Available online at http://www.journalijdr.com

IJDR

ISSN: 2230-9926

International Journal of Development Research
Vol. 09, Issue, 12, pp. 32775-32783, December, 2019

RESEARCH ARTICLE **OPEN ACCESS**

USE OF FISH AS BIO-INDICATOR OF THE HEAVY METALS POLLUTION IN AQUATIC ENVIRONMENT

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ARTICLE INFO

Article History:
Received 18th September, 2019
Received in revised form
19th October, 2019
Accepted 21st November, 2019
Published online 31th December, 2019

Key Words:

Accumulation, Connectivity, Ecological, Habitat, Integrity, Pollutant, Structures, Toxicant, Water Framework Directive.

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ABSTRACT

In this review paper, the role of fish as bio indicators is discussed. No other aquatic organism is suitable for the application of so many different methods which allow the evaluation of the severity of toxic impacts by determining the accumulation of toxicants in tissues, by using histological and haematological approaches or by detecting morphological anomalies. Due to its complex habitat requirements, the fish fauna is a crucial indicator of the ecological integrity of aquatic systems at different scales, from microhabitat to catchment. The fitness of fish species both at the individual level (e.g. growth performance) and at population level (e.g. population structure) is determined by the connectivity of different habitat elements in a broad spatial-temporal context. Thus bio indication using fish represents a good monitoring tool especially with regard to both pollution aspects and to river engineering, e.g. river restoration and management.

Citation: Dugasa Gerenfes and Samuel Chufamo. 2019. "Use of fish as bio-indicator of the heavy metals pollution in aquatic environment", *International Journal of Development Research*, 09, (12), 32775-32783.

INTRODUCTION

Aquatic systems are considered as suitable sites for disposal and recycling the sewage and toxic wastes and drain off the excess to the sea. However, the increasing pollutant load and the over exploitation of the water resources for potable supplies, irrigation, industries and thermal power plants to meet the requirements of the ever-increasing population, significantly reduces their assimilative capacity. Thus, the dual stress exerted on the watercourses is ultimately faced by the biological communities inhabiting them. Of these, fish is one of the most important aquatic communities concerning man (Subhendu, 2000). Naturally occurring Bioindicators are used to assess the health of the environment and are also an important tool for detecting changes in the environment, either positive or negative, and their subsequent effects on human society. There are a certain factors which govern the presence of Bioindicators in environment such as transmission of light, water, temperature, and suspended solids. Through the application of Bioindicators we can predict the natural state of a certain region or the level/degree of contamination (Khatri and Tyagi 2015).

Bioindicator is an organism (or a part of an organism or a community of organisms) that contains information on the quality of the environment. Thus, the use of bioindicators should help to describe the natural environment, to detect and assess human impacts and to evaluate restoration or remediation measures; in all these cases fish are intensively used for indication purposes. There are several reasons why fish are widely used to describe natural characteristics of aquatic systems and to assess habitat alterations (Boon *et al*., 2000; Schiemer, 2000; Schmutz *et al*., 2000). A large number of abiotic environmental variables at different spatio-temporal scales are linked to the complex habitat requirements of particular species and their ontogenetic stages. Due to the specific habitat requirements and habitat shifts during the larval and juvenile stages, fish for example are suitable indicators of the ecological status of river systems (Schiemer *et al*., 1991; Keckeis *et al*., 1996).A long tradition of ecological, physiological and ecotoxicological research on fish has led to an advanced knowledge of the ecological requirements of a large number of fish species. The effectiveness of bioindication approaches depends on the sound knowledge of the indicators' ecological demands and physiology (Schiemer *et al*., 2001). Due to the size of fish (and their organs) a great variety of analytical procedures can be carried out. Pathological results concerning fish illustrate the effects of water pollution to the scientific community, water management and the public. Some methods, such as haematological and histo-pathological approaches, are taken from human medicine. Due to the longevity of fish certain indication effects, e.g. accumulation processes, are increased. As primary and secondary consumers at different levels fish reflect trophic conditions in aquatic systems. The reconstruction of pristine reference communities is possible due to the existence of historical information (Muhar *et al*., 2000).Fishery and sport fishing have a long history, in which fish play an important role as indicators of water quality; because of the use of fish by man particularly as food resource, the condition of fish communities is an important factor in water resource management. The number of species is relatively small and species are already determinable in the field. Environmental pollution is a worldwide problem as heavy metals belong to the most important pollutants. Of different pollutants, heavy metal pollution of aquatic environment has become a great concern in recent years because they are very harmful as a result of their non-biodegradable nature, long biological half-life and their potential to accumulate in different body parts of organism. They can also be concentrated along the food chain, producing their toxic effect at points after far removed from the source of pollution. Thus compared to other types of aquatic pollution, heavy metals pollution is less visible but its effects on the ecosystem and humans can be intensive and very extensive (Edem *et al.,* 2008).

