Water Quality as Index of Healthy Aquatic Life: A Review

Abubakar Haruna[1*], Lawan Gana Ali[1] Shafiu Nafiu Abdullahi[2] Samaila Audu Jovial[1]

[1]Department of Science Laboratory Technology, Mai Idris Alooma Polytechnic, Geidam, Yobe State

[2]Department of Life Sciences, Kano State Polytechnic, Kano, Nigeria

[*]Corresponding author: abubakarboyz21@gmail.com

Abstract

Water quality is impacted by anthropogenic activity such as wastewater from industries and improper waste management. Constant discharge of untreated effluent and sewage, dumping and processing of metal and microplastic scraps, local dyeing and tanning, atmospheric deposit, and excessive use of agrochemicals continue to contaminate the surrounding environment with hazardous heavy metals. These toxins remain in the aquatic environment and affect non-target organisms such as fish. Water pollution is significant because of its impact on the environment on which we rely. Destroying the environment eventually lowers the quality of our lives. Portable water is essential for human existence and survival. To keep alive, we need to consume it and use it to clean our food, utensils, clothes, bodies, and environment. Unfortunately, this same water is the source of many diseases, particularly in developing countries. The paper evaluated relevant research and provided an outline of how these toxins affect aquatic biota. The following bio-indicators of heavy metal poisoning that cause changes in fish physiology were discussed: hematology, antioxidant enzyme activity, histology, and growth performance. Environmental standards are being violated, and environmental regulatory bodies are failing to enforce environmental protection laws, compounding the situation.

Keywords: *Anthropogenic activities, Heavy Metals, Fish physiology, Pollution, Industrial Pollutants.*

Introduction

Freshwater resources are essential for providing support and addressing a variety of domestic, agricultural, commercial, and industrial demands (Akhtar et al., 2021). It is one of the most valuable, yet limited, natural resources on earth. However, there are growing concerns regarding water quality, particularly in tropical places (Busico et al., 2020). Although the earth's surface contains 70% water, only 3% of it is freshwater, and it deteriorates primarily owing to manmade activity (Davies and Day 2016). Water quality issues caused by pollution are serious concerns around the world since cities, industrial sectors, and commercialized agriculture all contribute to the contamination (pollution) of the aquatic ecosystem (Chidiac et al., 2023).

Global fear exists regarding the progressive pollution of valuable freshwater systems on which most creatures, including people, rely (El-Sayed et al. 2018). Water pollution caused by the contamination of water bodies (e.g., rivers, lakes, oceans, aquifers, and groundwater) can be damaging to plants and other species that live in and/or rely on the water bodies (Aragaw et al., 2021). Aquatic ecosystems are currently being heavily impacted by anthropogenic impacts such as changes in biological, chemical, and physical properties of waterways, which can endanger ecosystem integrity and human health (FAO/WHO, 2018). Unsanitary disposal and inadequate treatment of human and livestock wastes, inadequate management and treatment of industrial garbage, unsuitable agricultural practices, and dangerous solid waste emissions are all associated with these activities. In developing nations, for example, more than 80% of sewage is released directly into waterways (UNEP/WHO, 2017). Every year, industries' byproducts dump an estimated 300-400 million tons of heavy metals, solvents, sludge, and other garbage (United Nations Water Assessment Programme, 2017). Toxins and chemicals either directly affect humans or bio-accumulate in fish and other species consumed by humans, causing developmental and neurological damage (Abbasi, 2012). Every year, 1.8 million people die as a result of diarrheal infections caused by contaminated water or poor sanitation and hygiene. More than 1.5 million are children under the age of five, who are more vulnerable to diarrhea than malaria, HIV, or even other types of fatal injuries combined (WHO, 2016).

Degraded water quality, among other factors, affects the aquatic ecology. The biodiversity of aquatic ecosystems has been destroyed more than that of any other ecosystem, including tropical rainforests, according to the Millennium Ecosystem Assessment (2017). While the aquatic environment has often been viewed as a source of water supply and waste disposal, or contaminated without regard for the consequences, there is a growing appreciation for the vital goods and services it provides, which are critical for livelihood in many parts of the world. The degradation of ecosystems caused by polluted water has a direct impact on humanity as a whole as fisheries and biodiversity are destroyed, jeopardizing the food supply and other human benefits (Welcome, 2013). Those most affected are those who live near polluted waterways and lack alternate access to safe water or improved sanitation. In 2017, 2.6 billion people, or 42% of the global population, did not have access to better sanitation (WHO, 2015). Given the aforementioned, the purpose of this study is to examine the impact of heavy metal contaminants on several bioindicators, with a focus on fish as a model.

