REVIEW ARTICLE **INSIGHT** ECOLOGY

DOI: 10.5567/ECOLOGY-IK.2015.1.12

Bioaccumulation of Cadmium in Freshwater Fish: An Environmental Perspective

[1]P.A.C.T. Perera, [2]Suranga P. Kodithuwakku, [3]T.V. Sundarabarathy and [2]U. Edirisinghe
[1]Post Graduate Institute of Agriculture, University of Peradeniya, Peradeniya, Sri Lanka
[2]Department of Animal Science, Faculty of Agriculture, University of Peradeniya, Sri Lanka
[3]Department of Biological Science, Faculty of Applied Sciences, University of Rajarata, Mihintale, Sri Lanka

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

Insight Ecology 4 (1): 1-12, 2015

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[1]. 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[2]. Metal bioaccumulation is influenced by multiple routes of exposure (diet and solution) and geochemical effects on bioavailability[3]. 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[4]. All trace metals are toxic at some bioavailability[5]. 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[6].

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[7]. In this process, many heavy metals are concentrated at different levels in

---

Corresponding Author: P.A.C.T. Perera, Post Graduate Institute of Agriculture, University of Peradeniya, Peradeniya, Sri Lanka

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^{-1}. 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[15]. Therefore, crop fields that are heavily contaminated with Cd may have resulted from long-term overuse of phosphate fertilizers[17]. 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[18] 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 tend to accumulate heavy metals in their tissues[25]. 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)[26].

UPTAKE OF CADMIUM BY FISH

In general, considerations of metal bioavailability and bioaccumulation in aquatic media can be direct and indirect exposure. Fish takes in Cd directly from exposure to a contaminated medium or by consumption of food containing the chemical[27]. Direct uptake of Cd by fish from the water is mainly in its free ionic form (Cd^{2+})[11] and the indirect exposure is possible as dietary means when consumer organisms subsequently ingest metals bioaccumulated in organisms at a lower trophic level with the potential for effects or bioaccumulation[2]. Despite the fact that direct and indirect exposure of bioavailability and bioaccumulation are considered separately, both of these processes act integrated with each other in the natural systems. Metal uptake in fish differs fundamentally from that of terrestrial animals because fish have gills that are constantly submersed in a solution of metal ions. Therefore, in freshwater fish, gills are the main point of entry for dissolved metals. The gastrointestinal tract also acts as an important route for metal absorption in fish. Li and the colleagues[28] reported that a small fraction of Cd present in the dissolved form in water might be ingested directly by fish through the skin as well. 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 Cd ions enter the chloride cells in the gills through calcium channels[29]. Cadmium that absorbs across the gills or the intestinal walls is distributed via the circulation, bond to transport proteins and distributed, to different tissues of the body[29]. Once Cd enters into the cells, the metal is made available for the interaction with cytoplasmatic components such as enzymes causing toxic effects and Metallothioneins (MTs).

Metallothioneins (MTs) are a low-molecular-weight metal binding proteins and are known to play several important roles, especially in the metabolism and protection against heavy metal toxicity[30]. In addition to the detoxification of toxic metals such as Cd, MTs are involved in the maintenance of homeostasis of essential trace elements such as zinc and copper[31]. 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[32]. The MTs play a role in transport, detoxification and storage of Cd[33]. After the absorption, Cd is bound to albumin and transported to liver[34]. Following release from the liver, MT-bound Cd enters the plasma and appears in the glomerular filtrate, from where it is re-released intracellularly by renal tubule cells[35]. At this stage, Cd is cleaved from the MT-Cadmium complex by lysosomal action and Cd^{2+} 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)[36], 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[37] 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[13,25,38,39]. Hardness is one of the most important factors that affect fish physiology and metal toxicity[40]. Elevated dietary Ca^{2+} protected fish against both, dietary and waterborne Cd uptake[41]. 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[24]. Water acidification directly affects metal accumulation rates by the fish[25,42]. 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[25]. Therefore, toxicity of Cd generally increases with reducing water hardness and reducing concentrations of dissolved organic matter[1,43]. Water temperature may cause the differences in metal deposition in various organs[25,44] of freshwater fish. Humus content in water also contributes to determine the concentration of Cd in fish[45]. 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[46-47].

Mebane[48] 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 experiments[49].

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 habits[25]. Nakayama *et al*.[50] 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 Luoma[52] 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 based[53] and little is known about the effects of Cd on genetic and biochemical adaptive responses of aquatic species under chronic and long-term exposure[54]. Toxicological studies at cellular level have shown that Cd inhibits the mitochondrial electron transfer chain and induces relatively oxygen species production[55].

