**TOPIC: HEAVY METAL CONCENTRATIONS IN THE TISSUES AND ORGANS OF THREE FISH SPECIES FROM DIFFERENT TROPHIC LEVELS IN LEKKI LAGOON**

**INTRODUCTION**

All over the world aquatic pollution is a major concern. Over 400 million tons of chemical products are discharged from domestic, agricultural and industrial activities into aquatic ecosystems (Schwarzenbach *et al*., 2006). Also, heavy metals may come from natural sources, leached from rocks and soils according to their geochemical mobility and also from anthropogenic source as the result of human land occupation and industrial pollution (Anand and Kumarasamy, 2013). Depending on their solubility, these metals may be eventually associated with suspended particulate matter or accumulate in the bottom sediments. Heavy metal pollution in lagoons and rivers has become a matter of great concern over the last few decades, not only because they are threat to public water supplies, but also the hazards to human consumption of fishery resources (Terra *et al*., 2007). Heavy metals from natural and anthropogenic sources are continually released into rivers, and they are serious threats because of their toxicity, long persistence, bioaccumulation and bio-magnification in the food chain (Eisler, 1988; Clark *et al.,* 1997; Asuquo *et al.,* 1999; Asuquo *et al.,* 2004). Heavy metal contamination in water and its uptake by fishes is a direct consequence of urban and industrial pollution (Azcue *et al.,* 1988; Campbell, 1995; Chapman, 1996).

In the aquatic environment, trace metals are not degraded and due to their affinity for biomolecules such as lipids and amino acids, they accumulate in cells of phytoplankton and zooplankton. In this way, high concentrations of the metals in organisms can be found on tops of food chain. Considering that the aquatic environment is the final sink of trace metals and chemical products, the essential ecological services provided by fish i.e. nutrient cycling, regulation of trophic structure, aquatic food web dynamics, and carbon flux (Holmlund and Hammer, 1999) may be affected. Most heavy metals are essential for the functioning of physiological processes in fish. However, tolerable limits and environmental changes may in turn affect the metals bio-kinetics of the fish leading to mortality, while sub-lethal concentrations may lead to behavioral and biochemical changes in fish (Wang, 2002; Amin *et al*., 2003). The degree of contamination depend on pollutant type, fish species, sampling location, trophic level and their mode of feeding (Asuquo *et al.,* 2004). Monitoring heavy metal contamination in river systems by using fish tissues helps to assess the quality of aquatic ecosystems (Adams, 2002). In this sense, fish samples are considered as one of the most indicative factors for estimation of trace metals pollution in freshwater systems (Cinier *et al.,* 1999; Rashed, 2001; Has-Schön *et al.,* 2006). Heavy metal concentration in fish tissues reflects past or present exposure (Canli et al. 1998; Yilmaz 2003; Henry et al. 2004) and incorporation occurs mainly through the gills, skin or by food (Bordajandi et al. 2003).

Each fish species has a particular way to accumulate (and/or to eliminate) metal when exposed to such contaminants. Overall species in relatively low trophic levels are exposed to comparatively lower contamination, although plants can accumulate metals in high levels (Peakall and Burger 2003). On the other hand, fish in the upper food web position are prone to accumulate metals and cause human contamination, through food causing chronicle and acute diseases (Al-Yousuf *et al.,* 2000; Has-Schön *et al.,* 2006). Biomarkers have often been employed to assess the health status of organisms and can serve as early-warning indicators of the effects of environmental pollution (Payne *et al.,* 1987). Biomarkers are measureable biological responses that may indicate exposure to and/or effects from anthropogenic substances at sub-lethal concentrations. A number of biochemical, physiological, enzyme and immune assays are considered suitable markers of exposure to and effects of aquatic contamination (Zelikoff *et al.,* 2000; Skouras *et al.,* 2003; Farombi *et al.,* 2007; Olarinmonye *et al.,* 2009; Obiakor *et al.,* 2010).

The coastal zone is considered as the place of action and reaction between terrestrial and marine ecosystems that is very important for the survival of a large variety of marine species (Castro *et al*., 1999). On the other hand, coastal zones receive a large amount of metal pollution from coastal towns, industrial sewages and polluted rivers. Pollution by heavy metals is an important problem due to their toxicity and their ability to accumulate in the biota (Islam and Tanaka, 2004; Reyahi-khoram et al., 2016).

Trace metals such as lead (Pb), cadmium (Cd), mercury (Hg) chromium (Cr) and arsenic (As) copper (Cu) and zinc (Zn) selinium (Se), nickel (Ni,), and manganese (Mn) are discharged into the aquatic environment from coal-burning power plants, iron and steel plants, non-ferrous metals smelters, domestic effluents and sewage sludge disposal (Nriagu et al. 1988; Kanu and Idowu, 2017).

