The Effects of Heavy Metals on Aquatic Animals

Khayatzadeh J., Abbasi E.

Department of Biology, Sciences Faculty, Islamic Azad University, Mashhad Branch, Mashhad, Iran
E-mail :j.khayatzadeh@mshdiau.ac.ir , Tel: +98 511 8435050

Abstract

Heavy metals consist less than one percent of living mass organisms, and their different density cause to some disorders. Surface waters and also acidic rains can transfer these metals to oceans via washing polluted environment. Heavy metals naturally exist in very little amount in watery places. Metals pollution of the sea is less than other types of watery pollution but its effects on marine ecosystems and humans are very extensive. Industrial wastes in aquiculture cause toxic effects in aquatic organisms specially in fishes. Aquatic organisms absorb the pollutants directly from water and indirectly from food chains. Some of the toxic effects of heavy metals on fishes and aquatic invertebrates are; reduction of the developmental growth, increase of developmental anomalies, reduction of fishes survival- especially at the beginning of exogenous feeding or even cause extinction of entire fishes population in polluted reservoirs. These consequences can affect on geological, hydrological and finally on biological cycles. Thus it seems that more consideration of bioconservation protocols are so important.

Introduction

Water is one of the most valuable natural resources .The quality of water is of vital concern for the mankind since it is directly link with human welfare [15]. A major environmental concern due to dispersal of industrial and urban wastes generated by human activities is the contamination of soil and water. Controlled and uncontrolled disposal of waste, accidental and process spillage, mining and smelting of metalliferous ores, sewage sludge application to agricultural soils are responsible for transferring of contaminants into non-contaminated sites as dust or leachate and contribute towards contamination of our ecosystem[11]. A wide range of inorganic and organic compounds cause contamination, includes heavy metals, combustible and putrescible substances, hazardous wastes, explosives and petroleum products, Phenol and textile dyes. Major component of inorganic contaminates are heavy metals. They have some different problems than organic contaminants [11, 10,13].

Metal pollution of the sea is less visible and direct than other types of marine pollution but its effects on marine ecosystems and humans are very extensive. The presence of metals varies between fish species; depend on age, developmental stage and other physiological factors. Fish accumulate substantial concentrations of mercury in their tissues and thus can represent a major dietary source of this element for humans. Fish are the single largest sources of mercury and arsenic for man. Mercury is a known human toxicant and the first sources of mercury contamination in man are fishes. Biotransformation of mercury and methyl mercury formation constitute a dangerous problem for human health [7]. Soil microorganisms can degrade organic contaminants, while metals need immobilization or physical removal. Although many metals are essential, all metals are toxic at higher concentrations, because they cause oxidative stress by formation of free radicals. Another reason why metals may be toxic is that they can replace essential metals in pigments or enzymes disrupting their function. Thus, metals render the land unsuitable for plant growth and destroy the biodiversity [11].

What are the heavy metals?

Heavy metals have variously been used to denote:(I) metals with atomic number 23(i.e. vanadium) onwards except Rb, Y, Cs, Ba, and Fr; (II) metals with density greater than 5; and (III) metals which are toxic to man and other life forms when found in the environment. The eight most common pollutant heavy metals listed by the Environment Protection Agency (EPA) are: As, Cd, Cr, Cu, Hg, Ni, Pb, and Zn[4].

Distribution in ecosystem

Biosphere is the natural environment of living objects. It envelops the earth and contains surficial parts of the lithosphere, the lower part of the atmosphere, and the hydrosphere. A relative homeostatic environment is essential for the survival of organisms in ecosystem. This necessitates the study of the chemical composition of air, water, and soil in order to monitor any abnormal changes due to industrial progression and consequent advancement of society[4].

What are the roles of heavy metals on animal bodies?

