singh and Banerjee, 2008). As and its compounds are very poisonous at higher concentrations. It is an important and ubiquitous environmental contaminant, that can exerts carcinogenic risks to the public health worldwide (Rossman, 2003). As exposure in the aquatic environment causes bioaccumulation in aquatic organisms and can lead to physiological and biochemical disorders, such as poisoning, liver lesions, decreased fertility, cell and tissue damage, and cell death (Bears *et al*., 2006; Ribeiro *et al*., 2005).

Lead (Pb)

Lead (Pb) is a dangerous environmental contaminant and due to its higher toxicity it can possess a great threat for human health (Afshan *et al*., 2014). Depending on the degree and duration of Pb exposure, a variety of consequences might occur. Lead accounts for most of the cases of pediatric heavy metal poisoning. Lead accumulates in the liver, kidney, brain and bone (Afshan *et al*., 2014). Newborns and young children are especially delicate to even low levels of lead (Elder and Collins, 1991). Acute Pb toxicity after absorption of contaminated seafood usually occurs in brain and kidney, and it is absorbed through the gastrointestinal tract (Markowitz, 2000) is regulated by nutritional calcium and iron status and age (children adsorb more, and consequently, are more vulnerable than adults) of exposed humans and solubility and lead species, among others (Flegal, 1986).

Mercury (Hg)

Mercury toxicity depends on its chemical form, methyl mercury is found to be more hazardous than metallic form of mercury (Verma *et al*., 2018). Mercury in the atmosphere has nearly tripled through human activities and the atmospheric burden is increasing 1.5 percent per year (Clifton II, 2007). Natural mercury arises from volcanoes, land or water surfaces due to the use of land, biomass burning, by evaporation from the ocean, meteorological conditions and gaseous mercury at air water soil snow ice exchange (Boening, 2000; Mason, 2009; Pirrone *et al*., 2001). Whereas, major anthropogenic source of mercury (~ 60% of the year 2000) is the combustion of fossil fuels (coal; stationary combustion) followed by gold mining, non-ferrous metals manufacturing, cement production, waste disposal and caustic soda production (Pacyna *et al*., 2006; Pirrone *et al*., 2010). Fish is the primary source of MeHg poisoning in humans (Rice *et al*., 2014) as well as various species of fish tend to have higher rates of MeHg bioaccumulation (Mozaffarian and Rimm, 2006).

Cadmium (Cd)

Cadmium is known as the most toxic and non-essential heavy metal (Jaishankar *et al*., 2014) and enters the environment by natural sources, such as volcanism. Anthropogenic activities such as smelting, mining nonferrous metals, production of nonferrous metals, iron and steel and the production and disposal of Cadmium containing materials (electroplating, pigments, stabilizers and Ni-Cd batteries) use phosphate fertilizers, arsenic pesticides, herbicides, fungicides, plastic stabilizers, wood preservatives and others (Thornton, 1992). Additionally, Cd chronic toxicity affects bones, causing fractures, severe pain, malformations, hypercalciuria and impaired vitamin D metabolism (Bhattacharyya *et al*., 1992). Cd is transported by blood and distributed mainly to the liver and kidney where it is long-term stored in the organism.

Chromium (Cr)

Chromium is one of the most common pollutants in the environment where Cr (VI) and Cr (III) being the most stable forms (Velma *et al*., 2009). The toxicity of chromium is mainly relate to its Cr (VI) form. In hexavalent [Cr (VI)] form, health risks of Cr exposure vary depending on its oxidation state, ranging from moderate toxicity to high toxicity (Velma *et al*., 2009). Chromium enters into aquatic environment from a wide variety of natural and anthropogenic sources like as industrial applications (leather tanning, electroplating, and corrosion protection) contaminate ground water (Palmer and Wittbrodt, 1991), discharges from manufacturing processes and cooling towers (Elwood *et al*., 1980).

Iron (Fe)

Iron is mostly abundant metal which have basic roles in cellular respiration and metabolism. Iron can switch its redox state and in case of oxygen availability convert into ferrous to ferric iron ($Fe2+$ to $Fe3+$). This reaction generates the superoxide anion, which through a series of redox reactions leads to the generation of toxic hydroxyl radicals. Henceforth, iron can be both beneficial and toxic effects to organisms and it is mandatory to balance iron status in the body for maintaining biological functions, whereas excess $Fe2+$ which can lead to oxidative stress (Carriquiriborde *et al*., 2004).