TOXICITY OF CADMIUM IN FRESHWATER FISH

Cadmium as a toxic element might act as stress inducing agent for fish[53]. Cadmium exposure may lead to the results of some pathophysiological damages including growth rate reduction in fish[56]. Moreover, Cd produces both hepatic and renal injuries in mammals and fish[28] with the potential to induce oxidative stress[57]. It was also found to interfere with many protein and carbohydrate metabolism by inhibiting the enzymes involved in the processes[58] and known to perturb ion balance in teleost fishes[59]. 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 growth[60]. 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 concentrations[45]. Chronic exposure can lead to mortality; sub-lethal effects such as reduced growth and reproductive failure are more common[60]. 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 toxicity[46,47,61] 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 effect[46-47]. Interestingly, after exposing three freshwater species (*Cyprinus carpio*, *Carassius gibelio* and *Corydoras paleatus*) to different doses of Cd, Cavas and co-workers[62] clearly shows that the frequencies of micronucliated and binucliated 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[63-64]. However, accumulated levels among organs varied following different treatment doses of Cd^{2+} and exposure times[65]. 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[66-67] but different tissues show different capacity for accumulating heavy metals[68]. 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[25]. 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)[72]	*Sperata aor*	Long-whiskered catfish	M,K,G,Ac,L	Ac	L	Dhaleshwari river, Bangladesh
Akan (2009)[82]	*Clarias anguillaris*	Mudfish	L,G,K,Ac,B	L	Ac	Lake Chad, Nigeria
Alhashemi *et al*. (2012)[83]	*Barbus grypus*	Shirbot barb	M,G,Go,L	L	M	Southwest Iran
Ambedkar and Muniyan (2011)[73]	*Tilapia mossambica*	Mozambique tilapia	L,K,G,M,Ac	L	K	Kollidam river, Tamilnadu
	Heteropneustes fossilis	Stinging catfish	Ac,L,K,G,M	Ac	M	
Anim-Gyampo *et al*. (2013)[84]	*Sarotherodon galilaeus*	Mango tilapia	M,G	M	G	Tono reservoir, Ghana
Brázová *et al*. (2012)[85]	*Perca fluviatilis*	European perch	K,L,M,B	K	M	Ru_ín reservoir, Slovakia
Chi *et al*. (2007)[86]	*Aristichthys nobilis*	Bighead carp	L,M	L	M	Lake Taihu, China
Coulibaly *et al*. (2012)[87]	*Sarotherodon melanotheron*	Black-chinned tilapia	L,G,K,M	L	M	Ebrie lagoon, Ivory Coast
Cyrille *et al*. (2012)[88]	*Sarotherodon melanotheron*	Black-chinned tilapia	M,G,L	M	G,L	Aby lagoon system, Cofe d'Ivoire
Demirak *et al*. (2006)[89]	*Leuciscus cephalus*	Chub	G,M	G	M	Southwest Turkey
Dimari and Hati (2009)[90]	*Heterotis niloticus*	African bonytongue	L,Ac,G	L	G	Lake Alau, Nigeria
Duman and Kar (2012)[91]	*Squalius cephalus*	European chup	L,G,M	L	M	Yamula dam lake, Turkey
Ebrahimpour *et al*. (2011)[92]	*Carassius gibelio*	Prussian carp	L,K,G,Ac,M	L	M	Anzali, Iran
	Esox lucius	Northern pike	L,K,G,Ac,M	L	M	
Eneji *et al*. (2011)[74]	*Tilapia zilli*	Redbelly tilapia	G,Ac,M	G	M	Benue river, Nigeria
Eneji *et al*. (2011)[74]	*Clarias gariepinus*	African catfish	G,Ac,M	Ac	M	
Fatma (2008)[93]	*Lates niloticus*	Nile perch	L,G,Ac,M	L	M	Lake Nasser, Egypt
Gwaski *et al*. (2013)[94]	*Polypterus ansorgii*	Guinean bichir	G,K,L,Lg,M	L	K,M	Lake Chad, Nigeria
	Clarias anguillaris	Mudfish	G,K,L,Lg,M	Lg	K	
	Oreochromis niloticus	Nile tilapia	G,K,L,Lg,M	L	K	
Gwaski *et al*. (2013)[94]	*Synodontis nigrita*	catfish	G,K,L,Lg,M	G	L,M	Lake Chad, Nigeria
	Bagrus docmac	Semutundu catfish	G,K,L,Lg,M	L	M	
	Lates niloticus	Nile perch	G,K,L,Lg,M	M	L	
Has-Schön *et al*. (2006)[95]	*Cyprinus carpio*	Common carp	K,G,L,M,Go	K	M	Neretva river, Croatia
Liu *et al*. (2012)[96]	*Ctenopharyngodon idellus*	Grass carp	L,G,K,M	L	M	Southeast China
Mahesh *et al*. (2010)[97]	*Etroplus suratensis*	Pearlspot		K		Kerala, India
Malik *et al*. (2010)[98]	*Labeo rohita*	Rohu	L,K,G,M	L	M	Lake Bhopal, India
	Ctenopharyngodon idella	Grass carp	G,L,K,M	G	M	
	Labeo rohita	Rohu	L,K,G,M	L		
Nwani *et al*. (2010)[99]	*Tilapia zillii*	Redbelly tilapia	G,M	G	M	Afikpo, Nigeria
Obasohan (2007)[100]	*Parachanna obscura*	African snakehead	G,L,M	G	M	Ogba River, Nigeria
Rauf *et al*. (2009)[101]	*Catla catla*	Catla	L,Sk,K,Sc,M,G	L	G	Ravi river, Pakistan
	Cirrhina mrigala	Mrigal	L,Sk,K,Sc,M,G	L	G	
	Labeo rohita	Rohu	L,Sk,K,Sc,M,G	L	G	
Sönmez *et al*. (2012)[102]	*Capoeta capoeta umbla*	-	M,L,G		M	Karasu river, Turkey
	Chalcalburnus mosullensis	-	M,L,G		M	
Squadrone *et al*. (2013)[103]	*Silurus glanis*	European catfish	M,L,K,G	K		Italian rivers
Taweel *et al*. (2011)[104]	*Oreochromis niloticus*	Nile tilapia	L,M,G	L	M	Langat river, Malaysia
Tekin-Özan (2008)[105]	*Cyprinus carpio*	Common carp	M,L,G	L	M	Bey^{a}ehir kale, Turkey
Ural *et al*. (2012)[106]	*Capoeta umbla*	-	G,L,K,H,M	K		Uzuncayir dam lake, Turkey
Uwem *et al*. (2013)[107]	*Tilapia zilli*	Redbelly tilapia	B,L,G	L	G	Cross river state, Nigeria
	Oreochromis niloticus	Nile tilapia	B,L,G	L	B	
	Schilbe mystus	African butter catfish	B,L,G	L,B	G	
Yousafzai *et al*. (2010)[108]	*Wallago attu*	Wallago	G,M,L,Sk,Ac	G	Ac	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 depuration[25]. 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 kidneys[69]. Another study on *Oncorhynchus 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 levels[70]. 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-workers[70] 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 Muhammad[71] 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-workers[72], Ambedkar and Muniyan[73] and Eneji and co-workers[74] 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 environment[75]. 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 systems[79,80,81]. 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.