The biological and toxic roles of metals have been studied extensively in recent years. The following metals/metalloids are considered essential for animals: As(non specific growth stimulation), Co(constituent of vitamin B_{12}), Cr(regulator of metabolism of glucose and cholesterol), Cu; High concentrations of copper in combination with low pH are believed to be fatal to fish(constituent of oxidases which are important for the regulation of redox reactions, respiration, cartilage formation), Fe is one of the most abundant metals on the earth and is essential to almost all organisms (in hemoglobin for respiration, cytochromes, catalyses, peroxides), Mn (a transition metal). Similar to the other transition metals, Mn (manganese) occurs in a number of states in the environment(as arginase, super oxide dismutase and pyruvate carboxylase in urea synthesis, protecting mitochondria from free radical damage and citric-acid cycle), Mo(baldheaded and xanthenes oxidases formation of fatty acids and uric acid respectively), Ni inhibits a number of enzymes and is bound to various proteins, including metallothioneins and albumins (constituent of several enzymes, undefined growth stimulation), Se(as glutathione peroxidase, acts in tissue oxidation and cardiomyopathy), Sn(as a constituent of gastrin with digestive and growth-promoting functions), V(in lipid metabolism and bone mineralization) and Zn For aquatic organisms, is both an essential nutrient and environmental contaminant. The intestine is potentially the most important organ for zinc absorption, but little is known regarding this uptake pathway for zinc in fish. In contrast to copper and iron, zinc does not form free radical ion, and in fact has antioxidant properties (constituent of several enzymes: proteases, anhydrates, super oxide dismutase with role in protein biosynthesis, energy metabolism, protection against damage by super oxide radicals, fertility, etc.) [4,14].

Effects on fishes and other marine animals

Growth of fish larvae and juveniles is very fast. Many environmental factors influence growth: temperature, accessible alimentary base and presence of toxicants. Under optimum conditions, at appropriate temperature and at sufficient quantities of food, the fish increase in both body length and mass. On the other hand, in the water polluted with toxicants, e.g. heavy metals, fish growth may be inhibited. Inhibition of growth is one of the most distinct symptoms of toxic action of metals on fish larvae. Therefore, fish body length and mass are indicators of environmental conditions [17].

Results of a research (Begum et al 2009) showed that the highest concentration of heavy metals is in kidney and liver of ten different fish species. Contaminated sediments can threaten creatures in the benthic environment, exposing worms, crustaceans and insects to hazardous concentrations of toxic chemicals. Some kinds of toxic sediments via killing the benthic organisms, reducing the food availability for larger animals such as fish. Some contaminants in the sediment are taken up by benthic organisms in a process called ***bioaccumulation***. When larger animals feed on these contaminated organisms, the toxins are taken into their bodies, moving up the food chain with increasing concentrations in a process known as ***biomagnification*** [5].

Heavy metals are diluted and affected by various surface water components (carbonate, sulphate, organic compounds – humic, fulvic, amino acids) that formed unsoluble salts or complexes. These salts and complexes are predicted to be not harmful to aquatic organisms. Part of them sink and are accumulated in bottom sediments. However, when water pH has declined (during acidic rains or other acidic episodes) heavy metals can be mobilized and released into the water column and become toxic to aquatic biota. In addition, low concentrations of heavy metals can cause a chronic stress which may not kill individual fish, but lead to a lower body weight and smaller size and thus reduce their ability to compete for food and habitat. Toxic effects of heavy metals on soil microorganisms *in situ* (near the roadside of the Vilnius–Kaunas–Klaipėda highway) were investigated by Jadhey et al. (2010) and a negative influence of the test metals on actinomycetes, mineral nitrogen assimilating and oligonitrophilic bacteria was found[13].

Aquatic organisms, such as fish, accumulate pollutants directly from contaminated water and indirectly via the food chain. Application of chemical fertilizers containing trace of heavy metals causes contamination of fish with these metals. The effects of pesticides either organophosphorous or chlorinated pesticides have been extensively studied and confirmed in fish. The impact of toxic materials on the integrity and functioning of DNA has been investigated (Sun et al.2010) in many organisms under field conditions [20]. Several biomarkers have been utilized as tools for detection of exposure to genotoxic pollutants. Such biomarkers include presence of DNA adducts, chromosomal aberrations, DNA strand breaks and micronuclei measurements. In fish, erythrocytes are mainly used as sentinel markers of exposure to genotoxic compounds [8].