Concept of Aquatic Pollution

Pollution of aquatic habitats is a global issue that requires immediate response (Samson et al., 2020). The quality of drinking water is essential for existence. Bacteria, viruses, heavy metals, nitrates, and salt have polluted water supplies as a result of inadequate treatment and disposal of waste from humans, livestock, industrial discharges, residence discharge, and the widespread use of limited water resources. Heavy metals constitute a core group of aquatic pollutants due to their toxicity, persistence, bioaccumulative, and non-biodegradable characteristics in the natural environment (Ibrahim and Said, 2011).

Availability of Pollutants in the Environment

Pesticides come into direct contact with water bodies via unintentional spills, aerial drift, or runoff, damaging aquatic environments and wreaking havoc on aquatic habitats, among other consequences (Adeboyejo et al., 2011). Pesticides have been observed in a wide range of aquatic compartments, including the water column, biota, and sediments (Ezenwosu et al., 2020). They can be found by examining three key routes: organic substrates (epilithic and epiphytic algal parts, hydrophytes, branches, and leaf litter), water column, and inorganic substrate (sediments and other detritus) (Murthy et al., 2013).

Factors Related to Transport of Heavy metals in the Aquatic Environment

Physical and chemical properties, as well as the form of rainfall, are factors determining heavy metals' influence on aquatic environments (Sani et al., 2019). Heavy metals in water transfer from compartment to compartment through processes such as transfer (mobility) and biotransformation (degradation) (Sawut et al., 2018). Surface runoff, vapourization to the atmosphere, plant absorption, and soil water fluxes are common modes of transfer (Nsofor et al., 2014). Biotransformation occurs frequently as a result of microbial activity, oxido-reductive activity, hydrolysis, volatilization, and photocatalysis, resulting in the synthesis of metabolites that can be harmful or non-toxic (Abdulmojeed & Abdulrahman, 2011). Heavy metals' molecular size, solubility, and stability are additional properties that exhibit their specific impacts in an aquatic domain (Chowdhury et al., 2016). Solubility is a key component in determining how, where, and when heavy metals transition across aquatic ecosystems (Samson, 2015).

Factors Related to Circumstances of Heavy metals Exposure in the Water Body

Heavy metal toxicity is influenced by the amount/quantity (dose), mode of entry, exposure duration, and sensitivity of an organism (Abdullahi et al., 2021). Heavy metal complexes found in agrochemicals that are used in agricultural activities penetrate the environment via a variety of pathways. Pollutants comprising heavy metals leached into the soil or by accidental releases into aquatic ecosystems and/or residential intake, according to Abdullahi et al. (2021). Heavy metals' toxicity to non-target organisms may be influenced by the process by which they react with water bodies due to pH fluctuations (Sivakumar et al., 2016). However, differences in susceptibility and sensitivity among numerous aquatic creatures demonstrated that numerous biochemical reactions are dependent on the prevailing environment and the genetic makeup of the organism (Shawai et al., 2019).

Disruption of Ecological Balance by Pollutants to the Environment

Pesticides currently used in diverse aquatic environments may jeopardize non-target species populations by limiting their natural environments, such as wetlands and irrigation regions (Akan et al., 2013). Pesticides have been shown to affect the aquatic food chain by interfering with fish food supply and altering habitat (Olutona et al., 2016). In addition to habitat change, fish species can be preyed upon via lowering habitat suitability and changing behavior. Pesticides can contaminate water systems and impact the biology of numerous non-target species (Ullah et al., 2019). Disruption of the ecological equilibrium of freshwater fish through biological controls inevitably results in the production of pests that were previously of minor consequence, creating a new problem of resistance and unsustainable dependence on more pesticides (USEPA, 2017).