REFERENCES

1. UNEP., 2010. Final review of scientific information on cadmium. Chemicals Branch, DTIE, United Nations Environment Programme.
2. Drexler, J., N. Fisher, G. Henningsen, R. Lanno, J. Mcgeer and K. Sappington, 2003. Issue paper on the bioavailability and bioaccumulation of metals. U.S. Environmental Protection Agency, Risk Assessment Forum, Washington, DC., USA.
3. Luoma, S.N. and P.S. Rainbow, 2005. Why is metal bioaccumulation so variable? Biodynamics as a unifying concept. Environ. Sci. Technol., 39: 1921-1931.
4. Philips, D.J.H. and P.S. Rainbow, 1994. Biomonitoring of Trace Aquatic Contaminants. 2nd Edn., Chapman and Hall, London, UK.
5. Luoma, S.N. and P.S. Rainbow, 2008. Metal Contamination in Aquatic Environments: Science and Lateral Management. Cambridge University Press, Cambridge, UK., pp: 141-150.
6. Rainbow, P.S., B.D. Smith and S.N. Luoma, 2009. Biodynamic modelling and the prediction of Ag, Cd and Zn accumulation from solution and sediment by the polychaete Nereis diversicolor. Mar. Ecol. Prog. Ser., 390: 145-155.
7. Karadede, H., S.A. Oymak and E. Unlu, 2004. Heavy metals in mullet, *Liza abu* and catfish, *Silurus triostegus*, from the Ataturk Dam Lake (Euphrates), Turkey. Environ. Int., 30: 183-188.
8. Bervoets, L., R. Blust and R. Verheyen, 2001. Accumulation of metals in the tissues of three spined stickelback (*Gasterosteus aculeatus*) from natural fresh waters. Ecotoxicol. Environ. Saf., 48: 117-127.
9. Rao, L.M. and G. Padmaja, 2000. Bioaccumulation of heavy metals in *M. Cyprinoids* from the harbor waters of Visakhapatnam. Bull. Pure Applied Sci., 19: 77-85.
10. Scharenberg, W., P. Gramann and W.H. Pfeiffer, 1994. Bioaccumulation of heavy metals and organochlorines in a lake ecosystem with special reference to bream (*Abramis brama* L.). Sci. Total Environ., 155: 187-197.
11. Okocha, R.C. and O.B. Adedeji, 2011. Overview of cadmium toxicity in fish. J. Applied Sci. Res., 7: 1195-1207.
12. Klaassen, C.D., J. Liu and S. Choudhuri, 1999. Metallothionein: An intracellular protein to protect against cadmium toxicity. Annu. Rev. Pharmacol. Toxicol., 39: 267-274.
13. Kotze, P., H.H. du Preez and J.H.J. van Vuren, 1999. Bioaccumulation of copper and zinc in *Oreochromis mossambicus* and *Clarias gariepinus*, from the Olifants River, Mpumalanga, South Africa. Water SA, 25: 99-110.
14. Borgmann, U., Y. Couillard, P. Doyle and D.G. Dixon, 2005. Toxicity of sixty-three metals and metalloids to *Hyalella azteca* at two levels of water hardness. Environ. Toxicol. Chem., 24: 641-652.
15. Hooda, P.S., 2010. Front Matter. In: Trace Elements in Soils, Hooda, P. (Ed.). John Wiley and Sons, Ltd., New York, USA., ISBN-13: 9781444319484.
16. Loganathan, P., M.J. Hedley and N.D. Grace, 2008. Pasture soils contaminated with fertilizer-derived cadmium and fluorine: Livestock effects. Rev. Environ. Contam. Toxicol., 192: 29-66.