Daei et al.(2009)with study on (*Chalcalburnus chalcoides*) showed that cadmium with ratio $P<0.05$ replaced with ferritin(Fe) over the time in the fish blood but metal Pb couldn't so. Those results indicated that by increasing in lead density, in fishes this metal was absorbed by other tissues [6].

Heavy metals in water are particularly dangerous for fish juveniles and may considerably reduce the size of fish populations or even cause extinction of entire fish population in polluted reservoirs. The data of many authors indicate that heavy metals reduce survival and growth of fish larvae. They also cause behavioral anomalies (such as impaired locomotors performance resulting in increased susceptibility to predators) or structural damages(mainly vertebral deformities). Somiñska et al study Common carp larvae under laboratory conditions, in water containing lead or copper. Exposure to heavy metals resulted in slowed down development and growth rate, and reduced survival. Exposure to copper inhibited skeletal ossification, while lead caused scoliosis[19].

Vinodhini et al.(2009) in common carp with exposing of fish to heavy metals showed that the concentrations of red blood cells, blood glucose and total cholesterol were significantly elevated. The level of serum iron and copper was increased. The results showed the decreased activity of vitamin C during chronic exposure to toxic heavy metals, which indicates the presence of reactive oxygen species–induced per oxidation. They suggested that the presence of toxic heavy metals in aquatic environment has strong influence on the hematological parameters in the fresh water fish common carp (*Cyprinus carpio* L)[22].

Hayat et al.(2007) on three species of main carps(*Catla catla, Labeo rohita* and *Cirrhina mrigala*) showed that they had negative growth with weight in exposing to sub-lethal concentrations of manganese for 30 days. In fish, the toxic effects of heavy metals may influence physiological functions, individual growth, reproduction and mortality. High concentration of manganese detected in the gills of various fish species showed that the main route of manganese uptake was through the gills because little absorption of this metal occurred through the gut via the food. Long-term exposure (20 days or more) to waterborne cadmium at sub-lethal concentrations showed decreased growth in juvenile and adult rainbow trout, *Oncorhynchus mykiss*[12].

Abu Helal et al.(2008) on eleven fish species of Northern Gulf about concentration of heavy metals(Cd, Co, Cr, Cu, Fe, Mn, Ni, Pb and Zn) showed that;

Cd: accumulated primarily in major organ tissues of fish like liver, stomach and gill.

Co: Is highest in gills (11.0) and stomach (5.0) while is lower in muscle (3.0 μg g-1).

Cr: High concentrations were found in gills (13.8 μg g-1) while the values in muscles (3.8), and livers (4.9) is lower.

Cu: Relatively low concentrations of Cu were found in muscles (1.1 μg g-1), compared to those found in gills (4.3), gonads (5.5), liver (19.1) and stomach (7.6).

Fe: There were higher concentrations in liver and lower concentrations in muscle.

Mn: the lowest concentration was in muscle and the highest concentrations of Ni and Pb found in gills[3].

Creatures as biomonitoring organisms

During the past few decades, many species have been studied to determine their potential as a ***biomonitoring*** organism, and mollusca have become a popular choice for heavy metal monitoring. Mollusca have a depuration mechanism to reduce heavy metal toxicity in their body. This mechanism might diminish the effectiveness of molluscs as biomonitoring organism, as the concentration of heavy metal in the mollusc may not accurately reflect the concentration in the environment. Therefore, there is a need to evaluate the effects of heavy metal accumulation and depuration in the biomonitoring organism. Studies have shown that *Meretrix meretrix* is able to accumulate Cu, Zn, and Pb in the natural environment and this species may be used as a biomonitoring organism [2].