Manganese (Mn)

Manganese is one of the vital elements for aquatic animals that have a negative effects on total erythrocyte count (TEC), haemoglobin (Hb), haematocrit (Hct), mean corpuscular volume (MCV) and mean corpuscular haemoglobin (MCH) concentrations (Sharma and Langer, 2014). Mn toxicity accounted for abnormal structure of nucleus in RBCs which finally impacts on RBCs production in blood levels. Several researchers reported that Mn toxicity is noticeable in some aquatic species such as goldfish (*Carassius auratus*) (Vieira *et al*., 2012). In addition, it caused oxidative stress and increases GPx activity.

Nickel (Ni)

Initial effects of Ni on the respiratory system of aquatic animals are causing swollen gill lamellae, distress in the ventilation and respiratory system (Pane *et al*., 2003). Ni toxicity is highly prevalent in goldfish (*Carassius auratus*), streaked prochilod (*Prochilodus lineatus*) and mummichog (*Fundulus heteroclitus*) (Palermo *et al*., 2015). Behavioral effects of Ni exposure were studied and found out that Ni affects locomotors activity in fish, thus causing hypo activity in goldfish (*Carassius auratus*) and round goby (*Neogobius melanostomus*) (Blewett and Leonard, 2017).

Links Researchers

Zinc (Zn)

Zinc is common heavy metals for aquatic toxicity worldwide. Geological rocks, industrial wastages and domestic garbage's are the major source for Zinc pollution in freshwater and sea water (Adeyeye, 1996). Excessive levels of Zn causes reduce physical and growth performance of fish. Zn initially deposits in gills and resulting top hypoxia which leads to death. Alternations of hatchability and blood hematology also caused by excessive levels of Zn. Deficiency of Zn effects the fish behavior such as restless swimming, air guzzling, periods of dormancy and death (Kori-Siakpere and Ubogu, 2008).

Public health hazards of heavy metals by fish and fish products intake

Arsenic: Arsenic contamination is an alarming issue in worldwide and has given a higher weight in Bangladesh. Arsenic is one of the crucial heavy metals causing public health hazards. Semi-metallic nature of As accounted for toxic and carcinogenic effects (Singh *et al*., 2007). The primary signs and symptoms of acute arsenic poisoning includes nausea, vomiting, abdominal cramping, muscle pain and diarrhea. This is followed by immobility and creeping of the head, hand and legs, muscle shivering and death. In case of chronic exposure due to contaminated drinking water resulting different lesions such as pigmentation in skins, and hyperkeratosis in palms and soles of the feet. Lower levels of arsenic exposure can cause decrease production of blood cells such as erythrocytes and leukocytes (Jaishankar *et al*., 2014). Damaging blood vessels and heart beat abnormality also occurred due to low As exposure. Long time exposure of As can develop cancer in the skin, liver, kidneys and lungs. Cardiovascular and pulmonary complications, hypertension and neurotoxicity also outcomes of long term As consumption by human (Smith *et al*., 2000).

Lead (Pb)

Fossil fuel burning, manufacturing and mining play vital role for accumulation of Pb in water, soil and air. According to the Environmental Protection Agency (EPA), lead is considered a carcinogen agents. Chronic exposure of lead by fish and fish products intake can cause in pregnancy difficulties, mental disorder, autism, dyslexia, hyperactivity, muscular atony, kidney and brain damage (Martin and Griswold, 2009). Acute exposure leads to anorexia, hypertension, abdominal pain, renal dysfunction, fatigue, arthritis and hallucinations. Plasma membrane influx into the interstitial spaces of the brain when the blood brain barrier is exposed to elevated levels of lead concentration, resulting edema (Teo *et al*., 1997). It also disturbs the intracellular second messenger systems and alters the central nervous system functions.

Mercury

People mainly exposed to mercury when they continuous intake of fish and shellfish. Mercury is toxic for peripheral and central nervous system (Washington, 2005). It also harmful for digestive and immune systems, lungs and kidneys, and may be fatal. Symptoms include tremors, insomnia, memory loss, neuromuscular effects, headaches and cognitive and motor dysfunction. Mild, subclinical signs of central nervous system toxicity can be seen in workers exposed to an elemental mercury level in the air of 20 μg/m3 or more for several years (Washington, 2005).

Cadmium

Cadmium is a byproduct of zinc production (Jaishankar *et al*., 2014). Cadmium is highly deposited in proximal tubular cells of kidney which caused kidney toxicity and renal dysfunction (Bernard, 2008). Hypercalciuria, renal stones formation and osteoporosis caused by continuous exposure of Cd. Deposition of excess concentrations in lungs may cause severe damage (Bernard, 2008). Inhaling higher levels of Cd have a detrimental effects in lungs. In gastrointestinal system, Cd causes irritation, vomiting and diarrhea. Pregnancy complications, premature birth and unexpected birth weights are occurred due to high levels of exposure during pregnancy period (Henson and Chedrese, 2004).

