GERF Bulletin of Biosciences
December 2010, 1(1): 41-47

Review Article

Cadmium toxicity in fish: An overview

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Abstract

Environmental pollutants have hazardous impact on living organism present on this planet. Environmental pollutants give bad impact on the health of livestock as well as human beings and have been categorized as heavy metals, pesticides etc. Cadmium and its compounds are most common environmental toxicants with potential for bioaccumulation and persistence in the body, and produce versatile biotic changes in the aquatic ecosystem. Monitoring toxic metal level in aquatic ecosystem (especially fish) is the need of the awareness from public health point of view. It concluded that our fishes also carry good quantity of cadmium. It is inferred from the study that selective removal of tissues that accumulate highest levels of cadmium *i.e.* kidney and liver might reduce the chances of toxicity due to this metal in human consumers and in animals fed with fish-meal.

Keywords: Cadmium toxicity, fish, heavy metals, immunotoxicity, nephrotoxicity

Introduction

Next to air, water is essential constituent of life support system and its quality play pivotal role in the maintenance of health. Being as an important natural resource it is used for many purposes especially for aquaculture, industry, irrigation and domestic needs. Abundant resource of water is available in our country. Unfortunately, rapid industrialization, fast growth in population and non-judicious use of natural resources has resulted into many fold increase in water pollution problem. Most of the 14 major rivers of India are victims of water pollution; Ganga and Yamuna ranking top among them (Ajmal *et al.*, 1985; Singh, 2001; Jain and Sharma, 2001; Kaushik *et al.*, 2003; Sharma, 2003 and Kumar *et al.*, 2007, 2008, 2009).

Industrial effluents are major source of water pollution besides sewage, agricultural discharges and other household residues. Industrial effluents contain a variety of toxic pollutants including suspended solids, organic compounds, inorganic compounds, pesticides and various toxic metal compounds. The chief source of contaminants are the industrial waste discharge, mining, agriculture, household waste disposal and fuel combustion (Woodling *et al.* 2001; Patra *et al.*, 2005 and Swarup *et al.*, 2006; Saxsena and Garg, 2011). Aquaculture is totally based on aquatic ecosystem and accounts for substantial contribution to Indian economy and also provide livelihood to millions of people. Spectacular achievements have been made in the field of aquaculture by adapting modern techniques of fish culture and hence there is substantial growth in the production of culture fishes. Total fish production in India in year 2002-2003 was to the tune of 6.2 million metric tones (Dwivedi, *et al.* 2004). Fishes are highly nutritious and consumed as a delicacy food through out country (Prasad and Kumar, 2007). But addition of pollutants in water has impact on the aquatic ecosystem and poses adverse effect on the fish health. As a result fish production is generally encumbered and fish farmers face a great economic loss. Thus monitoring and understanding pathophysiology of various toxicants would be helpful in minimizing losses and providing safeguard to public health.

A variety of contaminants including toxic heavy metals (cadmium, copper, mercury and zinc) are reported to be ubiquitously present in rivers, reservoirs and are disadvantageous for aquatic organisms (Olsson, 1998). In general, they are not biodegraded and therefore, their bioaccumulation in fish, oyster, mussels, sediments and other components of aquatic ecosystems have been reported from all over the world. It appears that problem of heavy metals accumulation in aquatic organisms including fish needs continuous monitoring and surveillance owing to

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biomagnifying potential of toxic metals in human food chain (Das and Kaviraj 2000; Laxi, 2005; Jayakumar and Paul 2006; Kumar *et al.*, 2007; Kumar *et al.*, 2008; Kumar *et al.*, 2009).

Physico-chemical property of cadmium

Pure cadmium is a soft, silver-white metal. The physical property of cadmium is atomic number-48, atomic weight-112.411, electro-negativity-1.5, crystal ionic radious (Principal valence state)-0.97, ionisation potential-8.993, oxidation state +2, electron configuration Kr $4d^1$ $5S^2$, density-8.64 g/cm^3, melting point - 320.9°C and boiling point-765°C at 100 kPa. It is usually found as a mineral combined with other elements such as oxygen (cadmium oxide), chlorine (cadmium chloride), or sulfur (cadmium sulfate, cadmium sulfide).

