Bioaccumulation of Cadmium in Freshwater Fish: An Environmental Perspective

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ABSTRACT

Background: Cadmium (Cd) is considered as one of the most toxic heavy metal. Intake of Cd by fish has serious implications. Metal pollution from multifarious sources has adverse effects on aquatic ecosystems. In aquatic systems, Cd is most readily absorbed by organisms directly from the water in its free ionic form. In many contaminated situations with heavy metals, Cd has become an important element of concern because of its bioaccumulative nature in food webs. Therefore, fish living in polluted waters tend to accumulate heavy metals in their tissues.

Objectives: To assess the influence of Cd on freshwater fish, this review briefly addresses the Cd emission sources, uptake and impacts of Cd on freshwater fish and bioaccumulation nature of Cd by emphasizing the Cd accumulation affinity in freshwater fish tissues.

Results and Discussion: Many studies have been carried out on Cd thresholds in diet and tissues of freshwater fish species. Affinity of freshwater fish to Cd is diverse. Generally, Cd accumulation depends on concentration, time of exposure, way of uptake, environmental conditions and intrinsic factors. Metal accumulation primarily depends on waterborne and dietary pathways. It shows a relationship of Cd level in fish tissues with the age and size of fish. Some species of fish show the highest Cd accumulation in the liver while others in kidneys and gills. Accumulation of Cd by the body muscles is always reported as comparatively low. Cd in freshwater environments results biological and environmental implications by altering reproductive and physiological behaviors of freshwater fish and abilities which ultimately affect environmental permanence and biodiversity of the ecosystem.

Key words: Environmental permanence, physiological implications, fish tissues, dietary pathways, metal pollution

INTRODUCTION

The term bioaccumulation is defined as a process by which the chemicals are taken up by an organism either directly from exposure to a contaminated medium or by consumption of food containing the chemical. Where metals are concerned, it can be defined as the net accumulation of a metal in a tissue of interest or a whole organism that results from exposure. Metal bioaccumulation is influenced by multiple routes of exposure (diet and solution) and geochemical effects on bioavailability. As metals are not metabolized, bioaccumulation of metals and metalloids is of particular value as an exposure indicator. Similarly, bioaccumulation is often a good integrative indicator of the chemical exposures of organisms in polluted ecosystems. All trace metals are toxic at some bioavailability. Thus, aquatic organisms exposed to atypically high local bioavailable toxic metal may come under selection for changes in one or more physiological processes, including the rate of metal uptake from an available source of the metal, the rate of efflux and the rate of detoxification of accumulated metal into a relatively metabolically inert form.

The metal contamination in aquatic ecosystem is considered to be unsafe not only for aquatic organisms but also for terrestrial organisms including the human. The long-term consumption of fish from the polluted waters may result in bioaccumulation of persistent pollutants in ultimate recipient (perhaps human) of the food web. In fish, heavy metals are taken up through different organs because of the affinity of such organs for the accumulation of heavy metals. In this process, many heavy metals are concentrated at different levels in...
different organs of the body \(^8-^{10}\). As an example, cadmium (Cd) is considered as one of the most toxic heavy metals\(^{11}\) and an environmental pollutant toxic to a number of tissues\(^{12}\). The persistence and ubiquitous nature of Cd is coupled with their tendency to accumulate in organisms ultimately produce toxic reactions in aquatic biota, especially in fish. Thus, the deleterious effects of metals on aquatic ecosystems necessitate the continuous monitoring of their accumulation in key species, since it affords indication of temporal and spatial extent of the process and impact on organism’s health\(^{13}\). As the bioaccumulation of Cd in aquatic biota is a serious current issue, it should be closely monitored. The intent of the present review is to briefly address the Cd emission sources, uptake and impacts of Cd on freshwater fish and bioaccumulation. Mainly, try to emphasis the Cd accumulation affinity in freshwater fish tissues; e.g., gills, kidney, liver and the muscle tissue. This study also gives an overview of differences in the magnitude of Cd residues accumulated in different freshwater fin-fish tissues in several natural environments of the world. Nevertheless, metal bioaccumulation in terms of biodynamic modelling and physiological handling of metals like Cd in freshwater fish, through the studies of genomics and proteomics studies will not be discussed.