17. Cheraghi, M., B. Lorestani and H. Merrikhpour, 2012. Investigation of the effects of phosphate fertilizer application on the heavy metal content in agricultural soils with different cultivation patterns. Biol. Trace Element Res., 145: 87-92.
18. Pavlik, Y., 1997. Ecological problems in industrially exposed East Slovakian regions in relation to agriculture. VUZV Nitra, (In Slovak).
19. Eisler, R., 2000. Handbook of Chemical Risk Assessment: Health Hazards to Humans, Plants and Animals. Vol. 3, CRC Press, Boca Raton, FL., USA.
20. Lane, T.W. and F.M.M. Morel, 2000. A biological function for cadmium in marine diatoms. Proc. Natl. Acad. Sci. USA, 97: 4627-4631.
21. Adams, W.J., R. Blust, U. Borgmann, K.V. Brix and D.K. DeForest *et al*., 2011. Utility of tissue residues for predicting effects of metals on aquatic organisms. Integr. Environ. Assess. Manage., 7: 75-98.
22. WHO., 2000. Cadmium. In: Air Quality Guidelines for Europe, WHO (Ed.). Chapter 6.3, World Health Organization, Regional Office for Europe, Copenhagen, Denmark, ISBN-13: 9789289013581, pp: 136-138.
23. Sorensen, E.M.B., 1991. Metal Poisoning in Fish. CRC Press, Boston, MA., USA.
24. Irwin, R.J., M. van Mouwerik, L. Stevens, M.D. Seese and W. Bashaw, 1997. Environmental contaminants encyclopedia: Copper entry. National Park Service, Water Resources Divisions, Water Operations Branch, Fort Collins, CO., USA., July 1, 1997, pp: 1-99.
25. Twardowska, I., H.E. Allen, M.M. Haggblom and S. Stefaniak, 2006. Soil and Water Pollution Monitoring, Protection and Remediation. Springer, Dordrecht, Netherlands, ISBN-13: 978-1-4020-4728-2, pp: 107-114.
26. Mebane, C.A., 2006. Cadmium risks to freshwater life: Derivation and validation of low-effect criteria values using laboratory and field studies (version 1.2). U.S. Geological Survey Scientific Investigations Report 2006-5245, pp: 130.
27. USEPA., 2002. Summary of biological assessment programs and biocriteria development for states, tribes, territories and interstate omissions: Streams and wadeable rivers. EPA 822-R-02-048, U.S. Environmental Protection Agency, Washington, DC., USA.
28. Li, H., K. Mai, Q. Ai, C. Zhang and L. Zhang, 2009. Effects of dietary squid viscera meal on growth and cadmium accumulation in tissues of large yellow croaker, *Pseudosciaena crocea* R. Front. Agric. China, 3: 78-83.
29. Olsson, P., P. Kling and C. Hogstrand, 1998. Mechanism of Heavy Metal Accumulation and Toxicity in Fish. In: Metal Metabolism in Aquatic Environments, Langston, W.J. and M.J. Bebianno (Eds.). Chapman and Hall, London, UK., ISBN-13: 978-0412803703, pp: 321-341.
30. Nordberg, M. and G.F. Nordberg, 2009. Metallothioneins: Historical development and overview. Met Ions Life Sci., 5: 1-29.
31. Coyle, P., J.C. Philcox, L.C. Carey and A.M. Rofe, 2002. Metallothionein: The multipurpose protein. Cell Mol. Life Sci., 59: 627-647.
32. King, L.A., P.C. MacDonald and M.L. Casey, 1997. Regulation of metallothionein expression in human amnion epithelial and mesenchymal cells. Am. J. Obstet. Gynecol., 177: 1496-1501.
33. Thompson, J. and J. Bannigan, 2008. Cadmium: Toxic effects on the reproductive system and the embryo. Reprod. Toxicol., 25: 304-315.
34. Nordberg, G.F., R.F. Herber and L. Alessio, 1992. Cadmium in the Human Environment: Toxicity and Carcinogenicity. International Agency for Research on Cancer, Lyon, France.
35. Annabi, A., I. Messaoudi, A. Kerkeni and K. Said, 2011. Cadmium accumulation and histological lesion in mosquitofish (*Gambusia affinis*) tissues following acute and chronic exposure. Int. J. Environ. Res., 5: 745-756.
36. Wepener, V., J.H.J. van Vuren and H.H. du Preez, 2001. Uptake kinetics and distribution of a copper, iron and zinc mixture in gill, liver and plasma of a freshwater teleost, Tilapia sparrmanii. Water SA, 27: 99-108.
37. Pelgrom, S.M.G.J., L.P.M. Lamers, R.A.C. Lock, P.H.M. Balm and S.E.W. Bonga, 1995. Interactions between copper and cadmium modify metal organ distribution in mature tilapia, *Oreochromis mossambicus*. Environ. Pollut., 90: 415-423.
38. Golovanova, I.L., 2005. Effects of heavy metals on the physiological and biochemical status of fishes and aquatic invertebrates. Inland Water Biol., 1: 93-101.
39. Spry, D.J. and J.G. Wiener, 1991. Metal bioavailability and toxicity to fish in low-alkalinity lakes: A critical review. Environ. Pollut., 71: 243-304.