Studies from the field and laboratory works showed that accumulation of heavy metals in a tissue is mainly dependent on water concentrations of metals and exposure period; although some other environmental factors such as water temperature, oxygen concentration, pH, hardness, salinity, alkalinity and dissolved organic carbon may affect and play significant roles in metal's accumulation and toxicity to fish (Linbo *et al*., 2009; Sassi *et al.,* 2010). Ecological needs, size and age of individuals, their life cycle, feeding habits, and the season of capture were also found to affect experimental results from the tissues. Fish have the ability to uptake and concentrate metals directly from the surrounding water or indirectly from other organisms such as small fish, invertebrates, and aquatic vegetation (Polat *et al*., 2015). Fish accumulate pollutants preferentially in their fatty tissues like liver and the effects become apparent when concentrations in such tissues attain a threshold level (Omar *et al*., 2014). However, this accumulation depends upon their intake, storage and elimination from the body. This means that metals which have high uptake and low elimination rates in tissues of fish are expected to be accumulated to higher levels (Kalay and Canli, 2000). Heavy metals can be taken up into fish either from ingestion of contaminated food via the alimentary tract or through the gills and skin (Drevnick *et al*., 2006; Sfakianakis *et al.,* 2015). Effectively, after the absorption, metals in fish are then transported through blood stream to the organs and tissues where they are accumulated by aquatic organism (Adeyemo *et al*., 2010; Fazio *et al*., 2014). The heavy metal concentration in fish tissues reflects past exposure via water and/or food and it can demonstrate the current situation of the animals before toxicity affects the ecological balance of populations in the aquatic environment (Birungi *et al*., 2007).

The obvious sign of highly polluted water, dead fish, is readily apparent, but the sub-lethal pollution might result only in unhealthy fish. According to Dupuy *et al.*, 2015 reported that the fish health status in some polluted systems (estimated by the condition factor) indicated that the fish have a lower condition. Generally, the uses of fish as bioindicators for aquatic environment treatments lead to certain disadvantages such as incomplete removal of heavy metals from the aquatic environments, high-energy requirements and production of toxic sludge (Eccles, 1999). Numerous approaches have been studied for the development of more effective methods in removing metal pollution and the bioremediation process is found to be more practicable over other techniques. Bioremediation process is one of the easiest, safest and more cost-effective methods for heavy metal removal from industrial effluents (Rahmani *et al*., 2009) and this process is already established as a simple operation and an easy-handling process (Sharma *et al.,* 2009). Extensive studies have been undertaken in recent years with the aims of finding an alternative in the form of economic bioremediation and biosorption for water treatment. The main objective of this review is to provide a summary of information concerning the uses of as bioindicators in aquatic environments and process using different methods for heavy metal removal from waste treatments.