Chromium

Chromium derivatives are highly perpetual in water sediments. Cr(III) and Cr(VI) are the common stable forms and only their relation to human exposure is of high interest (Zhitkovich, 2011). Chromium derivatives such as lead chromates, strontium chromate, zinc chromates and calcium chromate are showed toxic and carcinogenic properties. Metal coatings and alloys, magnetic tapes, paint pigments, rubber, cement, paper, wood preservatives, leather tanning and metal plating are responsible for Cr contamination in freshwater and seawater (Martin and Griswold, 2009). Higher concentration exposure of chromium compounds caused decrease levels of erythrocyte glutathione reductase, which in turn lowers the capacity to reduce methemoglobin to hemoglobin (Jaishankar *et al*., 2014). Chromate compounds also responsible for chromosomal aberrations, DNA adducts, exchange of sister chromatid, alterations in replication and transcription of DNA (Matsumoto *et al*., 2006).

Iron

Aquatic animals is the prominent source of iron and it shows various health benefits in humans (Rahmani *et al*., 2018). However, continuous high intake initiates toxic effects in human body (Ashraf *et al*., 2006). Mammals are not capable for eliminate excess amount of Fe from body through secretions and continuous deposition of Fe causing organs failure with detrimental outcomes. The maximum permitted concentration of Fe in fish fillet established by FAO/WHO 100 µg/kg ww, respectively (FAO/WHO, 2009).

Manganese (Mn)

Manganese is very pivotal elements for both animals and plants, especially for skeletal and reproductive system in mammals. Mn helps the body absorb vitamins B1 and E, and works with all B-complex vitamins in combating depression, anxiety, and other disorders of the nervous system (Eneji *et al*., 2011). Excess Mn interferes with the absorption of dietary Fe and long-term exposure may result in Fe-deficiency anemia and the impairment of the activity of copper dependent metalloenzymes. Significant increases in Mn concentrations have been observed in patients with severe hepatitis, dialysis patients, and patients who have had cardiac arrests. In addition, studies on mice injected with Mn chloride tetrahydrate during gestation have shown fetotoxicity.

Nickel (Ni)

Ni is considered one of the most important elements to perform functions of vital organs but excess amount is pernicious for human body (Genchi *et al*., 2020). In human body, Ni combines with thiol resulting in the formation of Ni-Thiol complexes. When these complexes react with molecular oxygen it results in free radicals production that ultimately causes Ni toxicity (Das et al., 2006). Researchers investigated that because of Ni exposure to human body its physiological chemistry is altered because of decreased excretion of calcium ions via urinary routes and also because retention of nitrogen is decreased following Ni exposure. Red Blood Cells in blood, packed cell volume (PCV) %, and the concentration of hemoglobin were increased due to raised synthesis of erythropoietin and this happened in response to tissue hypoxia produced by Ni exposure (Denkhaus and Salnikow, 2002). Placental membrane is disrupted because of peroxidation of lipids induced by prenatal Ni exposure. Because of this peroxidation pathway permeability of placenta is increased and toxic damage is induced in fetus (Cortijo *et al*., 2010).

Zinc

Zinc is an eccentric element that is little essential for human vital organs. Hence, lack of Zn resulting reduce in sense of taste and smell, slow wound healing, loss of appetite, and skin sores (Afshan *et al*., 2014). Although humans beings can manage large concentrations of Zn, too much Zn can cause prominent health problems such as skin annoyances, such as stomach cramps, anemia, vomiting and nausea. Excessive concentration of Zn is deleterious for pancreas, initiate disturbances in protein metabolism and resulting arteriosclerosis. Several researchers reported that adverse effects of the fish are neutralized in the process of cooking (Afshan *et al*., 2014).

Conclusions and Recommendations

The concentration of HMs is dangerous for the aquatic animals as well as human health. Environmental contamination from HMs may damage the marine organisms at the cellular level and causes imbalance in the ecosystem. HMs in the aquatic organism might entered through the three ways: the body surface, gills and food. In aquatic environment, microorganisms accumulate metals and consequently, small fish become enriched with the accumulated substances. Predatory fish again, general display higher levels than their prey. Man at the end of food chain suffers from the results of an enrichment having taken place at each trophic level, where less is excreted than ingested. Therefore, preventive measures should be taken to reduce the intensity of aquatic pollution through the HMs.

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Novelty Statement

This review paper narrates the recent information's about the effects of heavy metals on aquatic animals with their public health importance.

Author's Contribution

MAM and SIA: Conceptualization.
MAM and MAR: Literature review.
MAM, MAR and SIA: Writing the original paper, review, edit and supervision.
All authors have read carefully and approved the manuscript.

Compliance with ethics requirements
Not applicable

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