Direct Effects of Pollutants on Aquatic biota

Pesticides have been demonstrated to cause different kinds of toxicity in aquatic biota, including fish, which include behavioral changes (Rani and Kumaraguru, 2014; Rakesh and Kumar, 2019), hematological changes (George et al., 2017), histopathological changes (Dane and Sisman, 2017), enzyme changes (Annett et al., 2014), genotoxicity (Ansari, 2011), biochemical modifications (Banee, 2011 and Akan et al., 2013) and changes in antioxidant enzymes activity (Nwani et al., 2010).

Heavy metals are continuously discharged into water bodies through a variety of ways, including discharge from industrial activities, irrigation, atmospheric deposition, and point sources where metals are created as a result of refining and refinishing products (Butu et al., 2019). Many dissolved heavy metals that reach bodies of water are adsorbed onto colloid particles. Metals, notably lead, and cadmium, precipitate by forming complexes at high alkalinity and pH, significantly impacting their toxicity (Jamila and Sule, 2020). Water bodies are commonly recognized as the final sink for heavy metals discharged into the environment and can serve as sensitive indicators for pollution monitoring (Habu et al., 2021).Therefore, pollution by heavy metals on aquatic biota recorded increasing attention in the last few decades in both developing and developed countries throughout the world (Ahmad *et al*., 2015).

The length-weight relationship and condition factor are vital biological tools that have been used to determine the effect of environmental changes on the fish's well-being (Olapade and Conteh, 2019). They are used to investigate the growth pattern and condition factor of fish species. According to Nafiu and Ibrahim (2017), length-weight relationships provide valuable information on the habitat where the fish lives.

Rakesh and Kumar (2019) describe behavior as the culmination of genetic, physiological, and biochemical processes. Herbicide-induced behavioral changes are one of the markers used to assess their impact on aquatic fauna such as fish (Madhusoodanan et al., 2016). It enables an organism to adapt to changing external and internal inputs in a variety of demanding environments. Swimming-oriented alterations, opercular movement, discoloration, lack of reflex, erratic swimming, and schooling are examples of anomalous behavioral changes observed in many fish species (Rakesh and Kumar, 2019). The impact of heavy metals on fish populations and other non-target creatures is frequently determined by the compound's solubility, mobility, concentrations, and exposure length, all of which have an impact on behavior (Mishra and Verma, 2016). Heavy metals induced aberrant alterations in fish by causing a sluggish pattern; altering swimming ability, reducing eating ability, and causing reflex loss (Ahmad et al., 2015).

According to USEPA (2014) guidelines, the BAF is defined as the ratio of chemical concentration in the organism to that in the surrounding water. Bioconcentration occurs through uptake and retention of a substance from water only, through gill membranes or other external body surfaces.

Fish have been employed for water quality monitoring and hence act as bioindicators of pollution (Akinwande et al., 2016). Heavy metals, as well as other xenobiotics, have been shown to accumulate in fish tissue, causing catalytic reactions that produce reactive oxygen species, resulting in environmental oxidative stress (Nafiu and Ibrahim, 2019). Many vertebrates, especially aquatic organisms such as fish, have defensive mechanisms that counteract the impact of ROS (Akhiromen and Ogbonne, 2018To prevent the effects of reactive oxygen species (ROS), fish developed an immunity mechanism (Ullah et al., 2019). Superoxide dismutases (SOD), which catalyze the dismutation of superoxide radical to hydrogen peroxide, and catalase (CAT), which acts on hydrogen peroxide by converting it to water and oxygen, are examples of antioxidant defense enzymes found in these systems (Akinwande et al., 2016). Industrial wastes, agricultural wastes, landfill leachates, oil pollutants, pesticides, and other substances that might form reactive oxygen species (ROS) and cause oxidative stress (Arojojoye and Adeosun, 2016). Fish, like humans, have antioxidant enzymes such as glutathione reductase, glutathione peroxidase, glutathione S-transferase, superoxide dismutase, and catalase that help to counteract the detrimental effects of ROS (Nafiu and Ibrahim, 2021Oxidative stress is caused by an imbalance between the body's antioxidant defense and free radical (pro-oxidant) production, which results in peroxidation of the cell's lipid bilayer and ROS synthesis (Ansari and Ansari, 2014). Heavy metals, for example, have been shown to bypass the antioxidant defense system, causing oxidative damage in aquatic organisms via ROS generation and other free radicals (Akinwande et al., 2016). High concentrations of free radicals and ROS overwhelm the antioxidant defense system, impairing normal cellular processes and inactivating enzymes, resulting in oxidative stress, peroxidation of cell components, and DNA damage (Ahmad et al., 2015). Superoxide dismutase (SOD), catalase (CAT), and glutathione transference (GST) are the enzymes responsible for ROS detoxification in an organism. These enzymes become quickly inducible under oxidative stress, demonstrating their ability to adapt to stress conditions (Ezike et al., 2019).