Heavy Metals as Environmental Pollutant

Terms of Heavy Metal Pollution: Until recently, the chemical analysis of the water contaminants has been used as the conventional methods for monitoring water pollution. However, these methods are inadequate to determine the water pollution and do not reflect the effects of the pollutants on the aquatic organisms which live in that environment. Therefore, the aquatic organisms are used to determine the water pollution. For this purpose, the chemicals levels of the water, the sediment and the aquatic organisms are very important to determine the level of the chemical contamination of the marine and of the other aquatic environments (Bascinar, 2009;Taylan and Ozkoc, 2007). In many cases, the biotransformation may increase xenobiotic substances toxicity on organism via producing reactive metabolite compounds that are more toxic than original parent compounds. Moreover, the chemical approach is costly, usable to only a small proportion of the xenobiotic compounds in the environment, produces a little biologically meaningful data, and consequently simplifies the complexity of the ecosystem under monitoring. For those reasons, the classic chemical analysis should be accompanied by the biological approach which is so called “biomarker” that elucidates biological responses of environmental pollution. Biomarkers have been considered as sensitive and suitable tools for detecting either exposure, or effects of, pollutants since they can provide more comprehensive and biologically more relevant information on the potential impact of pollutants on the health status of organism. In respect to pollutants that has a lower stability in water such as organophosphate and carbamate pesticides, biomarkers are reliable tools for assessing the impacts of the pollutants on biota even if the existence of the pollutants in water cannot be detected. It is because biomarkers can detect persistent responses and/or effects of the pollutants in such duration of biota lifetime. Therefore, they have been used enormously in biomonitoring to assess the risk of marine ecosystem pollution (Yaqin*et al*., 2011).

Biomarkers/Bioindicators are the organisms which respond to the environmental pollution by changing the life functions or accumulating toxins in to their bodies. The aquatic organisms, such as fish, shellfishes, algae, protozoa, macrophytes, bacteria and plankton are used as a bioindicator in determining the quality of water. Due to feeding and living in the sea environments these organisms are heavily exposed to pollution (Bascinar,2009;Kazanci and Girgin, 1998). Therefore relative body size, long life span, being on the top step of the food chain and the direct effects on the human health are being researched; the fish and the prawns bioindicator species in the aquatic organisms are widely used in evaluating the quality of the systems for the environmental contaminants (Bascinar, 2009; Kock *et al.,* 1996; Zhou *et al*., 2008). Toxic pollutants often cause characteristic responses in the affected organism, commonly known as biomarkers. A biochemical, (genetic) cellular, physiological or behavioral variation that can be measured in tissue or body fluid samples or at the level of the whole organism (either individuals or populations), that provides evidence of exposure and/or effects of one or more chemical pollutants (and/or radiation) defined as biomarker (Depledge*et al.,* 1993). Biomarkers are powerful tools for detecting the impact of exposure to sublethal concentrations of a given substance or complex chemical mixtures, enabling the evaluation of less obvious effects on organisms.

ecosystem. According to Jarup,(2003)describes that heavy metals are applied to the group of metals and metalloids with atomic density greater than 4 g/cm or 5 times or more and are greater than water. Heavy metals can be classified into three different types including toxic metals (such as Hg, Cr, Pb, Zn, Cu, Ni, Cd, As, Co, Sn, etc.), precious metals (such as Pd, Pt, Ag, Au, Ru etc.) and radionuclides (such as U, Th, Ra, Am) (Wang and Chen, 2009). Source of heavy metals that penetrate into the water system can derive from both natural and anthropogenic sources. The main source of heavy metal contamination involves urban industrial aerosols, solid wastes from animals, mining activities, also industrial and agricultural chemicals (Dixit *et al*., 2015). Sometimes most heavy metals contaminate the water system through the various industrial activities or even from acid rain which breaks down the soils androcks, releasing heavy metals into water resources (Alluri *et al*, 2007). Table 1 summarizes the variety of sources of heavy metal that exist in the environment.