Source of exposure

It is an element that occurs naturally in the earth's crust and got rank 7 of ASTDR's "Top 20 list" (ASTDR, 1999). Percentage of cadmium in the upper soil has been increasing because it is found in insecticides, fungicides, sludge, and commercial fertilizers which are routinely used in agriculture. Dental alloys, electroplating, motor oil, and exhaust are other sources of Cd pollution. Hence, anthropogenic activities have increased Cd magnification in the environment. 10% of total Cd in the environment is derived from natural sources, whereas remaining 90% is derived form anthropogenic activity (Okada *et al.*, 1997). Volcanic activity contributes about 62% of natural emissions and other natural sources include decaying of vegetation (25%) airborne soil particles (12%) and forest fire (2%).

It's non-corrosive and cumulative nature has made it very important due to its applications in electroplating or galvanizing. It is also used as colour pigment for paints, plastics, and as a cathode material for nickel-cadmium batteries. Anthropogenic activities like; smelting operations, use of phosphate fertilizers, pigment, cigarettes smokes, automobiles etc. have contributed to the entry of cadmium into human and animal food chain (WHO, 1992; Okada *et al.*, 1997; Kumar *et al.*, 2007). Presence of cadmium at higher concentration than the maximum allowable limits in water, vegetation and food have been reported by author (Agarwal and Raj, 1978; Khandekar *et al.*, 1980; Allen, 1995; Laxi, 2005; Kumar *et al.*, 2008; Asagba, 2010).

Higher level of Cd has also been detected in sewage sludge (rich in almost all nutrients and hence generally used as plant fertilizer), various vegetables (Roblenbeck *et al.*, 1999), animals feed and their tissues (Kumar *et al.*, 2007). Topsoil enrich in sludge contributes Cd accumulation in the blood, milk, hair, liver and kidney of sheep, goat, cow, buffalo (Brebner *et al.*, 1993; Swarup *et al.*, 2005; Balagangatharathilagar *et al.*, 2006 and Patra *et al.*, 2007). In India, various levels of cadmium concentration have been reported to be present in aquatic ecosystem which is more than 5ng/ml in the Yamuna river water at Agra, Delhi, Etawah and Mathura (Ajmal *et al.*, 1985) and 0.50-114.8 mg/kg in the Yamuna river sediments at Agra and Delhi but the water around the industrial areas have been found to contain higher levels of cadmium (Singh, 2001 and Kaushik *et al.*, 2003). Similarly, Hindon River (Uttar Pradesh) has also been contaminated with heavy metals including cadmium (Jain and Sharma, 2001 and Sharma, 2003). Moreover, high concentration of cadmium (70-100 ng/ml) has been detected in Bombay city (Agrawal and Raj, 1978), Lalbag pond water of Baroda city (Kannan, 1997) and edible tissues of fish and chicken in western UP market (Kumar *et al.*, 2006 and 2007; Burger, 2008).

Site for absorption in fish

In the fish, the possible areas of absorption of dissolved metals are the gills (respiratory tract), the intestine (ingestive intake) and the skin (transcutaneous uptake).

Molecular mechanisms of absorption

There are various mode of Cd uptake in aquatic organism, where it is most readily absorbed by organisms directly from the water in its free ionic form Cd (II) (AMAP 1998). Metal ions are usually absorbed through passive diffusion or carrier mediated transport over the gills while metals associated with organic materials are ingested and absorbed by endocytosis through intestine. It has been suggested that cadmium ions enter the chloride cells in the gills through calcium channels (Olsson, P.E., 1998). Once enter in the cells the metal is made available for the interaction with cytoplasmatic components such as enzymes (causing toxic effects) and Metallothioneine (probably being detoxified). Although Metallothoneine is induced in the gills it does not appear to be as capable of sequestering the vast majority of accumulated Cd^{2+}, as it is in the liver (Olsson and Hogstrand, 1987). The reason for this is believed to be due to the high affinity of Cd^{2+} for Ca^{2+} binding sites in the gills (Flick *et al.*, 1987), and it is also believed that Cd^{2+} binds to the active sites on the basolateral Ca^{2+}-pump in chloride cells. It thus seems that Cd^{2+} enters the gills through Ca-channel on the apical side and is further translocated to the circulation interactions with Ca^{2+}-ATPases on the basolateral side.