**CADMIUM IN THE ENVIRONMENT**

Cadmium (Atomic Number: 48 and Relative Atomic Weight: 112.41U) is a relatively rare, silvery grey metallic, soft solid (standard state). It never occurs in nature in its elemental form and is always found in a compound with another element; i.e., cadmium oxide, cadmium chloride, cadmium sulphide, cadmium cyanide, cadmium carbonate and cadmium nitrate. Although rare in surface waters, Cd is highly toxic to some aquatic life. In comparative acute toxicity testing of all 63 atomically stable heavy metals in the periodic table, Cd clearly was the most toxic metal\(^{14}\). The important releases of Cd to the biosphere can be discussed as natural and anthropogenic activities. Natural emissions are mainly due to mobilization of naturally occurring Cd from the earth's crust and mantle; e.g., volcanic activity and weathering of rocks. Anthropogenic releases are mainly from the mobilization of Cd impurities in raw materials (e.g., phosphate minerals, fossil fuels) and releases by manufacturing, use, disposal, recycling, reclamation or incineration of products intentionally\(^1\).

Chemical elements in soil are referred to as trace elements (heavy metals) because of their occurrence at concentrations less than 100 mg kg\(^{-1}\)\(^{15}\). The term “Heavy metals” is the most popularly used and widely recognized term for a large groups of elements with density greater than 6 g cm\(^{-3}\). Agro-fertilizers are indispensable for ensuring sustainability of agricultural production\(^{16}\). Nitrogen, sulphur and potassium fertilizers are relatively free of impurities but phosphorus fertilizers contain several contaminants, of which Fluorine (F) and Cd are considered to be of most concerned. Application of phosphate fertilizers, lime and agrochemicals (pesticides) use in agriculture can be significantly contribute to enhance potentially hazardous trace elements in soils\(^{13}\). Therefore, crop fields that are heavily contaminated with Cd may have resulted from long-term overuse of phosphate fertilizers\(^{37}\). Once soils with elevated Cd concentrations are exposed, Cd will leach from the solids and dissolve in water. The soil is the primary source of trace elements for plants, animals and humans\(^{15}\). Pavlik\(^{38}\) has shown that, up to 90% Cd taken up by plants originates from soil and only 10% from the atmosphere. Trace elements such as Cd are retained in soils indefinitely because they are not degradable. Therefore, an increased level of Cd in water and soil increases its uptake by live organisms.

Cadmium has no known biological use in animals\(^{19-^{20}}\) or only little evidence to suggest that it plays a nutritive role in higher plants and animals\(^{15}\). Cadmium is poorly regulated by organisms, thereby increasing the likelihood that whole-body residues will increase with increasing exposure concentration\(^{21}\).

**IMPACTS ON THE AQUATIC ECOSYSTEM**

When Cd is introduced to freshwaters, the great bulk of the metal precipitates and resides in the bottom of sediments. Thus, sediment may be a significant source for Cd emitted to the aquatic environment\(^{22}\). The effects of Cd on aquatic organisms can be directly or indirectly lethal and can impact populations and ecosystems as well as individuals. As a persistent environmental pollutant, Cd can alter trophic levels for centuries and freshwater organisms such as fish are particularly vulnerable to Cd exposure\(^{23}\). Partitioning of Cd between the adsorbed-in-sediment state and dissolved-in-water state is therefore, an important factor in whether Cd emitted to waters is available or not to enter the food chains. Subsequently, Cd in sediments will be taken up by bottom feeding fauna and sediment-rooted flora. It then proceeds up the food chain to fish, with the precise pathways dependent upon the species present\(^{24}\). Metal concentrations in benthic macro-invertebrate tissues and fish tissues were strongly correlated, suggesting a transfer of metals through a dietary pathway. Therefore, fish living in polluted waters

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tend to accumulate heavy metals in their tissues. Even if, most of the data on the effects of Cd to aquatic species were generated from tests where Cd was tested as the single contaminant of concern, it probably seldom occurs as a single contaminant of concern in ambient waters (e.g., commonly occurs with zinc and copper). Metallothionein synthesis is considered as one of the best-known biochemical detoxification mechanisms for metal and it is widely demonstrated that its induction may be influenced by metal contamination. This low-molecular weight protein binds to Cd, limits its availability to cell and tissues. The MTs play a role in transport, detoxification and storage of Cd. After the absorption, Cd is bound to albumin and transported to liver. Following release from the liver, MT-bound Cd enters the plasma and appears in the glomerular filtrate, from where it is reReleased intracellularly by renal tubule cells. At this stage, Cd is cleaved from the MT-Cadmium complex by lysosomal action and Cd ions are re-excreted into the tubular fluid and finally eliminated in the urine.