Fish as indicators of environmental pollution: Despite rising efforts of many industrialised countries to reduce toxicants from industrial and motor vehicle exhausts and to purify industrial and communal waste waters,our ecosystems still contain harmful concentrations of an increasing number of chemicals.

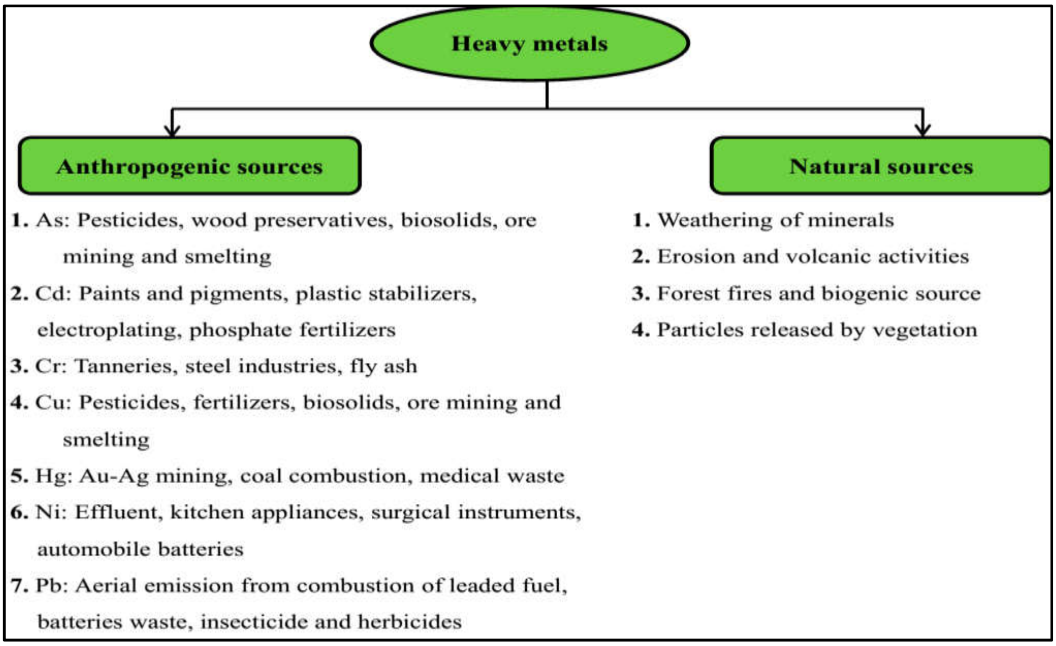

Figure 1. Sources of heavy metals in the environment (Dixit *et al*., 2015)

Table 1. Sources Heavy that exist in the environment

No	Sources	Effects	References
1	Natural Sources	Metals are found throughout the earth, in rocks, soil and introduce into the water body through natural processes, weathering and erosion.	Sposito *et al*.,1998
2	Industrial Sources	Industrial processes and processing of metal ores, the finishing and plating of metals and the manufacture of leather, dye andmetal objects.	Sumner,2000
3	Domestic wastewater	The prevalence of heavy metals in domestic formulations, such as cosmetic or cleansing agents, is frequently overlooked.	Hussein *et al*.,2001
4	Agricultural Sources	Agricultural discharge contains residual of pesticides and fertilizers which contains metals.	Sabiha*et al*.,2009
5	Mining runoff	Solid waste disposal areas.	Modaihsh*et al.,*2004
6	Atmospheric pollution	Acidrains containing trace metals as well as SPM input to the water body will cause the pollution of water with metals.	Sposito *et al*.,1998

Sources of Heavy Metals Pollution: Heavy metals are a natural constituent on earth commonly known with properties such as having persistence, high toxicity and also serving as non-biodegradable pollutants when they accumulate in the