Interaction with other elements

Zinc increases the toxicity of cadmium to aquatic invertebrates. However, high calcium concentrations in water protect them from cadmium uptake by competing at uptake sites. It is very rare that only one toxic element, at a time, is released into the aquatic ecosystem. Most of the heavy metals interact with each other and also influenced by other ions (e.g. Ca^{2+}, Mg^{2+}, Na^{2+}, Mn^{2+}, Fe^{2+}, Pb^{2+}, S^{2+}, Se^{2+} and Ni^{2+}). Calcium has been shown to interact with Cd^{2+} to potentiate or minimize their toxicity. Elevated ingestion Cd^{2+}

can produce deficiency states of both Cu^{2+} and Zn^{2+}. Exposure of animals to Cd^{2+} results in alteration in the Zn^{2+} metabolism.

Tissue distribution

Bioaccumulation of cadmium takes place at tropic level and found to be highest in algae (Ferard *et al.*, 1983; Pinto *et al.*, 2003). It also accumulates in considerable concentrations in various organs of fish (Sindayigaya *et al.*, 1994; Kumar *et al.*, 2006; Kumar *et al.*, 2008). Smet & Blust (2001) reported that cadmium accumulates in tissues of carp Cyprinus carpio in following order: kidney> Liver> Gills. Kumar *et al.* (2005) have also reported similar accumulation pattern in *Clarias batrachus* in an experimental study. Some insects can also accumulate high levels of cadmium without showing any adverse effects (Jamil and Hussain, 1992). Kidney is the prime target organ for cadmium. The liver also stores a considerable part of the accumulated cadmium. Cadmium is redistributed to these organs directly following uptake through the gills and intestine, but there may also be redistribution of cadmium form other organs (Olsson and Hogstrand, 1987).

Toxic effect

Cadmium has been reported to exert deleterious effects in terms of nephrotoxic, cytotoxic, genotoxic, immunotoxic and carcinogenic (ASTDR, 1999; Lippmann. 2000 and Risso-de-faverney, 2001).

1. Nephrotoxicity

Cadmium is heavy metal and poses high toxicity at very low level of exposure and has acute and chronic effects on aquatic animal health and environment. Long exposure of cadmium produces a wide variety of acute and chronic effects in aquatic animals. It's prime site is kidney (Thomas *et al.*, 1983 and Kuroshima, 1992). According to the current knowledge kidney damage (renal tubular damage) is probably the critical health effect (Jarup *et al.*, 1998). Not only this it also creates disturbances of calcium metabolism, hypercalciuria and takes part in the formation of stones in the kidney. The toxicity is variable in fish, salmonoids being particularly susceptible to cadmium. Sublethal effects in fish, notably malformation of the spine, have been reported.

2. Induction of Oxidative Stress

Free radicals and other reactive oxygen species (ROS) have been recently incriminated in the pathogenesis of various metal toxicities (Yiin *et al.*, 1999a and 1999b; Senapati *et al.*, 2001; Basha and Rani, 2003; Rahman, 2003; Suresh, 2009). There are many reports suggesting alterations in free radicals production and antioxidant defense system of the body after cadmium exposure. Administration of Cadmium chloride at the dose rate of 15μg/ml in drinking water for 30 days revealed significant increase in lipid peroxidation (LPO) in cortical region of kidney (Oner *et al.*, 1995). Treatment of rats with Cd^{2+} significantly increases in LPO in heart within 3 hours of Cd^{2+} injection and kidney and liver within 6-12 hours. Superoxide dismutase (SOD) activity increased in heart, liver and kidney within 24 hours of Cd^{2+} intoxication. Catalase activities were also increased significantly in heart after 9 hours of Cd^{2+} injection without any significant change in liver and kidney (Sarkar *et al.*, 1995).