The lagoons in Lagos State Nigeria are the final sink of effluents from over 2000 medium and large-scale industries. Also, the Ogun River discharges its municipal waste water into the lagoons (Uaboi-Egbenni *et al.,* 2010).

Lekki Lagoon situated at the southwestern part of Nigeria has vast aquatic resources suitable for fisheries. The lagoon supports many species of fish and aquatic plants and it’s a major biodiversity reserves, it is also the largest low brackish lagoon in southwestern Nigeria. Lekki Lagoon is part of a rich folk lore and provides an important source of livelihood for the people of Lagos and Ogun State. It is the most important common property aquatic resources and the largest source of freshwater fish production in the states.

**Justification**

Fish health can be adversely affected by temperature changes, habitat deterioration and aquatic pollution (Skouras *et al.,* 2003). Fish species have attracted considerable interest in studies assessing the biological effects of environmental contaminants (Powers, 1989). The ability of fishes to accumulate pollutants in their cells, tissues or body fluids and respond to these pollutants, some times in a specific way, makes them valuable biomonitoring tools for water quality assessment. Fishes may also accumulate trace metals to a level that may pose health risk to the fish and humans via dietary intake. Also, heavy metal contamination may have damaging effects on the ecological balance and diversity of aquatic organisms and marine species (Farombi *et al*., 2007; Ayandiran *et al*., 2009; Mohammadi-Rouzbahani, 2017). They also can affect water and sediment quality and may affect fish health and other biological attributes like taxonomic richness, trophic structure, and health of individual organisms will be changed (Fernandes *et al*., 2007; Batzias and Siontorou, 2008). They can also accumulate in food chains because of their persistence. (Feng Li *et al*., 2008).

Moreover, the use of these species aims to assess if they could be used as environmental indicators of aquatic ecosystems quality. Therefore, determination of metal accumulation in organisms should be part of any assessment and monitoring program in the coastal zone. Heavy metal concentrations in aquatic ecosystems are usually monitored by detecting their concentration in water, sediments and aquatic organisms (Camusso *et al*., 1995). So, fish samples are considered to be one of the most indicative factors, in aquatic systems, for the estimation of heavy metal pollution. Many studies were published about heavy metal accumulation in fish (Rashed, 2001; Papagiannis *et al*., 2004; Koca *et al*., 2008; Erdogrul and Erbilir, 2007; Qiao-qiao *et al*., 2007).

**Objective of the study**

The main aim of this study is to evaluate the level of heavy metals concentrations in three fish species from different trophic levels

Specific objectives are to:

1. determine heavy metal concentrations in the tissues, liver and kidney of the fish
2. compare and contrast heavy metal concentrations in the tissue, liver and kidney at the trophic levels
3. determine if heavy metal concentrations present in the fish species were within the recommended limits for human consumption.

**CHAPTER TWO**

**2.0 LITERATURE REVIEW**

**2.1 Heavy metals**

Metals are natural constituents of the earth crust that exists in higher or lower concentrations. Metals that occur in higher concentrations are referred to as major metals while metals occurring in very low concentrations are referred to as heavy metals. The metals with the highest concentration of the earth crust are aluminum and iron, which have a concentration of around 8% and 5% respectively (Kabata-Pendias and Mukherjee, 2007). Most metals exist in trace concentrations, but can however, due to variations in the mineral composition of the crust, locally exist naturally in higher concentrations as veins or ores (Ashraf *et al.*, 2012). Metals released to the environment are often emitted in an insoluble form but could, due to changes in environmental conditions, change to a more soluble form (Ashraf, 2005). Some of the metals are essential for all living organisms in low concentrations, for example: iron, manganese, zinc and copper (Ashraf *et al.*, 2012).

**2.2 Heavy metal in Aquatic Environment**

Most important controls especially on heavy metal speciation and mobility include the pH, Eh, temperature, surface properties of solids, abundance and speciation of ligands, major cations and anions, presence or absence of dissolved and/or particulate organic matter, and biological activity (Arantes *et al.*, 2016). Metal absorption of various (organic and inorganic) colloids by a variety of processes facilitates their concentration in soil and near-surface sediment. While the inorganic colloids comprises of various soluble and insoluble humic substances, the inorganic colloids include a variety of secondary clay minerals, and Fe-Mn oxides and hydroxides formed due to weathering processes. Therefore, not only do colloids have the capacity to absorb a great amount of heavy metals but they may also incorporate the most active phases of the metals (Forstner, 1989). During the dry season the metal concentration of interstitial water increases and metals may form metal-Cl complexes, or be adsorbed by clay or organic particles. During wet season however, the sediment pore water becomes slightly acidic as a result of a rise in water-table. This in turn promotes desorption and export of heavy metals (Ashraf *et al.*, 1991).