FACTORS AFFECTING THE ABSORPTION OF CADMIUM IN FISH

Although metals are non-degradable (can neither be created nor destroyed), they might be altered into more toxic forms or complex to more stable and less toxic compounds. Natural waters are usually contaminated with mixtures of metals and other toxic compounds. Accumulation of some metals in fish may be affected due to the occurrence of the others metals and interactions among various metals may be related to their different affinities to various organs. In an aquatic environment, the impact of metals (perhaps the metal toxicity) can also be influenced by various abiotic environmental factors; e.g., water hardness, temperature and pH. Hardness is one of the most important factors that affect fish physiology and metal toxicity. Elevated dietary Ca protected fish against both, dietary and waterborne Cd uptake. The mobility and bioavailability of Cd in aquatic environments is enhanced under conditions of low pH, low hardness, low suspended matter levels, high redox potential and low salinity. Water acidification directly affects metal accumulation rates by the fish. Water acidification affects bioaccumulation of metals by the fish in an indirect way, by changing solubility of metal compounds or directly, due to damage of epithelia which become more permeable to metals. Therefore, toxicity of Cd generally increases with reducing water hardness and reducing concentrations of dissolved organic matter. Water temperature may cause the differences in metal deposition in various organs of freshwater fish. Humus content in water also contributes to determine the concentration of Cd in fish. Cadmium is more toxic in freshwater than in saltwater because it combines with chlorides in saltwater to form a molecule that is less available from solution.
Mebane48 shows that fish incubated in higher hardness water were about two times more resistant to Cd toxicity than the fish incubated in extremely soft water. However, the impacts of water hardness on Cd toxicity need further assessment and analysis because alkalinity varied with hardness levels in many of the toxicity experiments49.

**BIOACCUMULATION OF CADMIUM IN FISH**

Bioaccumulation is the net result of the interaction of uptake, storage and elimination of a chemical. Nevertheless, it is a normal and essential process for the growth and nurturing of organisms. Fish daily bioaccumulate many vital nutrients, such as vitamins, trace minerals essential fats and amino acids. Many toxic organic chemicals are concentrated in biota several orders of magnitude greater than their aqueous concentrations and therefore, bioaccumulation can cause a serious threat to both the biota of surface waters and the humans that feed on these surface-water species. Cadmium that enters into the aquatic ecosystem may not directly impart toxicity to the organisms at low concentrations. Nevertheless, it can be accumulated in aquatic organisms through bio-concentration, via the food chain process and eventually threaten human health as they consume fish. Various species of fish living in the same aquatic environment may accumulate different amounts of metals in their tissues. Interspecies differences in metal accumulation may be related to living and feeding habits50. Nakayama et al.51 and Croteau and Luoma52 show that carnivorous fish (*Serranochromis thumbergi*) shows low accumulated levels of Cd in its tissues and heavy metal concentration is generally inversely correlated with the trophic level. However, Croteau et al.51 and Croteau and Luoma52 show that toxic effects of Cd are likely to occur with increasing trophic positions. However, there have been unequivocal evidences that the resistance differences are genetically based53 and little is known about the effects of Cd on genetic and biochemical adaptive responses of aquatic species under chronic and long-term exposure54. Toxicological studies at cellular level have shown that Cd inhibits the mitochondrial electron transfer chain and induces relatively oxygen species production55.