40. Saglam, D., G. Atli and M. Canli, 2013. Investigations on the osmoregulation of freshwater fish (*Oreochromis niloticus*) following exposures to metals (Cd, Cu) in differing hardness. Ecotoxicol. Environ. Saf., 92: 79-86.
41. Baldisserotto, B., M.J. Chowdhury and C.M. Wood, 2005. Effects of dietary calcium and cadmium on cadmium accumulation, calcium and cadmium uptake from the water and their interactions in juvenile rainbow trout. Aquat. Toxicol., 72: 99-117.
42. Horwitz, R.J., B. Ruppel, S. Wisniewski, P. Kiry, M. Hermanson and C. Gilmour, 1995. Mercury Concentrations in Freshwater Fishes in New Jersey. In: Mercury as a Global Pollutant, Porcella, D.B., J.W. Huckabee and B. Wheatley (Eds.). Springer, Netherlands, pp: 885-888.
43. Khayatzadeh, J. and E. Abbasi, 2010. The effects of heavy metals on aquatic animals. Proceedings of the 1st International Applied Geological Congress, April 26-28, 2010, Department of Geology, Islamic Azad University-Mashad Branch, Iran, pp: 688-694.
44. Wong, C.K.C., R.Y.H. Cheung and M.H. Wong, 2000. Heavy metal concentrations in green-lipped mussels collected from Tolo Harbour and markets in Hong Kong and Shenzhen. Environ. Pollut., 109: 165-171.
45. Levit, S.M., 2010. A literature review of effects of cadmium on fish. Centre for Science in Public Participation, Bozeman, Montana, November 2010. http://www.nature.org/images/cadmium-literature-review-dec-2010-2.pdf
46. Bradl, H., 2005. Heavy Metals in the Environment: Origin, Interaction and Remediation. 1st Edn., Academic Press, New York, USA., ISBN-13: 9780120883813, Pages: 282.
47. Wright, D.A. and P. Welbourn, 2002. Environmental Toxicology. Cambridge University Press, Cambridge, UK., ISBN-13: 9780521588607, Pages: 630.
48. Mebane, C.A., 2010. Relevance of risk predictions derived from a chronic species sensitivity distribution with cadmium to aquatic populations and ecosystems. Risk Anal., 30: 203-223.
49. Niyogi, S., R. Kent and C.M. Wood, 2008. Effects of water chemistry variables on gill binding and acute toxicity of cadmium in rainbow trout (*Oncorhynchus mykiss*): A Biotic Ligand Model (BLM) approach. Comp. Biochem. Physiol. C: Toxicol. Pharmacol., 148: 305-314.
50. Nakayama, S.M.M., Y. Ikenaka, K. Muzandu, K. Choongo and B. Oroszlany *et al*., 2010. Heavy metal accumulation in lake sediments, fish (*Oreochromis niloticus* and *Serranochromis thumbergi*) and crayfish (*Cherax quadricarinatus*) in Lake Itezhi-tezhi and Lake Kariba, Zambia. Arch. Environ. Contam. Toxicol., 59: 291-300.
51. Croteau, M.N., S.N. Luoma and A.R. Stewart, 2005. Trophic transfer of metals along freshwater food webs: Evidence of cadmium biomagnification in nature. Limnol. Oceanogr., 50: 1511-1519.
52. Croteau, M.N. and S.N. Luoma, 2005. Delineating copper accumulation pathways for the freshwater bivalve *Corbicula* using stable copper isotopes. Environ. Toxicol. Chem., 24: 2871-2878.
53. Annabi, A., K. Said and I. Messaoudi, 2013. Cadmium: Bioaccumulation, histopathology and detoxifying mechanisms in fish. Am. J. Res. Commun., 1: 60-79.
54. Gonzalez, P., M. Baudrimont, A. Boudou and J.P. Bourdineaud, 2006. Comparative effects of direct cadmium contamination on gene expression in gills, liver, skeletal muscles and brain of the zebrafish (*Danio rerio*). Biometals, 19: 225-235.
55. Wang, Y., J. Fang, S.S. Leonard and K.M.K. Rao, 2004. Cadmium inhibits the electron transfer chain and induces reactive oxygen species. Free Radic. Biol. Med., 36: 1434-1443.
56. Hansen, J.A., P.G. Welsh, J. Lipton and M.J. Suedkamp, 2002. The effects of long-term cadmium exposure on the growth and survival of juvenile bull trout (*Salvelinus confleuentus*). Aquat. Toxicol., 58: 165-174.
57. Kim, J.H., J.S. Rhee, J.S. Lee, H.U. Dahms, J. Lee, K.N. Han and J.S. Lee, 2010. Effect of cadmium exposure on expression of antioxidant gene transcripts in the river pufferfish, *Takifugu obscurus* (Tetraodontiformes). Comp. Biochem. Physiol. C: Toxicol. Pharmacol., 152: 473-479.
58. Sobha, K., A. Poornima, P. Harini and K. Veeraiah, 2007. A study on biochemical changes in the fresh water fish, *Catla catla* (Hamilton) exposed to the heavy metal toxicant cadmium chloride. Kathmandu Univ. J. Sci. Eng. Technol., 1: 1-11.
59. Garcia-Santos, S., A. Fontainhas-Fernandes and J.M. Wilson, 2006. Cadmium tolerance in the Nile tilapia (*Oreochromis niloticus*) following acute exposure: Assessment of some ionoregulatory parameters. Environ. Toxicol., 21: 33-46.
60. AMAP., 1998. AMAP assessment report: Arctic pollution issues. Arctic Monitoring and Assessment Programme (AMAP), Oslo, Norway.