Ruditapes decussatus and *Venerupis pullastra* are commercially fished clams with a wide distribution in the shallow inshore waters. They are usually contaminated with heavy metals. Contamination of bivalve shellfish (e.g. oysters, clams, mussels and cockles) is a major food safety concern, so suppliers and retailers need to be sure that the products they sell are safe. Bivalves respond to changes in concentrations of contaminants in water, and they integrate contaminants from the water. Shellfish contamination is caused, among other things, by the discharge of chemical substances such as metals, pesticides and organochlorine compounds from industrial and municipal treatment processes. Contaminated mollusc shellfish (oysters, clams) may cause illness in humans [9].

While many heavy metals are nutrients at trace levels, Pb, Cd and Hg are non-essential and recognized as important industrial hazards, causing severe toxic effects in higher animals upon acute or chronic exposure. These three elements arc highly persistent and in the bivalent form stable inorganic and organic complexes in biological systems [1].

In the aquatic environment, heavy metals in dissolved form are easily taken up by aquatic organisms where they are strongly bound with sulfhydril groups of proteins and accumulate in their tissues. Fish absorb dissolved or available metals and can therefore serve as a reliable indication of metal pollution in an aquatic ecosystem. Tench (Tinca tinca) is considered a good test organism for heavy metal contamination because of its feeding behavior and bottom feeding habits[18].

Fish embryos and larvae are generally considered to be the most sensitive to environmental pollutants, thus they have been widely used as bio-indicators for water quality evaluation[16].

Conclusion

Every pollution in the aquatic environment which impacts physiology, development, growth or survival of fish, affects human that, at the top of the food chain, consume fish [16]. The accumulation of heavy metals in the tissues of organisms can result in chronic illness and cause potential damage to the population. Aquatic animals have often been used in bioassays to monitor water quality of effluent and surface water. The development of biological monitoring techniques based on fish offers the possibility of checking water pollution with fast responses on low concentrations of direct acting toxicants.

Development of chemical and biological methods for effectively monitoring environmental levels of heavy metals is a subject of interest and a critical step in development of environmental waste management [1].

Table: occurrence of some heavy metals in sea and fresh natural waters [4]

Metal/ Metalloid	Sea water	Fresh water
Aluminum	2	300
Antimony	0.2	0.2
Beryllium	0.006	0.3
Cadmium	0.1	0.1
Chromium	0.3	1.0
Cobalt	0.02	0.2
Copper	0.3	3
Lead	0.03	3
Manganese	0.2	8
Mercury	0.03	0.1
Molybdenum	10	0.5
Nickel	0.6	0.5
Silver	0.04	0.3
Tin	0.004	0.009
Uranium	3	0.4
Vanadium	2.5	0.5
zinc	5	15

References

1- Allah, A. T., Wanas, M. Q., Thompson, S. N., 1997, Effects of Heavy Metals on Survival and Growth of GASTROPODA: Journal of Moll. Study, V.63, p. 79-86.

2- Abdul Rashid, W., Wan, V. L., Harun Abdullah, A., 2009, Accumulation and Depuration of Heavy Metals in the Hard Clam(Meretrix meretrix)under Laboratory Conditions; Tropical Life Sciences Research, V. 20(1), p. 17–24.

3- Abu Hilal, A. H., Ismail, N. S., 2008, Heavy Metals in Eleven Common Species of Fish from the Gulf : Journal of Biological Sciences, V.1, Number 1, P. 13 – 18.

4- Athar, M, Vohora. S.B, 2001, Heavy metals and environment, New Delhi, New Age International Publisher, p. 3-40

5- Begum, A., HariKrishna, S., Khan, I., 2009, Analysis of Heavy metals in Water, Sediments and Fish samples of Madivala Lakes of Bangalore, Karnataka: International Journal of ChemTech Research, V.1(2), p. 245-249.

6- Daei, S., Jamili, S., Mashinchian, A., Ramin, M., 2009, Effect of Pb and Cd on the iron solute in blood (Chalcalburnus chalcoides), Journal of fisheries and aquatic science,V.4 (6),P.323-329.