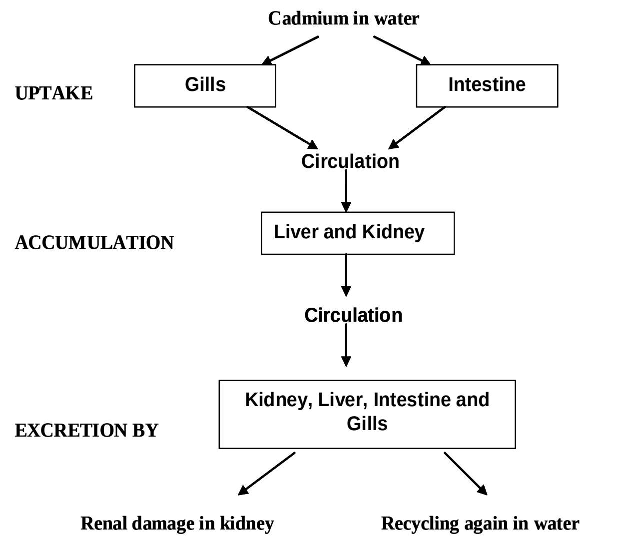

Fig. : 1 The cycle of Cadmium in aquatic ecosystem

3. Immunotoxicity

A number of investigations have suggested that cadmium may exert immunosuppressive effects of cadmium exposure in both fishes and mammals (Zellkoff *et al.*, 1995; Kim *et al.*, 2000 and Giari *et al.*, 2007). Recent reports suggest that cell mediated immunity is most affected (Kumar *et al.*, 2008) and phagocytosis, natural killer cell activity and host resistance towards experimental infections are markedly impaired in cadmium toxicity. Sovenyl and Szakolczal (1993) also reported marked immunosuppressive effects of cadmium exposure on common carp in terms of lowered antibody response, lysozyme level and microcidal capacity of phagocytes. Some reports suggest that cadmium enhances humoral immune repsponse at low level of exposure (Descotes, 1992; Krumschnabel *et al.*, 2010).

4. Effect on organ structure and function

Cadmium in high doses induce structural and function alterations in various vital organs including liver, kidney, gill and intestine of fishes.

Liver: Cadmium accumulates in liver of fishes in high concentrations (Smet and Blust, 2001; Rangsayatorn *et al.*, 2004). It also induces various pathological changes in liver tissues including engorgement of blood vessels, congestion, vacuolar degeneration of hepatocytes, necrosis of pancreatic cells and fatty changes in the peripancreatic hepatocytes (Rani and Ramamurthi, 1989; Dangre *et al.*, 2010).

Kidney: Cadmium accumulates in kidney of fishes in maximum concentration. Cadmium has been reported to posses nephrotoxic action in man and various animals. In fact, kidney is the principle target organ of cadmium toxicity and chronic cadmium exposure in almost all animal species is characterized by varying degree of renal damage (Roméo *et al.*, 2000; Shukla and Gautam, 2004; Kumar *et al.*, 2006; Kumar *et al.*, 2009; Vesey, 2010).

Gills: Gills are also reported to act as storehouse of cadmium in experimental studies (Allen, 1995; Tao *et al.*, 2000; Fafioye *et al.*, 2004; Ramesh and Nagaranjan, 2007). Wong and Wong (2000) studied morphological and biochemical changes in the gills of Tilapia (*Oreochromis mossambicus*) after experimental cadmium exposure. In scanning electron microscopic studies, they found an augmentation of microbridges in pavement cells and an increase in the apical membrane of chloride cells. They further reported chloride cells as a prime target of cadmium toxicity, resulting into fish hypocalcemia.

Other organs like intestine and gonads of fishes also appear susceptible for ill effects of cadmium toxicity (Taylor, 1983; Kumari and Ram, 1997; Singh *et al.*, 2007; Kumar, 2007).

Conclusion

Cadmium enters into the aquatic ecosystem through anthropogenic activity and gets further biomagnified in the food chain. Studies revealed the high concentration in of Cadmium in kidney in comparison to the liver and disrupts the normal calcium metabolism resulting into hypocalcaemia and hyperglycemia. It is vivid that it can be concluded that fishes are the major concern to increase the cadmium in their haematopotic organs *viz.* kidney and liver. This study indicates that high levels of Cd in fish are potential risk concern on human consumer's health.

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