61. Landis, W.G. and H.Y. Ming, 2003. Introduction to Environmental Toxicology: Impacts of Chemicals upon Ecological Systems. 3rd Edn., CRC Press, Boca Raton, FL., USA., ISBN-13: 9781566706605, Pages: 512.
62. Cavas, T., N.N. Garanko and V.V. Arkhipchuk, 2005. Induction of micronuclei and binuclei in blood, gill and liver cells of fishes subchronically exposed to cadmium chloride and copper sulphate. Food Chem. Toxicol., 43: 569-574.
63. Peakall, D. and J. Burger, 2003. Methodologies for assessing exposure to metals: Speciation, bioavailability of metals and ecological host factors. Ecotoxicol. Environ. Safety, 56: 110-121.
64. Vijver, M.G., C.A. van Gestel, R.P. Lanno, N.M. van Straalen and W.J.G.M. Peijnenburg, 2004. Internal metal sequestration and its ecotoxicological relevance: A review. Environ. Sci. Technol., 38: 4705-4712.
65. Wu, S.J., Y.H. Chang, C.W Fang and W.H. Pan, 1999. Food sources of weight, calories and three macro-nutrients-NAHSIT 1993-1996. Nutr. Sci. J., 24: 41-58.
66. Hollis, L., C. Hogstrand and C.M. Wood, 2001. Tissue-specific cadmium accumulation, metallothionein induction and tissue zinc and copper levels during chronic sublethal cadmium exposure in juvenile rainbow trout. Arch. Environ. Contam. Toxicol., 41: 468-474.
67. Kraemer, L.D., P.G.C. Campbell and L. Hare, 2005. A field study examining metal elimination kinetics in juvenile yellow perch (*Perca flavescens*). Aquat. Toxicol., 75: 108-126.
68. Creti, P., F. Trinchella and R. Scudiero, 2010. Heavy metal bioaccumulation and metallothionein content in tissues of the sea bream *Sparus aurata* from three different fish farming systems. Environ. Monitor. Assess., 165: 321-329.
69. Szebedinszky, C., J.C. McGeer, D.G. McDonald and C.M. Wood, 2001. Effects of chronic Cd exposure via the diet or water on internal organ-specific distribution and subsequent gill Cd uptake kinetics in juvenile rainbow trout (*Oncorhynchus mykiss*). Environ. Toxicol. Chem., 20: 597-607.
70. Wood, C.M., N.M. Franklin and S. Niyogi, 2007. The protective role of dietary calcium against cadmium uptake and toxicity in freshwater fish: An important role for the stomach. Environ. Chem., 3: 389-394.
71. Yaqub, S. and M. Javed, 2012. Acute toxicity of water-borne and dietary cadmium and cobalt for fish. Int. J. Agric. Biol., 14: 276-280.
72. Ahmed, A.T.A., S. Mandal, D.A. Chowdhury, A.R.M. Tareq and M.M. Rahman, 2012. Bioaccumulation of some heavy metals in Ayre fish (Sperata Aor Hamilton, 1822), sediment and water of dhaleshwari river in dry season. Bangladesh J. Zool., 40: 147-153.
73. Ambedkar, G. and M. Muniyan, 2012. Analysis of heavy metals in water, sediments and selected freshwater fish collected from Gadilam river, Tamilnadu, India. Int. J. Toxicol. Applied Pharmacol., 2: 25-30.
74. Eneji, I.S., R. Sha'Ato and P.A. Annune, 2011. Bioaccumulation of heavy metals in fish (*Tilapia zilli* and *Clarias gariepinus*) organs from River Benue, North-Central Nigeria. Pak. J. Anal. Environ. Chem., 12: 25-31.
75. Dural, M., M.Z.L. Goksu and A.A. Ozak, 2007. Investigation of heavy metal levels in economically important fish species captured from the Tuzla Lagoon. Food Chem., 102: 415-421.
76. Ciardullo, S., F. Aureli, E. Coni, E. Guandalini and F. Iosi *et al*., 2008. Bioaccumulation potential of dietary arsenic, cadmium, lead, mercury and selenium in organs and tissues of Rainbow trout (*Oncorhyncus mykiss*) as a function of fish growth. J. Agric. Food Chem., 56: 2442-2451.
77. Farkas, A., J. Salanki and A. Specziar, 2003. Age-and size-specific patterns of heavy metals in the organs of freshwater fish *Abramis brama* L. populating a low-contaminated site. Water Res., 37: 959-964.
78. Giguere, A., P.G.C. Campbell, L. Hare, D.G. McDonald and J.B. Rasmussen, 2004. Influence of lake chemistry and fish age on cadmium, copper and zinc concentrations in various organs of indigenous yellow perch (*Perca flavescens*). Can. J. Fish Aquat. Sci., 61: 1702-1716.
79. Adams, S.M., 2002. Biological Indicators of Aquatic Ecosystem Stress. American Fisheries Society, Bethesda, MD., USA., pp: 644.
80. Akueshi, E.U., E. Oriegie, N. Ocheakiti and S. Okunsebor, 2003. Levels of some heavy metals in fish from mining lakes on the Jos Plateau, Nigeria. Afr. J. Nat. Sci., 6: 82-86.
81. Jenkins, J.A., 2004. Fish bioindicators of ecosystem condition at the Calcasieu Estuary, Louisiana. Open-File Report 2004-1323, National Wetlands Research Center, USGS, Lafayette, pp: 47.