**2.3 Heavy metals in Aquatic Fishes**

Metals could enter fish either directly through the digestive tract due to consumption of contaminated water and food, or non-dietary routes across permeable membranes such as gills (Burger *et al.*, 2002). Determination of heavy metals levels in the aquatic environment has received massive attention for the last few decades which has led to the measurement of contamination levels in public food supplies, particularly fish (Rose *et al.*, 1999). The accumulation of metals in fish is mainly traced to the organs, while a small accumulation has been observed in the muscle (Ashraf *et al.*, 2012). Toxicological and environmental studies have prompted interest in the determination of toxic elements in food. The ingestion of food is an obvious means of exposure to metals, not only because many metals are natural components of foodstuffs, but also because of environmental contamination and contamination during processing (Voegborlo *et al.*, 1999). Bioaccumulation can also be defined as an increase in the concentration of pollutants by an increase in age, which sometimes is reflected in size of the organism (Fernandes *et al.*, 2007). Metal bioaccumulation is influenced by various environmental and biological factors particularly the feeding source (Agusa *et al.*, 2004; Wang and Rainbow, 2008).

In recent years fish consumption has increased many folds due to its nutritional and therapeutic benefits. Fish are at the top level of aquatic food chain and are good indicators of heavy metal contamination because they accumulate metals in their tissues (Yilmaz *et al.*, 2007). Since metal is known to affect the central metabolic pathways it may have a major detrimental impact on both human and animal life (Pandey *et al.*, 2008), thus there is a growing concern that metals accumulated in fish tissues may represent a health risk, especially for fish consuming population (Burger and Gochfeld, 2009; Ling, 2009). Gale *et al*. (2004) reported that the consumption of contaminated fish caused acute and chronic effects to humans. Monitoring heavy metal contamination in river systems by using fish tissues helps to assess the quality of aquatic ecosystems (Jabeen and Chaudhry, 2010). Heavy metals enter fish through five main routes (food or non-food particles, gills, water, and skin), follow into the blood, and are carried to either a storage point or to the liver for its transformation or storage (Adam, 2002). However the metal concentrations in muscle tissues are reported to be usually lower than in other organs (Pourang *et al.*, 2005; Kojadinovic *et* *al.*, 2007; Mashroofeh *et al.*, 2013)

**2.4 Trophic level**

The trophic level of an organism is the position it occupies in a food chain. The word trophic derives from the Greek (trope) referring to food or feeding. A food chain represents a succession of organisms that eat another organism and are, in turn, eaten themselves (Joshi *et al.,* 2016). The number of steps an organism is from the start of the chain is a measure of its trophic level. Food chains start at trophic level 1 with primary producers such as plants, move to herbivores. The three basic ways organisms get food are as producers, consumers and decomposers (Joshi *et al.,* 2016).

**2.4.1 Producers**

This are also known as autotrophs, which are typically plants or algae. Plants and algae do not usually eat other organisms, but pull nutrients from the soil or the ocean and manufacture their own food using photosynthesis (Joshi *et al.,* 2016). For this reason, they are called primary producers. In this way, it is energy from the sun that usually powers the base of the food chain. An exception occurs in deep-sea hydrothermal ecosystems, where there is no sunlight. Here primary producers manufacture food through a process called chemosynthesis (Joshi *et al.,* 2016).

**2.4.2 Consumers**

This are also known as heterotrophs, which are animals which cannot manufacture their own food and need to consume other organisms. Animal that eat primary producers (like plants) are called herbivores. Animals that eat other animals are called carnivores, and animals that eat both plant and other animals are called omnivores (Joshi *et al.,* 2016).

* + 1. **Decomposers**

They are known as detritivores, which break down dead plant and animal material and wastes and release it again as energy and nutrients into the ecosystem for recycling. Decomposers, such as bacteria and fungi (mushrooms), feed on waste and dead matter, converting it into inorganic chemicals that can be recycled as mineral nutrients for plants to use again (Joshi *et al.,* 2016).

****

**Figure 1. Trophic level of an ecosystem**

Trophic levels can be represented by numbers, starting at level 1 with plants. Further trophic levels are numbered subsequently according to how far the organism is along the food chain (Joshi *et al.,* 2016).