7- Emami Khansari, F., Ghazi-Khansari, M., Abdollahi, M., 2005, Heavy metals content of canned tuna fish: Food Chemistry , V.93, P. 293–296.

8- Fagr, K. A., Saber, A. E., Farag, A. S., Wagdy, K.B. K., 2008, Effect of water pollution on expression of immune response genes of Solea aegyptiaca in Lake Qarun : African Journal of Biotechnology, V. 7 (10), p. 1418-1425.

9- Gabr, H. A., Gab-Alla, A., 2008, Effect of transplantation on heavy metal concentrations in commercial clams of Lake Timsah, Suez Canal, Egypt: Oceanology,V. 50 (1), P. 83–93.

10- Gad, N. S., Saad, A. S., 2008, Effect of Environmental Pollution by Phenol on Some Physiological Parameters of Oreochromis niloticus : Global Veterinaria , V.2 (6),P. 312-319.

11- Ghosh, M., Singh, S.P, 2005, Review on phytoremediation of heavy metals and utilization of its byproducts: Applied Ecology Research, V.3 (1),P. 1-18.

12- Hayat, S., .Javed, M., Razzao, S., 2007, Growth performance of metal stressed: Pakistan Veterinary. Journal, V. 27(1), P. 8-12.

13- Jadhav, J.P., Kalyani, D.C., Telke, A.A., Phugare, S.S., Govindwar, S.P., 2010, Evaluation of the efficacy of a bacterial consortium for the removal of color, reduction of heavy metals, and toxicity from textile dye effluent: Bioresource Technology,V. 101,P. 165–173.

14- Kačániová, M., Andreji, J., Stráňai, I., Haščík, P., Čuboň, J., Felšöciová, S., 2007, Microbiological quality of fish meal and the effect on the heavy metals contents : Slovak Journal Animal Science, 40, (4): 185 – 188.

15- Kumar, A, 2004, Water pollution: New Delhi, A.P.H publishing corporation, p. 199.

16- Lin, H. C, Hwang, P. P, 1998, Acute and Chronic Effects of indium Chloride (InCI3) on Tilapia (Oreochromis mossambicus) Larvae: Bull. Environ. Contam. Toxicol , V. 61, P.123-128.

17- Sarnowski, P., Jezierska B., 2007, A new coefficient for evaluation of condition of fish: Electronic Journal of Ichthyology, V. 2, P. 69-76.

18- Shah, S. L., Altindac, A., 2005, Effects of Heavy Metal Accumulation on the 96-h LC_{50} Values in Tench Tinca tinca: Turkish Journal Veterinary Animal Science, V. 29, P. 139-144.

19- Stomiñska, I., Jezierska, B., 2000, The effect of Heavy metals on post embryonic development of COMMON CARP, Cyprinus carpio L., Archives of Polish Fisheries, Vol. 8 Fasc. 1 119-128.

20- Sun, L. N., Zhang, Y. F., He, L. Y., Chen, Z. J., Wang, Q. Y., Qian,M., Sheng, X. F., 2010, Genetic diversity and characterization of heavy metal-resistant-endophytic bacteria from two copper-tolerant plant species on copper mine wasteland, Bioresource Technology 101, 501–509.

21- Tastan, B. E., Ertugrul, S., Donmez, G., 2010, Effective bioremoval of reactive dye and heavy metals by Aspergillus versicolor, Bioresource Technology 101, 870–876.

22- Vinodhini, R., Narayanan, M., 2009, The impact of toxic heavy metals on the hematological parameters in common CARP (Cyprinus carpio l.): Iran. J. Environ. Health. Sci. Eng., V. 6(1), p. 23-28.

23- Vosylienė, M. Z., Jankaitė, A., 2006, Effect of heavy metal model mixture on rainbow trout biological parameters: Ecologia,Nr.,V.4.,P.12-17.