82. Akan, J.C., F.I. Abdulrahman, O.A. Sodipo and P.I. Akandu, 2009. Bioaccumulation of some heavy metals of six fresh water fishes caught from Lake Chad in Doron Buhari, Maiduguri, Borno State, Nigeria. J. Applied Sci. Environ. Sanitat., 4: 103-114.
83. Alhashemi, A.H., A. Karbassi, B.H. Kiabi, S.M. Monavari and M.S. Sekhavatjou, 2012. Bioaccumulation of trace elements in different tissues of three commonly available fish species regarding their gender, gonadosomatic index and condition factor in a wetland ecosystem. Environ. Monit. Assess., 184: 1865-1878.
84. Anim-Gyampo, M., M. Kumi and M.S. Zango, 2013. Heavy metals concentrations in some selected fish species in Tono irrigation reservoir in Navrongo, Ghana. J. Environ. Earth Sci., 3: 109-119.
85. Brazova, T., J. Torres, C. Eira, V. Hanzelova, D. Miklisova and P. Salamun, 2012. Perch and its parasites as heavy metal biomonitors in a freshwater environment: The case study of the Ruzin water reservoir, Slovakia. Sensors, 12: 3068-3081.
86. Chi, Q.Q., G.W. Zhu and A. Langdon, 2007. Bioaccumulation of heavy metals in fishes from Taihu Lake, China. J. Environ. Sci., 19: 1500-1504.
87. Coulibaly, S., B.C. Atse, K.M. Koffi, S. Sylla, K.J. Konan and N'Guessan J. Kouassi, 2012. Seasonal accumulations of some heavy metal in water, sediment and tissues of black-chinned Tilapia Sarotherodon melanotheron from Bietri Bay in Ebrie Lagoon, Ivory Coast. Bull. Environ. Contam. Toxicol., 88: 571-576.
88. Cyrille, Y.D.A., K. Victor, T.A. Sanogo, S. Boukary and W. Joseph, 2012. Cadmium accumulation in tissues of *Sarotherodon melanotheron* (Ruppel, 1852) from the Aby Lagoon system in Cote d'Ivoire. Int. J. Environ. Res. Public Health, 9: 821-830.
89. Demirak, A., F. Yilmaz, A.L. Tuna and N. Ozdemir, 2006. Heavy metals in water, sediment and tissues of *Leuciscus cephalus* from a stream in Southwestern Turkey. Chemosphere, 63: 1451-1458.
90. Dimari, G.A. and S.S. Hati, 2009. Interaction profile for As, Cd, Cr and Pb in tissues of fishes (*Tilapia gallier*, *Clarias lazera* and *Heterotis niloticus*). Sci. Res. Essays, 4: 894-899.
91. Duman, F. and M. Kar, 2012. Temporal variation of metals in water, sediment and tissues of the European chup (*Squalius cephalus* L.). Bull. Environ. Contam. Toxicol., 89: 428-433.
92. Ebrahimpour, M., A. Pourkhabbaz, R. Baramaki, H. Babaei and M. Rezaei, 2011. Bioaccumulation of heavy metals in freshwater fish species, Anzali, Iran. Bull. Environ. Contam. Toxicol., 87: 386-392.
93. Fatma, A.S., 2008. Mohamed: Bioaccumulation of selected metals and histopathological alteration in tissues of *Oreochromis niloticus* and Late niloticus form lake Nasser, Egypt. Global Vet., 2: 205-218.
94. Gwaski, P.A., S.S. Hati, N.P. Ndahi and V.O. Ogugbuaja, 2013. Emergent pollution bio-monitoring triad (target species-tissues-analyse) for the aquatic environment of Chad lake. Adv. Applied Sci. Res., 4: 181-189.
95. Has-Schon, E., I. Bogut and I. Strelec, 2006. Heavy metal profile in five fish species included in human diet, domiciled in the end flow of river Neretva (Croatia). Arch. Environ. Contam. Toxicol., 50: 545-551.
96. Liu, F., H.G. Ni, F . Chen, Z.X. Luo, H. Shen, L. Liu and P. Wu, 2012. Metal accumulation in the tissues of grass carps (*Ctenopharyngodon idellus*) from fresh water around a copper mine in Southeast China. Environ. Monit. Assess., 184: 4289-4299.
97. Mahesh, M., M. Deepa and A.P. Thomas, 2010. Comparison of metal accumulation in the selected fishes from two sites of Vembanad backwaters, Kerala, India. J. Environ. Sci. Eng., 52: 193-198.
98. Malik, N., A.K. Biswas, T.A. Qureshi, K. Borana and R. Virha, 2010. Bioaccumulation of heavy metals in fish tissues of a freshwater lake of Bhopal. Environ. Monit. Assess., 160: 267-276.
99. Nwani, C.D., D.A. Nwachi, O.I. Okogwu, E.F. Ude and G.E. Odoh, 2010. Heavy metals in fish species from lotic freshwater ecosystem at Afikpo, Nigeria. J. Environ. Biol., 31: 595-601.
100. Obasohan, E.E., 2007. Heavy metals concentrations in the offal, gill, muscle and liver of a freshwater mudfish (*Parachanna obscura*) from Ogba River, Benin city, Nigeria. Afr. J. Biotechnol., 6: 2620-2627.
101. Rauf, A., M. Javed and M. Ubaidullah, 2009. Heavy metal levels in three major carps (*Catla catla*, *Labeo rohita* and *Cirrhina mrigala*) from the river Ravi, Pakistan. Pak. Vet. J., 29: 24-26.
102. Sonmez, A.Y., A.M. Yaganoglu, G. Arslan and O. Hisar, 2012. Metals in two species of fish in Karasu River. Bull. Environ. Contam. Toxicol., 89: 1190-1195.
103. Squadrone, S., M. Prearo, P. Brizio, S. Gavinelli and M. Pellegrino *et al*., 2012. Heavy metals distribution in muscle, liver, kidney and gill of European catfish (*Silurus glanis*) from Italian Rivers. Chemosphere, 90: 358-365.