They accumulate in soils and sediments from which they can be remobilized after changing their physico-chemical condition. Concentrations of heavy metals in sediments may exceed those of the overlying water by a factor of one to ten thousand (Bryan and Langston, 1992). The water quality of many rivers and lakes has improved significantly due to the increasing number of purification plants. However, the treatment of waste water reduces not only the concentration of toxic substances but also that of non-toxic organic compounds. This may lead to changes in the bioavailability of chemicals and their toxicity, in particular of those entering the water by run-off and atmospheric deposition. Suspended inorganic and organic particles have a large surface area and thus a high capacity for physically absorbing toxicants. Toxic chemicals have been shown to interact with dissolved or colloidal organic matter by various modes of binding and absorption (Spry and Wiener, 1991). Many of these complexes are too large or too polar to diffuse across the gill membrane (Haitzer *et al.,* 1998). Some metal cations can form lipophilic complexes with specific organic compounds used in agriculture, forestry and industry whicheasily pass the gill membrane. This leads to both higher levels of metal accumulation than expected from water concentrations and an altered distribution pattern, with the highest increase in the brain and eyes of fish. Uptake and toxicity of mercury strongly depends on methylation by bacterial activity (Boening, 2000). Due to its lipophilic character, methyl mercury is absorbed about ten times faster than the ionic form. On the other hand, several studies have shown that selenium may reduce mercury toxicity.

Bioindicators and, in particular, long-living organisms such as fish are sensitive to the impact of a complex mixture of chemicals on a specific aquatic ecosystem, integrating the environmental load over time and space. Pollutants usually cause a wide spectrum of effects and responses in organisms ranging from the cellular and biochemical level to the level of behaviour, growth and reproduction. During low and limited exposure to toxicants, fish respond at a sub-cellular level, but usually organisms can compensate for the toxic effect, and their health is not seriously affected. Prolonged and severe exposure, however, may induce a sequence of functional and structural changes which impair vital functions. Tissue concentrations of chemicals are excellent indicators of the environmental load of a specific toxicant but usually do not directly reflect the physiological and ecological consequences (Bryan and Langston, 1992). Most of the biomonitoring techniques, however, focus on different kinds of stress responses which are often more or less general responses and cannot be attributed to specific toxicants.

Permanent stress - even if it is moderate - interferes with hormonal and biochemical processes leading to increased metabolism, immunosuppression, disturbed osmoregulation, failure of reproduction or tissue damages. The low toxicant specificity of many stress responses is not just a disadvantage, it increases the value of bioindicators for monitoring the general environmental load in natural water bodies which may contain several out of hundreds of different harmful chemicals. For practical use in the field, biomonitoring methods based on fish should be insensitive to the stress of capture which may mask the effects of toxicants. The biological parameters analyzed in the assay should be well understood and their modulation induced by endogenous and exogenous factors other than toxicants should be known (Bryan and Langston, 1992). Data on commercially manipulated fish species should be handled with caution, and possible loads of geogenic origin (e.g. metals) have to be considered.

Toxicant accumulation in Fish tissues: Tissue concentrations of chemicals are a function of uptake, storage, and excretion. In fish, two different routes of uptake are important, (Andersson *et al*.,1988) directly from the water, in freshwater fish almost exclusively via the gills, in marine species at a low percentage also through the drinking of water, and (Angermeier and Karr, 1994) the oral uptake and assimilation of contaminated food. Hydrophilic molecules are unlikely to pass the gill membrane unlessthey are very small (diffusion along an osmotic gradient) or transported by ionic pumpsor channels. Lipophilic compounds, however, are soluble in biological membranes and cross all barriers. The relatively low oxygen solubility in water requires an extremely large respiratory surface and a high pumping rate of water (Banjeree and Baughman, 1991). Consequently, the direct uptake of water-borne toxicants (whose concentration is two orders of magnitude higher than in the air) is the main route in fish (bioconcentration; see Table 2).