Level 1: Plants and algae make their own food and are called primary producers.

Level 2: Herbivores eat plants and are called primary consumers.

Level 3: Carnivores which eat herbivores are called secondary consumers.

Level 4: Carnivores which eat other carnivores are called tertiary consumers.

Level 5: Apex predators which have no predators are at the top of the food chain (Joshi *et al.,* 2016).

**2.5 Biomass Transfer Efficiency**

Generally, each trophic level relates to the one below it by absorbing some of the energy it consumes, and in this way can be regarded as resting on, or supported by the next lower trophic level. Food chains can be diagrammed to illustrate the amount of energy that moves from one feeding level to the next in a food chain (Joshi *et al.,* 2016). This is called an energy pyramid. The energy transferred between levels can also be thought of as approximating to a transfer in biomass, so energy pyramids can also be viewed as biomass pyramids, picturing the amount of biomass that results at higher levels from biomass consumed at lower levels (Price *et al.,* 2012). The efficiency with which energy or biomass is transferred from one trophic level to the next is called the ecological efficiency. Consumers at each level convert on average only about 10 percent of the chemical energy in their food to their own organic tissue (Price *et al.,* 2012).

**2.6 Mean Trophic Level**

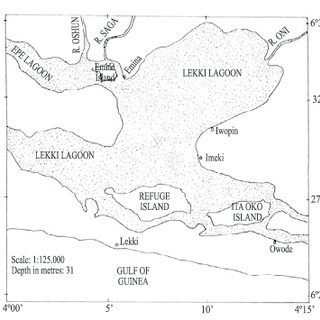
The mean trophic level is calculated by assigning each fish or invertebrate species a number based on its trophic level. The trophic level is a measure of the position of an organism in a food web, starting at level 1 with primary producers, such as phytoplankton and seaweed, then moving through the primary consumers at level 2 that eat the primary producers to the secondary consumers at level 3 that eat the primary consumers, and so on. In marine environments, trophic levels range from two to five for the apex predators (Price *et al.,* 2012). The mean trophic level can then be calculated for fishery catches by averaging trophic levels for the overall catch using the datasets for commercial fish landings. The trophic level of fishes usually increases with their size, and fishing tends to selectively capture the larger fishes (Price *et al.,* 2012). This applies both between species as well as within species. When the fishing is intense, the relative abundance of the larger fish positioned high in the food chain is reduced. Consequently, over time, small fishes start to dominate the fisheries catches, and the mean trophic level of the catches declines (Joshi *et al.,* 2016).

**CHAPTER THREE**

**3.0 MATERIALS AND METHODS**

**3.1 Study Area**

The Lekki lagoon is one of the largest lagoons in West Africa and it supports a major fishery. The lagoon is located between Lagos and Ogun States of Nigeria and lies between longitude 4° 00´ and 4° 15´E and between latitude 6° 25´ and 6° 37´N (Figure 1). According to Kusemiju (1973), the lagoon has a surface area of about 247 km2 and it is mostly shallow (less than 3.0 m deep) the maximum depth being 6.4 m. Lekki lagoon is a freshwater environment fed by the river Oni in the North eastern part and by Rivers Oshun and Saga in the north western parts of the lagoon. It opens into the sea via the Lagos lagoon and Lagos harbour. The lagoon is transitional in that it connects three south western states (Ondo, Ogun and Lagos). The lagoon is part of an intricate system of waterways made of lagoons and creeks that are found along the coast of South-western Nigeria from the Dahomey border to the Niger Delta (Emmanuel, 2009).

****

**Figure 2**. **Map of Lekki Lagoon and its environs**

**3.2 Sampling**

Three abundant and widely distributed fish species at different trophic levels where selected based on human preference in Lekki lagoon were studied. Nine adult samples, three each of

*Coptodon zilli* which is an herbivore, *Chryscthys nigrodigitatus*, an omnivore which feed near to the bottom, and *Hepsetus odoe* a carnivore will be collected with their mean weight and standartd length. These fish species will be put in sterile polythene bags and taken in icebox to the laboratory where they will be washed with running tap water to remove dirt.

**3.3 Samples Preparation**

Fish samples will de-scaled and rinsed with distilled water before dissection for the isolation of the following internal organs as test samples: tissues, kidney and liver. Care will be taking during dissection to prevent metal contaminations of the organ samples by using stainless steel dissecting kits.