**TOXICITY OF CADMIUM IN FRESHWATER FISH**

Cadmium as a toxic element might act as stress inducing agent for fish55. Cadmium exposure may lead to the results of some pathophysiological damages including growth rate reduction in fish56. Moreover, Cd produces both hepatic and renal injuries in mammals and fish57 with the potential to induce oxidative stress58. It was also found to interfere with many protein and carbohydrate metabolism by inhibiting the enzymes involved in the processes59 and known to perturb ion balance in teleost fishes60. Furthermore, it also interacts with the calcium metabolism and causes abnormally low calcium levels (hypocalcaemia), probably by inhibiting calcium uptake from the water as discussed under the section “factors affecting the absorption of cadmium in fish”. However, high calcium concentrations in water protect fish from Cd uptake by competing at uptake sites. It would be chronically toxic when the animal is exposed over a long period of time at a lower concentration. Effects of long-term exposure can include larval mortality and temporary reduction in growth60. Cadmium would be acutely toxic and animal may die from exposure to a high concentration over a short period of time. Cadmium may also accumulate in aquatic biota chronically exposed to sub-lethal concentrations45. Chronic exposure can lead to mortality; sub-lethal effects such as reduced growth and reproductive failure are more common60. As discussed above, the impact of Cd on aquatic organisms depends on a variety of possible chemical forms of Cd which can have different toxicities and bio-concentration factors. In most well oxygenated freshwaters that are low in total organic carbon, free divalent Cd will be the predominant form. The most bio-available form of Cd is also the divalent ion (Cd$^{2+}$). Exposure to this form induces the synthesis of metallothionein which binds with Cd and decreases its toxicity46,47,61 and this normally takes place in the liver of fish. However, when the Cd concentration is high, the metallothionein detoxification system can become overwhelmed and the excess Cd will be available to produce toxic effects. Reproduction processes and early life stages of fish are the most sensitive for this elevated Cd levels. Skeletal deformities in fish can cause impaired ability of the fish to find food and avoid predators; hence, this sub-lethal effect becomes a lethal effect46-47. Interestingly, after exposing three freshwater species (*Cyprinus carpio*, *Carassius gibelio* and *Corydoras paleatus*) to different doses of Cd, Cavas and co-workers62 clearly shows that the frequencies of micronucleated and binucleated erythrocytes were elevated in peripheral blood, gill epithelial cells and liver cells giving further evidence that Cd has cytotoxic and genotoxic effects.

**TREND OF ACCUMULATION OF CADMIUM IN FISH TISSUES**

A growing number of evidences have shown that several factors influence Cd accumulation in fish tissues. Some studies have been carried out exposing fish to
different doses of Cd in laboratories under control conditions. Several studies have examined the relationship between metal exposure, accumulation and toxicity. However, accumulated levels among organs varied following different treatment doses of Cd and exposure times. In the natural environment, explaining the reasons that affect the Cd bioaccumulation may be difficult because of complex and unidentified time related changes.

Several studies show that tissue-specific Cd accumulation in fish with the chronic exposure but different tissues show different capacity for accumulating heavy metals. Metal distribution in various organs is also time-related and the effect of time on metal distribution within the organism is a complex issue due to different affinity of various metals to the tissues of various fish species. In addition, they show that the accumulation of metals in different organs of fish is a function of uptake and elimination rates and metal concentrations in various organs may change during and after exposure. Most of these investigations of tissue level, Cd have been carried out to quantify this particular metal in several common fish tissues such as liver, kidneys, gills, muscles and alimentary canal. Cadmium shows different affinity to these fish tissues. According to many studies, Cd is accumulated primarily in the kidney and liver but it may reach high concentrations in the gill, alimentary canal and muscles as well (Table 1).

### Table 1: Accumulating tendency of Cadmium in different tissues of some freshwater fish species in their natural environments