Table 2. Sum definitions of bioindication in fish

Bioaccumulation (BA)	The accumulation of contaminants in organisms resulting from water or food uptake.
Bioconcentration (BC)	The accumulation of water-borne contaminants directly from the water by a non-dietary route.
Biomagnification	The accumulation of toxicants resulting from ingestion of contaminated diet.
Bioconcentration factor(BCF)	Quotient of the concentration of a chemical in an aquatic organism and in the H_2O. The BCF can be predicted from the concentration of a lipophilic chemical in theH_2O

Liver and kidney are the main sites of accumulation for most toxicants including metals. These organs are rich in metallothioneins with high affinities to Cd, Hg, Zn, and Cu. The liver is also involved in a variety of detoxification processes transforming harmful compounds into less toxic and water-soluble metabolites which are excreted into the bile. These metabolites are either eliminated with the faeces or reabsorbed from the gut and returned to the liver by enterohepatic circulation which may increase the half-life of toxicants in the fish. In the bile of trout exposed to several labelledorganic substances Statham *et al*. (1976) found concentrations between 11 and 10,000 times higher than in the water. Even under field conditions it has been shown that bile analysis is a useful tool to evaluate the environmental load of xenobiotics (Pointet and Milliet, 2000). The proportion of accumulated toxicants between different tissues of the fish largely depends on dynamic processes between uptake, storage, and elimination. After shortterm exposure, gills or the digestive tract and the liver usually show a high load of toxicants, whereas concentrations in kidney, bones (Pb, Zn), and muscles (lipophilic substances) increase more slowly after a time-lag, but the accumulated chemicals aremore persistent than in other organs. Due to active regulation tissue accumulation of essential metals (Cu, Zn) is saturated at low levels, and thus a relatively weak indicator of environmental contamination (McGeer *et al.,* 2000).Metal uptake by aquatic organisms is a two-phased process, which involves initial rapid adsorption or binding to the surface, followed by a slower transport into the cell interior (Crist *et al.*, 1988). In epithelial tissues the last step is the rate-limiting factor in transepithelial movement of metals (Foulkes, 1988). Transport of metals into the intracellular compartment may be facilitated by either diffusion of the metal ion across the cell membrane or by active transport by a carrier protein (Brezonik *et al*., 1991).

Fish macroparasites as pollution indicators: Heavy metals play an important role as substances affecting aquatic organisms. Their impact, particularly on fish, is receiving considerable attention. Investigations on chronic exposure to sublethal concentrations of pollutants and their effects on the host parasite interrelationship and the parasites in particular are often neglected (Overstreet, 1997).If fish parasites are to be used as indicators of pollutants they must meet several requirements to be comparable with free-living organisms. Kennedy (1997) suggested that the following conditions are necessary if fish parasites are likely to be indicators for pollution: the fish host must be abundant and easily accessible; parasite species, despite their over dispersed distribution, must show a high prevalence and abundance in the fish host population; parasites should be easily identified and not laborious to remove and count; information on the ecology and biology of both fish host and parasite should be available.

Mechanism of heavy toxicity metals in fish: The reaction and survival of organisms exposed to heavymetals depend not only on the biological state of the organisms but also on the toxicity and exposure time and type of the toxicant (Vinodhini and Narayanan, 2009). The heavy metals such as As, Cd, Pd and Hg are classified as most toxic to humans, animals, aquatic organisms and environment. They affect ecosystems due to their bioaccumulation in animals which causing toxic effects such as reduce the fitness on biota and even mortality in living beings. Fishes are inhabitants which can be highly affected by heavy metals. The toxicity of heavy metals on fishes depending on fish age, size and other physiological factors. These elements enter in biogeochemical cycle leading to toxicity in different organs (Govind and Madhuri, 2014). Certain heavy metals become toxic due to formation of toxic soluble compounds. However, a number of metals are without any biological role or they are not required by the body and they become toxic just in specific forms. However, Pb may cause harmful effect at any level of its amount. Beryllium and iron can also exhibit toxicity. Thus, most of the heavy metals are toxic to living beings. With abnormal oxidation state metals also can elicit toxic effect such as tetravalent chromium [Cr (VI)] exhibits the carcinogenic effect, however, trivalent chromium [Cr(III)] is recognized as an essential trace-nutrient for human and animals (Govind, 2013; Govind and Madhuri, 2014). Heavy metals can make harmful effects on tissues of aquatic organisms themselves. At high concentrations they may lead to mortality of the organism. This level of toxicity is known as lethal toxicity. At lower concentrations, organisms can show different kinds of adverse effects but no mortality seen. Histological changes can occur in the digestive tubular tracks, gills and neurological system. The reflection of alteration in enzymal or hormonal activities lead to the organism becomes weak and ecologically vulnerable to death. The disturbances in the respiration, growth or reproduction rates, or susceptibility to parasitic pathogens and diseases may occur but not easily detectable. Such effects are referred as sub-lethal toxic effects (Al-Sulami *et al*., 2002).