The isolated organs will be manually cut into small pieces with stainless-steel scissor and weighed accurately to 5.00g (wet weight basis) each. The weighed organs will then be placed on sanitized aluminum foil, neatly arranged on oven trays and subsequently dried to a constant weight in the oven drying at 140°C for 10hours. Each of the dried samples will be retrieved from the oven, reduced to fine powder (using pestle and mortar) and sieved using a plastic sieve (0.2 mm mesh size) with 1g of each samples weighed out for digestion.

**3.4 Digestion of the Samples**

The samples will be digested using method described by Poldoski (1980) with slight modification; 1 gram each of the powdered samples will be weighed into separate conical flasks after which 10mls of concentrated HNO3 and 3mls of HClO4 will be added, and heated on a hot plate for an hour. Each sample will be filtered and residue treated with 0.2%v/v HNO3 to 20mls mark, 4mls of HClO4 and 2mls of concentrated H2SO4 will be added and the mixture heated in an aluminum block digester until white fume evolves and a clear solution obtained. The clear solution will be subsequently diluted with distilled water to the 25mls mark for higher concentration as against standard 50mls (as recommended by the heavy metal laboratory technologist) because heavy metals exist as heavy metals in water and aquatic biota and stored until required for analysis.

**3.5 Preparation of standard metal ion solutions**

Stock solutions (1000mg/ L) of each of the metal (Cu, Pb, Co, Cr, Fe, Zn, Ni, Cd) ions will be prepared using appropriate metal salt of AR grade quality in dilute Nitric acid. The working standards of these solutions will be prepared by appropriate dilutions in distilled water.

**3.6 Determination of Heavy metal Concentration**

The metal analysis will be done at Fatlab in Ibadan, Oyo State, Nigeria. Atomic Absorption Spectrophotometer Buck Scientific model 210 AAS will be used with appropriate cathode lamps to estimate the concentration of heavy metals present.

**3.7 Statistical Analysis**

Data obtained will be subjected to Analysis of variance (ANOVA) using Statistics for Political and Social Sciences (SPSS) version 22 and Duncans Multiple Range Tests will be used to separate the means.

**REFERENCES**

Adam, S. M. (2002). Biological indicators of aquatic ecosystem stress p. 656. Bethesda, MD: American Fisheries Society.

Agusa, T., Kunito, T., Tanabe, S., Pourkazemi, M. and Aubrey, D.G., (2004): Concentrations of trace elements in muscle of sturgeons in the Caspian Sea. *Marine Pollution* *Bulletin,* 49, 789-800.

Al-Yousuf, M. H., El-Shahawi, M. S., & Al-Ghais, S. M. (2000): Trace metals in liver, skin and muscle of Lethrinus lentjan fish species in relation to body length and sex. The Science of the Total Environment, 256, 87–94.

Amin, O.A., Comoglio, L.I. and Rodriquez, E.M., (2003): Toxicity of cadmium, lead and zinc to larval stages of *Lithodes santolla (Decapoda, Anomura). Bulletin of Environmental Contamination and Toxicology*, 71, 527–534.

Anand M. and P. Kumarasamy (2013): Analysis of heavy metals in fish samples along the east coastal region of Valinokkam, Ramanathapuram District, Tamilnadu. *Advances in Applied Science Research.* 4(6):178-183

Arantes FP, Savassi LA, Santos HB, Gomes MVT, Bazzoli N. (2016): Bioaccumulation of mercury, cadmium, zinc, chromium, and lead in muscle, liver and spleen tissues of a large commercially valuable catfish species from Brazil. Annals of the Brazilian Academy of Sciences, doi.org/10.1590/0001-3765201620140434.

Ashraf M, Tariq J, Jaffar M (1991): Contents of heavy metals in fish, sediments and water from three freshwater reservoirs on the Indus River, Pakistan. *Fish Res*12: 355-364.

Ashraf, M.A., Maah, M.J. and Yusoff, I. (2012): Bioaccumulation of heavy metals in fish species collected from former tin mining catchment*.* International Journal of Environmental Research. 6(1):209-218.

Ashraf, W. (2005): Accumulation of heavy metals in kidney and heart tissues of Epinephelus microdon fish from the Arabian Gulf. *Environ Monit Assess., 101*, 311. <http://dx.doi.org/10.1007/s10661-005-0298-4>

Asuquo, F. E., Ogri, O. R., & Bassey, E. S. (1999): Distribution of heavy metals and total hydrocarbons in coastal waters and sediments of cross River State, South Eastern Nigeria. International Journal of Tropical Environment, 2, 229–242.

Asuquo, F.E., Ewa-Oboho, I., Asuquo, E. F. and Udo, P. J. (2004): Fish species used as biomarker for heavy metal hydrocarbon contamination for Cross river, Nigeria. The Environmentalist, 2, 29–37.