| References | Fish species | Common name | Tissues considered | Highest Cd level | Lowest Cd level | Research location |
|------------|--------------|--------------|--------------------|------------------|-----------------|-------------------|
| Ahmed et al. (2012) | Spratella aurata | Long-whiskered catfish | M,K,G,Ac,L | Ac | L | Dhaleshwari river, Bangladesh |
| Akan (2009) | Clarias anguillaris | Mudfish | L,G,K,Ac,B | L | Ac | Lake Chad, Nigeria |
| Alhassene et al. (2012) | Barbus grypus | Shariab barb | M,G,Ge,L | L | M | Southwest Iran |
| Ambekar and Muniyiam (2011) | Tilapia mossambica | Mozambique tilapia | L,K,G,M,Ac | L | K | Kollidam river, Tamilnadu |
| Anim-Gyampo et al. (2013) | Heterobranchus fossilis | Stining catfish | Ac,L,K,G,M | Ac | M | Tono reservoir, Ghana |
| Brixová et al. (2012) | Sarotherodon galilaeus | Mango tilapia | M,G | G | M | Lake Alan, Nigeria |
| Chi et al. (2007) | Aristichthys nobilis | Bighead carp | L,M | L | M | Lake Tahu, China |
| Coulthab et al. (2012) | Sarotherodon melanoperon | Black-chinned tilapia | L,G,M | L | M | Ebric lagoon, Ivory Coast |
| Cyrille et al. (2012) | Sarotherodon melanoperon | Black-chinned tilapia | M,G,L | M,G,L | M,G,L | Aby lagoon system, Côte d’Ivoire |
| Demirık et al. (2006) | Leuciscus cephalus | Chub | G,M | G | M | Southwest Turkey |
| Dimari and Hari (2009) | Heterobranchus fossilis | African bonytongue | L,G,G | L | G | Lake Alau, Turkey |
| Duman and Kar (2012) | Squallus cephalus | European chub | L,G,M | L | M | Yamula dam lake, Turkey |
| Ebrahimpour et al. (2011) | Carassius gibelio | Prussian carp | L,K,G,Ac,M | L | M | Anzali, Iran |
| Enjei et al. (2011) | Tilapia zilli | Redbelly tilapia | G,Ac,M | G | M | Benue river, Nigeria |
| Enjei et al. (2011) | Clarias gariepinus | African catfish | G,Ac,M | Ac | M | Lake Nasar, Egypt |
| Fatma (2008) | Lebistes reticulatus | Nile perch | G,L,G,Ac,M | L | M | Lake Chad, Nigeria |
| Gwaski et al. (2013) | Polypterus angolensis | Guinean bichir | G,K,L,G,M | L,K,M | L,K,M | Lake Chad, Nigeria |
| Gwaski et al. (2013) | Clarias anguillaris | Mudfish | G,K,L,G,M | L,G,M | L | Anzali, Iran |
| Gwaski et al. (2013) | Oreochromis niloticus | Nile tilapia | G,K,L,G,M | L | K | Lake Chad, Nigeria |
| Gwaski et al. (2013) | Spleonomygus nigrita | Catfish | G,K,L,G,M | G | M | Lake Chad, Nigeria |
| Has-Schön et al. (2006) | Buryx argus | Common carp | K,G,L,M,Go | K | M | Neretva river, Croatia |
| Liu et al. (2012) | Ctenopharyngodon idellus | Grass carp | G,L,K,M | L | M | Southwest China |
| Mahesh et al. (2010) | Enoplos suratensis | Pearlspot | L,G,M | L | M | Lake Bhopal, India |
| Malik et al. (2010) | Latheobates rohita | Rohu | L,G,M | L | M | Lake Bhopal, India |
| Nivani et al. (2010) | Tilapia zilli | Redbelly tilapia | G,M | G | M | Aifkip, Nigeria |
| Obasohan (2007) | Parachanna obscura | African snakehead | G,L,M | G | M | Ogba River, Nigeria |
| Rauf et al. (2009) | Catla catla | Catla | L,S,K,Sc,M,G | L | G | Ravi river, Pakistan |
| Sönmez et al. (2012) | Channaauceptus | Walleye | L,S,K,Sc,M,G | L | G | Aby lagoon system, Côte d’Ivoire |
| Squadrone et al. (2013) | Silurus glanis | European catfish | M,L,G,K | K | M | Italian rivers |
| Taweel et al. (2011) | Oreochromis niloticus | Nile tilapia | L,G,M | L | M | Langat river, Malaysia |
| Tekin-Özan (2008) | Cyprinodon vario | Common carp | M,L,G | L | M | Beychir kale, Turkey |
| Ural et al. (2012) | Porops sp. | - | G,L,K,H,M | K | M | Uzungol dam lake, Turkey |
| Uwern et al. (2013) | Tilapia zilli | Redbelly tilapia | B,L,G | L | G | Cross river state, Nigeria |
| Younas et al. (2010) | Sillago aurea | African butter fish | B,L,G | L | B | Kabul river, Pakistan |

Ac: Alimentary canal, G: Gills, K: Kidneys, L: Liver, M: Mussels, Sc: Scales, Sk: Skin, H: Heart, B: Bone, Br: Brain, Lg: Lung
Contamination of freshwater ecosystems by Cd and the accumulation and toxicity in aquatic animals through both waterborne and dietary routes are more concerned by the experts. During dietary administration of metals, their concentrations in the digestive tract increase and remain high until the end of exposure and rapidly decrease during depuration25. Therefore, in diet-exposed fish, Cd concentrations were generally higher in the gastrointestinal tract than in the gills whereas in case of waterborne exposure, Cd concentrations are generally higher in gills and kidneys69. Another study on Oncorhyncus mykiss (rainbow trout) has demonstrated that waterborne Cd causes toxicity in freshwater fish by inducing hypocalcemia because Cd$^{2+}$ ions compete with waterborne Ca$^{2+}$ ions for the active bronchial uptake pathway which normally ensures internal homeostasis of calcium levels70. Therefore, increases in waterborne calcium concentrations protect against waterborne Cd uptake and toxicity in both acute and chronic exposures. Natural waters are concerned; water-born calcium may affect the detected Cd levels in gills and other organs. Therefore, detected Cd levels in fish may be limited through the bronchial pathway. Wood and co-workers70 also state that dietary Cd can protect against diet-borne Cd exposure, although the physiological mechanisms appear to differ from those at the gills. Surprisingly, the principal site of this inhibitory action of dietary calcium on gastrointestinal Cd uptake appears to be the stomach which is also the major site of gastrointestinal calcium uptake. Thus, this can also affect the Cd levels in the fish alimentary canal. However, the toxicity of Cd may be different according to waterborne or dietary pathways. As an example, Sajid and Muhammad71 stated that after investigating the sensitivity of fish towards toxicity of water-borne and dietary Cd, the dietary Cd were significantly less toxic than that of water-borne Cd.