Distribution of Heavy Metals in the Aquatic Environment: Once in the aquatic environment, heavy metals are partitioned among various aquaticenvironmental compartments (water, suspended solids, sediments and biota). The metals in theaquatic environment may occur in dissolved particulate and complex form. The majority of metal contaminants partition onto particulate matter such as clay minerals, Fe and Mn oxides/hydroxides, carbonates, organic substances (e.g.humic acids) and biological materials (e.g., algae and bacteria) (Calmano *et al*., 1993). The main process governing distribution and partition are dilution, advection, dispersion, sedimentation, and adsorption/desorption. Adsorption could be the first step in the crucial removal of metal from water. In the course of distribution, permanent or temporary storage of metal takes place in the sediments of both freshwater and marine environments (Aksu *et al*, 1998). Microbial activity and redox processes may change the properties of sediments and affect the composition of interstitial water (Vale *et al*., 1998). Reworking to the sediments by organisms will also bring heavy metals from sediments to the surface water. The transformation of heavy metals in aquatic environments occurs as biochemical mediated reduction, methylation, demethylation and oxidation of single metal species. Redox reactions may also facilitate some transformations. The biochemical processes are carried out by microorganisms and algae. Heavy metals are taken up by both fauna and flora of the aquatic environment. This uptake could provoke an increase in the concentration of metals in an organism; if the excretion phase is slow, this can lead to the bioaccumulation phenomenon. Some heavy metals have been shown to undergo biomagnifications through the food chain (Sulter, 1993).

Accumulation of Heavy Metals in Fish: Fish are used as bio-indicator of aquatic ecosystems for estimation of heavy metal pollution and potential risk for human consumption (Agarwal *et al.,* 2007). Bioaccumulation of metals in fish takes place directly, from the water by gills and indirectly from food. The metals such as copper, zinc, iron, and cobalt are essential and have important biochemical functions in the organism as opposed to non-essential metals like lead, cadmium, mercury, and arsenic. But, if the heavy metal concentration at the source of supply such as water and food is too high, the homeostasis mechanism finishes functioning and the essential heavy metals act in either an acutely or chronically toxic manner. The function of uptake and excretion in fish is determined the accumulation of metal in fish. The gills are likely sites of metal uptake from water due to their large surface area and the close proximity of the internal constituent of the body and external environment (Wepener, 1997). Within the body, the degree of accumulation in different tissues is dependent on the binding of the metal to specific ligands (Dallinger *et al*., 1987) stated that as far as fish is concerned, there are three possible ways by which metals may enter the body (i) the body surface, (ii) the gill, (iii) the alimentary tract. But little is known about the uptake of heavy metals through the skin. It can be assumed that the body surface of fish is more or less impervious to harmful substances in the surrounding water.

Methods used for Heavy Metal Pollution: As reported by Joseph *et al*., 2010; the commonly used procedures for removing metal ions from aqueous streams include chemical precipitation, lime coagulation, ion exchange, reverse osmosis and solvent extraction (Rich and Cherry, 1987). The process description of each method is presented below.