Ayandiran, T.A., Fawole, O.O., Adewoye, S.O. and Ogundiran, M.A. (2009): Bioconcentration of metals in the body muscle and gut of *Clarias gariepinus* exposed to sublethal concentrations of soap and detergent effluent. *Cell and Animal Biology*, 3(8), 113–118.

Ayotunde, E.O., Offem, B.O. and Ada, F.B. (2011): Heavy Metal profile of Cross River: Cross River State, Nigeria: Using Bioindicators Indian Journal of Animal Research 45(4): 232-246.

Azcue, J. M. P., Pfeiffer, W. C., Donagelo, C. M., Fiszman, M., & Malm, O. (1988): Heavy Metals in Foods from the Paraíba do Sul River Valley, Brazil. Journal of Food Composition and Analysis, I, 250–258.

Batzias, A.F. and Siontorou, C.G. (2008): A new scheme for biomonitoring heavy metal concentrations in semi-natural wetlands. *Hazardous Materials*, 158(2–3), 340–358.

Bordajandi, L. R., Gómez, G., Fernández, M. A., Abad, E., Rivera, J., & González, M. J. (2003): Study on PCBs, PCDD/Fs, organochlorine pesticides, heavy metals and arsenic content in freshwater fish species from the River Turia (Spain). Chemosphere, 53, 163–171.

Burger, J., Gaines, K.F., Boring, C.S., Stephens, W.L. and Snodgrass, J. (2002): Metal levels in fish from the Savannah River: potential hazards to fish and other receptors. *Environ Res* 89: 85-97.

Campbell, P. G. C. (1995): Interaction between trace metal and aquatic organism. A critique of the free ion activity model. In A. Tessier, & D. R. Turner (Eds.) Metal speciation and bioavailability in aquatic systems (pp. 45–102). Chichester, UK: Wiley.

Camusso, M.L. and Baitstrini, R. (1995): Bioaccumulation of trace metals in rainbow trout. *Ecotoxicology and Environmental Safety*, 31, 133-141.

Canli, M., Ay, O., & Kalay, M. (1998). Levels of heavy metals (Cd, Pb, Cr and Ni) in tissue of Cyprinus carpio, Barbus capito and Chondrostoma regium from the Seyhan river, Turkey. Turkish Journal of Zoology, 22, 149–157.

Castro, H., Aguilera, P.A., Martinez, J.L. and Carrique, E., 1999. Differentiation of clams from fishing areas an approximation to coastal quality assessment. *Environmental Monitoring and Assessment*, 54, 229–237.

Chapman, D. (1996): Water quality assessments—A guide to the use of biota, sediment and water in environmental monitoring (p. 6262nd ed.). London: E & FN Spon.

Cinier, C. C., Petit-Ramel, M., Faure, R., Garin, D., & Bouvet, Y. (1999). Kinetics of cadmium accumulation and elimination in carp Cyprinus carpio tissues. Comparative Biochemistry and Physiology Part C, 122, 345–352

Clark, R., Frid, C., & Attrill, M. (1997): Marine pollution (4th ed.). New York: Oxford University Press.

Eisler, R. (1988). Zink hazards to fish, Wildlife and Invertebrates: A synoptic review. US Fish Wildlife Serv. Biol. Rep., 85.

Emmanuel BE (2009). The artisanal fishing gears, crafts technology and their efficiency in the Lekki lagoon, Nigeria. Ph.D Thesis, University of Lagos., p. 268.

Erdogrul, Ö. and Erbilir, F., (2007): Heavy metal and trace elements in various fish samples from Sır Dam Lake- Kahramanmaras in Turkey. *Environmental Monitoring and Assessment*, 130, 373–379.

Fairbrother, A., Wenstel, R., Sappington, S. and Wood, W. (2007): Framework for metals risk assessment. *Eco-toxicology and Environmental Safety*, 68,145–227.

Farombi, E.O., Adelowo, O.A. and Ajimoko, Y.R. (2007): Biomarkers of oxidative stress and heavy metal levels as indicators of environmental pollution in African catfish (*Clarias gariepinus*) from Nigeria Ogun River. I*nt. J. Environ. Res. Publ. Health.* 4: 158–165.

Farombi, E.O., Adelowo, O.A. and Ajimoko, Y.R., 2007. Biomarkers of oxidative stress and heavy metal lev-els as indicators of environmental pollution in African cat fish (*Clarias gariepinus*) from Nigeria Ogun River. *International Journal of Environmental Research and Public Health*, 4(2), 158–165.