104. Taweel, A., M. Shuhaimi-Othman and A.K. Ahmad, 2011. Heavy metals concentration in different organs of tilapia fish (*Oreochromis niloticus*) from selected areas of Bangi, Selangor, Malaysia. Afr. J. Biotechnol., 10: 11562-11566.
105. Tekin-Ozan, S. and I. Kir, 2008. Seasonal variations of heavy metals in some organs of carp (*Cyprinus carpio* L., 1758) from Beysehir Lake (Turkey). Environ. Monitor. Assess., 138: 201-206.
106. Ural, M., N. Yildirim, D. Danabas, O. Kaplan, N.C. Yildirim, M. Ozcelik and E.F. Kurekci, 2012. Some heavy metals accumulation in tissues in *Capoeta umbla* (Heckel, 1843) from Uzuncayir Dam Lake (Tunceli, Turkey). Bull. Environ. Contam. Toxicol., 88: 172-176.
107. Uwem, G.U., A.F. Emile, I.J. Udo and A.A. Bassey, 2013. Bioaccumulation of heavy metal in three fresh water fishes caught from cross river system. Eur. J. Exp. Biol., 3: 576-582.
108. Yousafzai, A.M., D.P. Chivers, A.R. Khan, I. Ahmad and M. Siraj, 2010. Comparison of heavy metals burden in two freshwater fishes *Wallago attu* and *Labeo dyocheilus* with regard to their feeding habits in natural ecosystem. Pak. J. Zool., 42: 537-544.