Reverse Osmosis: It is a process in which heavy metals are separated by a semi-permeable membrane at a pressure greater than osmotic pressure caused by the dissolved solids in polluted water. The disadvantage of this method is that it is expensive.

Electrodialysis: In this process, the ionic components (heavy metals) are separated through the use of semi-permeable ion selective membranes (Joseph *et al*., 2010). Application of an electrical potential between the two electrodes causes a migration of cations and anions towards respective electrodes. Because of the alternate spacing of cation and anion permeable membranes, cells of concentrated and dilute salts are formed. The disadvantage is the formation of metal hydroxides, which block the membrane.

Ultrafiltration: They are pressure driven membrane operations that use porous membranes for the removal of heavy metals. The main disadvantage of this process is the generation of sludge.

Ion-exchange: In this process, metal ions from dilute solutions are exchanged with ions held by electrostatic forces on the exchange resin. The disadvantages include: high cost and partial removal of certain ions.

Chemical precipitation: Precipitation of metals is achieved by the addition of coagulants such as alum, lime, iron salts and other organic polymers. Thelarge amount of sludge containing toxic compounds produced during the process is the main disadvantage (Joseph *et al.,* 2010).

Phytoremediation: According to Joseph et al., 2010 Phytoremediation is the use of certain plants to clean up soil, sediment, and water contaminated with metals. The disadvantages include that it takes a long time for removal of metals and the regeneration of the plant for further biosorption is difficult. Hence the disadvantages like incomplete metal removal, high reagent and energy requirements, generation of toxic sludge or other waste products that require careful disposal has made it imperative for a cost-effective treatment method that is capable of removing heavy metals from aqueous effluents.

Biosorption: The search for new technologies involving the removal of toxic metals from wastewaters has directed attention to biosorption, based on metal binding capacities of various biological materials. Biosorption can be defined as the ability of biological materials to accumulate heavy metals from wastewater through metabolically mediated or physico-chemical pathways of uptake (Fourest and Roux, 1992). Algae, bacteria, fungi and yeasts have proved to be potential metal biosorbents (Volesky, 1986). The major advantages of biosorption over conventional treatment methods include (Kratochvil and Volesky, 1998a).

Conclusion

Fish are one of the most frequently used group of bioindicators in ecotoxicological field studies. The advantage of a comprehensive basic knowledge of toxicology, physiology, and histology exceeds the disadvantage of fish mobility. No other aquatic organism is suitable for the application of so many different methods which allow the evaluation of the severity of toxic impacts ranging from compensatory responses at a molecular and an ultrastructural level (serving as an early warning indicator) to sublethal and pathological changes as alarm signals for population declines and irreversible consequences for the whole ecosystem. Some biomarkers are indicators of unspecific stress, others respond to a group of toxicants with comparable attributes, and only a few biomarkers are highly substance-specific. The bioindication of the occurrence of specific substances and their impact on specific biota and the ecosystem are the main focuses of ecotoxicological studies. Several methods of ecological and toxicological relevance with varying specificity have to be applied simultaneously to evaluate the ecotoxicological situation under the complex environmental conditions in the field. The use of macroparasites as indicators of heavy metal contamination is of increasing relevance in environmental control. There is a need to develop combined approaches including both parasite community aspects and accumulation aspects. Due to its complex habitat requirements the fish fauna is a crucial indicator of the ecological integrity of aquatic systems at different scales, from microhabitat to catchment. The fitness of fish species both at the individual level (e.g. growth performance) and at population level (e.g. population structure) is determined by the connectivity of different habitat elements in a broad spatio-temporal context. Thus bioindication using fish represents a good monitoring tool especially with regard to river engineering, e.g. river restoration and management. In order to further strengthen the role of fish as valuable indicators of the ecological integrity of aquatic systems, research is required ranging from the ecological demands of certain target species to ecosystem processes.

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