Pesticides Induce Oxidative Stress in Fish Tissues

The imbalance between the formation of free radicals (pro-oxidants), which leads to peroxidation of the cell's lipid bilayer, and the body's antioxidant defense is commonly referred to as oxidative stress (Ansari and Ansari, 2014). It is linked to an increase in the rate of cellular disruption produced by oxygen free radicals and other reactive oxygen species (ROS) such as hydrogen peroxide (H2O2), superoxide anion (O2), and hydroxyl radicals (OH-), nitric oxide (NO), and lipid peroxyl (LOO) (Ahmad et al., 2017). Free radicals are molecules with one unpaired valence electron in their outer shell, resulting in them being highly reactive (Ahmad et al., 2017). High concentrations of free radicals and ROS produce a deleterious influence on normal physiological processes, inactivate enzymes, and finally result in oxidative stress, peroxidation of cell components, and DNA damage (Ahmad et al., 2017). The toxicity of xenobiotics is directly related to the generation of free radicals in organisms (Ansari and Ansari, 2014). Superoxide dismutase is one of the essential enzymes that generate the first line of defense against free radicals (pro-oxidants) (Oluwatosin et al., 2016). It inhibits the conversion of superoxide radicals to H2O2 and O2, whereas catalase promotes the elimination of H2O2 into oxygen and water (Oluwatosin et al., 2016). Glutathione, on the other hand, shields the cell from reactive oxygen (ROS) and reactive nitrogen species (RNS), which play a vital part in maintaining normal cellular activities such as combating toxins and regulating various intercellular pathways (Ahmad et al., 2017). A high concentration of ROS in a cell, however, results in oxidative stress, which induces cellular inactivity via lipid peroxidation and protein denaturement (Ahmad et al., 2017). Glutathione detoxifies electrophilic toxins (both endogenous and exogenous). It preserves and keeps the critical thiol profile of proteins as well as other amino acids like cysteine (Oluwatosin et al., 2016). Pesticides have previously been identified as inducers of aberrant biochemical pathways in which they alter redox cycles, resulting in oxidative stress in a variety of organisms, including fish (Nwani et al., 2015; Oluwatosin and Abiola, 2016). They also cause cell damage by disrupting intracellular electron transport pathways with reactive oxygen species (ROS) (Ameur et al., 2012). These enzymes shield cells from reactive oxygen species (ROS) by neutralizing their effect and protecting them from oxidative damage (Doherty et al., 2010). According to Wu et al. (2013), exposing Clarias gariepinus to paraquat increased oxidative stress in the fish tissue due to changes in electrolyte levels. Nwani et al. (2015) discovered decreased physiological activities and metabolic pathways in C. gariepinus plasma protein, plasma glucose, and triglycerides after exposure to paraquat. According to Mastan and Shaffi (2010), sub-lethal organophosphate exposure disrupted multiple enzyme activities in brain tissue, including glutaminases and L-Keto acid-activated glutaminase, which are associated to brain area metabolism. Malathion insecticides have been linked to changes in Glutathione-S-transferase and Catalase activity in the gills, liver, and kidneys.

When *Tor putitora* was exposed to cypermethrin, the enzymes Glutathion Reductase, Peroxidase, Lipid Peroxidase, and Catalase were altered in the brain, liver, and muscle tissues (Ullah et al., 2014). After 14 days of bisphenol exposure, Faheem and Lone (2017) found an increase in lipid peroxidation and glutathione-S-transferase (GST) activity in the liver and kidneys of C. idella. The detoxification of BPA was linked to enhanced GST activity (Wu et al., 2011). Wu et al. (2011) observed an increase in GST activity in zebrafish embryos exposed to 0.1 g/l BPA. GST activity was similarly found to be increased in hepatocytes from pearl mullet and Japanese medaka (liver and gills) treated to BPA (Li et al. (2016). In another study, Prieto et al. (2006) looked at the antioxidant enzymes glutathione reductase (GSH), superoxide dismutase (SOD), catalase (CAT), and lipid peroxidation (LPO) as indicators of oxygen-mediated damage in Oreochromis sp. liver, kidney, and gill. Glutathione-S-transferase breaks down the correlation relationship between glutathione reductase and xenobiotic metabolites, allowing them to be excreted more quickly (Doherty et al., 2010). Oxidative damage occurs when antioxidant activity is insufficient to compensate for the formation of Reactive Oxygen Species (Glusczak et al., 2011).