Feng Li, Y.M., Wen, P. and Zhu, T., 2008. Bioavailability and toxicity of heavy metals in a heavily polluted river in PRD China. *Bulletin of Environmental Contamination and Toxicology*, 81, 90–94.

Fernandes, C., Fontainhas Fernandes, A., Peixoto, F. and Salgado, M.A., 2007. Bioaccumulation of heavy metals in Liza saliens from the Esmoriz–Paramos coastal lagoon in Portugal. *Ecotoxicology and Environmental Safety*, 66, 426–431.

Fernandes, C., Fontainhas-Fernandes, A., Peixoto, F., and Salgado, M. A., 2007. Bioaccumulation of heavy metals in *Liza saliens* from the Esmoriz– Paramos coastal lagoon, Portugal. *Ecotoxicology and Environmental* *Safety*, 66(3), 426-431.

Forstner, U. and Wittmann, G.T.W. (1979) Metalpollution in the Aquatic Environment. *Springer-Verlag*, Berlin, 1-486.

Has-Schön, E., Bogut, I., & Strelec, I. (2006). Heavy metal profile in five fish species included in human diet, domiciled in the end flow of river Neretva (Croatia). Archives of Environmental Contamination and Toxicology, 50, 545–551.

Henry, F., Amara, R., Courcot, L., Lacouture, D., & Bertho, M. L. (2004). Heavy metals in four fish species from the French coast of the Eastern English Channel and Southern Bight of the North Sea. Environmental International, 30, 675–683.

Holmlund, C.M. and Hammer M. (1999): Ecosystem services generated by fish populations. *Ecol. Econom.* 29: 253–268

Islam, M.D. and Tanaka, M., 2004. Impacts of pollution on coastal and marine ecosystems including coastal and marine fisheries and approach for management: a review and synthesis. *Marine Pollution Bulletin*, 48, 624–649.

Joshi, A., Desai, A.Y., Kumar, J., Saroj, J., and Tehseen, P., (2016): Assessment of mean trophic level and prey –predator relationship. International Journal of Science, Environment and Technology, Vol. 5, No 3, 1046 – 1056

Kabata-Pendias, A. and Mukherjee, A.B. (2007): Trace elements from soil to human. Berlin,

Koca, S., Koca, Y.B., Yildiz, S. and Gürcü, B., (2008): Geno-toxic and histopathological effects of water pollution on two fish species *Barbus capito pectoralis* and *Chon-drostoma nasus* in the Büyük Menderes River in Turkey. *Biological Trace Element Research*, 122, 276–291.

Kojadinovic, J., Potier, M., Le Corre, M., Cosson, R.P. and Bustamante, P., (2007): Bioaccumulation of trace elements in pelagic fish from the Western Indian Ocean. *Environmental Pollution*, 146, 548-566.

Kusemiju K (1973): A study of the catfishes of Lekki lagoon with particular reference to the *species Chrysichthys walkeri* Bagridae. Ph.D Thesis. University of Lagos., p. 188.

Mashroofeh, A., Bakhtiari, A.R., Pourkazemi, M. and Rasouli, S., (2013): Bioaccumulation of Cd, Pb and Zn in the edible and inedible tissues of three sturgeon species in the Iranian coastline of the Caspian Sea. *Chemosphere*, 90, 573-580.

Mohammadi Rouzbahani, M., 2017. Bioaccumulation of heavy metals (Ni, V, Cu, Pb) in various tissues of Metapenaeus affinis in the Northwest of Persian Gulf. Iranian *Journal of Aquatic Animal Health,* 3(1), 101-113.

Nriagu, J.O., Jozef, M. and Pacynar, J.M. (1988): Quantitative assessment of worldwide contamination of air, water and soils by trace metals. *Nature* 333: 134–139

Obiakor, M.O., Ezeonyejiaku, C.D., Ezenwelu, C.O. and Ugochukwu, G.C. (2010). Aquatic genetic biomarkers of exposure and effect in catfish (*Clarias gariepinus* Burchell, 1822). *Am. Euras. J. Toxicol. Sci.* 2: 196–202.

Olarinmoye, O., Taiwo, V., Clarke, E., Kumolu-Johnson, C., Aderinola, O. and Adekunbi, F. (2009): Hepatic pathologies in the brackish water catfish (*Chrysichthys nigrodigitatus*) from contaminated locations of the Lagos lagoon complex. *Appl. Ecol. Environ. Res.* 7: 277–286.

Papagiannis, I., Kagalou, I., Leonardos, J., Petridis, D. and Kalfakakou, V. (2004): Copper and zinc in four freshwater fish species from Lake Pamvotis in Greece. *Environment International*, 30, 357-362.