Cadmium levels in various freshwater fish tissues according to the studies carried out by several researchers in different locations are given in Table 1. As an example, Ahmed and co-workers72, Ambedkar and Muniyan73 and Eneji and co-workers74 detected highest Cd levels in the alimentary canal of fish (Table 1). In contrast, several other studies show that Cd accumulation in the gills is higher compared to other tissues (Table 1). These observations reveal that even if the liver and kidney are considered as the prime sites of metal accumulation, gills can be more vulnerable than any other organs in some situations. Although the fish liver is considered as a good monitor of water pollution with metals since their concentrations accumulated in this organ are often proportional to those present in the environment75. Twardowska et al.25 Showed in case of waterborne and dietary exposure, Cd concentrations in the gills and the digestive tract increase rapidly. However, the liver accumulates high concentrations of metals, irrespectively of the uptake route. Although the metal accumulation is primarily depends on waterborne and dietary pathways, some studies show the relationship of Cd level in fish tissues with the age and size of fish. Ciardullo et al.76, Farkas et al.77 and Giguere et al.78 show that the age of the fish a potentially confounding factor when studying Cd bioaccumulation because Cd concentrations in liver and kidney increase with the age.

CONCLUSION

Cadmium and other toxic heavy metal in water impair feral populations of freshwater fish by altering their reproductive and physiological behaviors and abilities which ultimately affect the environmental permanence and fish diversity. There has been an increasing interest in the utilization of fishes as bioindicators of the integrity of aquatic environmental systems79,80,81. The measurement of bioaccumulation and total protein in fish tissues may prove to be useful in biomonitoring of exposure to aquatic pollutants. In the developing world, especially in South East Asia, fish is one of the main sources of protein and provides a significant contribution to the diet of the rural communities. With increased urbanization, industrialization and human population, there has been a rapid increase in the municipal waste water (sewage water and industrial effluents) and use inorganic agricultural fertilizers (phosphate fertilizers) which in turn has intensified the environmental pollution. As a result, metal bioaccumulation is a major route by which increased levels of the pollutants are transferred across food chains. Affinity of freshwater fish species to Cd is diverse (Table 1). This may be due to different reasons such as physiological, biological or genetic changes. Cadmium residues accumulated in different organs are proportional to those present in the environment. Both waterborne and dietary pathways are responsible for uptake of Cd from their environments. At the same time, different species of fish show disparities in Cd accumulation even in the same environment. Similarly, the effect of Cd can also influence by abiotic environmental factors. As far as fish tissues are concerned the liver shows higher affinity towards Cd rather than kidneys and gills (Table 1). Accumulation tendency of Cd by the muscle tissue which consists of mainly the edible parts of a fish is comparatively low according to the studies carried out by many authors.
FUTURE DIRECTIONS

Metal accumulation and their effects on fish are more diverse and complex. Moreover, the dynamic nature of aquatic systems makes it more difficult to understand. Because of time to time changes in the type and strength of pollution, the so called effect of Cd on freshwater fish may be more challenging to explain. However, individual close investigations are required especially on commercial and threaten fish species under different water quality conditions because the amount of absorption of Cd and assembling depends on ecological, physical, chemical and biological condition and physiology of organisms. The understanding of the interaction between water quality conditions and Cd in fish as well as the occurrence of the others metals and interactions among various metals with Cd are not enough to close the gaps between Cd accumulation in freshwater fish and possible environmental impacts. Similarly, comprehensive understanding of the species-level temporal changes of Cd accumulation in freshwater fish in their natural environments help to protect them from the future threats. Further investigations are necessary to understand the genetic influence on Cd bioaccumulation. Identification of genetic reasons is useful to improve more resistant species in the future. Knowledge of the form of Cd accumulation is a prerequisite to understand why freshwater fish accumulate trace metals (Cd) to such different body concentrations.

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