Peakall, D., & Burger, J. (2003). Methodologies for assessing exposure to metals: Speciation, bioavailability of metals, and ecological host factors. Ecotoxicology and Environmental Safety, 56, 110–121.

Pourang, N., Tanabe, S., Rezvani, S.and Dennis, J., (2005): Trace elements accumulation in edible tissues of five sturgeon species from the Caspian Sea. *Environmental* *Monitoring and Assessment,* 100, 89-108.

Powers D.A. (1989). Fish as model systems. Science 246: 352–358.

Price, S.A., Hopkins, S.S.B., Smith, K.K. and Roth, V.L. (2012): Tempo of trophic evolution and its impact on mammalian diversification. Proc. Natl Acad. Sci. USA 109, 7008–7012.

Qiao Qiao, C.H.I, Guang Wei, Z.H.U. and Langdon, A., (2007): Bioaccumulation of heavy metals in fishes from Taihu Lake in China. *Journal of Environmental Sciences* 19, 1500-1504

Rashed, M.N. (2001). Monitoring of environmental heavy metals if fish from Naser Lake. *Environment International*, 27, 27-33.

Rashed,M. N. (2001). Monitoring of environmental heavy metals in fish from Nasser Lake. Environment International, 27, 27–33.

Reyahi-Khoram M., Setayesh-Shiri F., Cheraghi M., 2016. Study of the heavy metals (Cd and Pb) content in the tissues of rainbow trouts from Hamedan coldwater fish farms. *Iranian Journal of Fisheries Sciences,* 15(2)858-869.

Rose, J., Hutcheson, M.S., West, C.R., Pancorbo, O. and Hulme, K. (1999): Fish mercury distribution in Massachusetts, USA lakes. *Environ Toxicol Chem* 18: 1370-1379.

Schwarzenbach, R.P., Escher, B.I., Fenner, K., Hofstetter, T.B. and Johnson, C.A. (2006). The challenge of micropollutants in aquatic systems. *Science* 313: 1072–1077.

Skouras, A., Broeg, K., Dizer, H., Von Westernhagen, H., Hansen, P. and Steinhagen, D. (2003): The use of innate immune responses as biomarkers in a programme of integrated biological effects monitoring on flounder (*Platichthys flesus*) from the southern North Sea. *Helgol. Mar. Res.* 57: 190–198

*Springe*r. 576p.

Terra, B. F., & Araújo, G. F., Calza, C. F., Lopes, R.T. and Teixeira, T.P (2007): Heavy Metal in Tissues of Three Fish Species from Different Trophic Levels in a Tropical Brazilian River. Water Air Soil Pollut. DOI 10.1007/s11270-007-9515-9

Thomann, RV., Mahony, J.D. and Mueller, R., (1995): Steady state model of biota sediment accumulation factor for metals in two marine bivalves. *Environmental Toxicology and Chemistry*, 4, 989–998.

Uaboi-Egbenni, P.O., Okolie, P.N., Martins, O. and Teniola, O. (2010): Studies on the occurrence and distribution of heavy metals in sediments in Lagos Lagoon and their effects on benthic microbial population *Afr. J. Environ. Sci. Technol.* 4: 343–351.

Udosen, E.D., Offiong, N.O. and John, B.E. (2016): Distribution of trace metals in surface water and sediments of Imo River Estuary (Nigeria): Health risk assessment, seasonal and physicochemical variability Journal of Environmental Chemistry and Ecotoxicology 8(1): 1-8.

Voegborlo RB, El-Methnani AM, Abedin MZ (1999): Mercury, cadmium and lead content of canned tuna fish. *Food Chem* 67: 341-345.

Wang, W.X., (2002). Interactions of trace metals and different marine food chains. *Marine Ecology Progress Series*, 243, 295–309.

Wang, W.X. and Rainbow, P.S. (2008): Comparative approaches to understand metal bioaccumulation in aquatic animals. *Comparative* *Biochemistry and Physiology Part* *C: Toxicology and Pharmacology,* 148, 315-323.

Yilmaz, A. B. (2003): Levels of heavy metals (Fe, Cu, Ni, Cr, Pb, and Zn) in tissue of Mugil cephalus and Trachurus mediterraneus from Iskenderun Bay, Turkey. Environmental Research, 92, 277–281.

Zelikoff, J.T., Raymond, A., Carlson, E., Li, Y., Beaman, J.R. and Anderson, M. (2000): Biomarkers of immunotoxicity in fish: from the lab to the ocean. *Toxicol. Lett.* 112/113: 325–331.