The level of activity of SOD, Catalase, GSH, and GST reduced in the liver, kidney, and gills fish Clarias gariepinus in the Asejire River, while malondialdehyde (MDA) increased dramatically (Oluwatosin and Abiola, 2016). They determined that the decreased activity of these enzymes was caused by the high quantity of toxicants in the River. In an aquatic environment, significant oxidative damage occurs in biota exposed to pollutants, which enhances the formation of ROS, impairing antioxidant enzymes and leading to oxidative stress (Oluwatosin and Abiola, 2016). Antioxidant enzyme activities such as CAT, SOD, GSH, and GST have been used as biomarkers to evaluate the impact of aquatic pollution on the metabolic pathway and enzymatic activity in fish (Correia et al., 2010). The activity of glutathione peroxidase (GPx) was lowered in Prochilodus lineatus subjected to 10 mg/l glyphosate. SOD activity reduced after 24 hours, but hepatic glutathione concentration increased (Modesto and Martinez, 2010). Wu et al. (2011) discovered an increase in LPO activity in zebrafish embryos exposed to 0.1-1000g/L bisphenol.

Pollutants Induced Blood Indices Alterations in Fish

Previous studies demonstrated that several toxicants have an influence on hematological indices in aquatic life, including fish (Ahrar et al., 2012). Secondary responses of fish to toxicants are exhibited by haematological measures such as WBC count, RBC count, heamoglobin concentrations, and PCV (Hedayati and Hassan, 2015). According to Akinrotimi and Amachree (2016) and Ahmad et al. (2018), when toxicants impair water quality, any physiological changes will be reflected in the haematology of the aquatic biota. George et al. (2017) reported an increase in WBC, neutrophils, monocytes, Mean Cell Heamoglobin, and Mean Cell Heamoglobin doses in both male and female C. gariepinus after exposing it to varying doses of metalochlor and atrazine. Akinrotimi et al. (2012) observed an increase in WBC, neutrophils, and monocytes in African catfish (Clarias gariepinus) after cypermethrin exposure. Alterations in WBCs and RBCs, haemoglobin contents and packed cell volume of many fish species were reported such as Saeedi et al. (2012) who studied the effect of diazinon on haematological parameters of fry rainbow trout (*Oncorhynchus mykiss*), Akinrotimi et al. (2013) on haematological alterations of *Tilapia guineensis* challenged to varying concentrations of industrial effluents, Abdul-majid et al. (2014) on dichlorvos to freshwater fish (*Cyprinus carpio*), (Ullah *et al*., 2014) on cypermethrin to the haematological and physiological alterations in liver, brain and gills of Mahseer (*Tor putitora*), Gopala et al. (2017) on *Cyprinus carpio* challenged to pyrethroid (Permethrin) and Chandra et al. (2017) on the toxicological effects of dichlorvos to the freshwater fish.

Ullah et al. (2015) found that when Tor putitora was exposed to cypermethrin, the number of white blood cells (WBCs) increased but the number of red blood cells (RBCs) decreased. Previous research found that different synthetic pyrethroids caused changes in haematological indices in a variety of fish species. For example, Vani et al. (2012) studied the effect of cypermethrin on Catla catla, and Karatas (2016) studied the effect of deltamethrin on Salmo trutta fario. Ozok et al. (2018) investigated the effect of cypermethrin on Alburnus tarichi, whereas Vieira and Martinez (2018) investigated Prochilodus lineatus' response to lambda-cyhalothrin. Pesticide-induced changes in hematological indices have been linked to haemosynthesis inhibition, RBC disruption, RBC decrease due to hypoxia, hematopoietic system failure, and a heightened defense mechanism that modifies WBC count (Ullah et al., 2019).

Histological Alterations Induced by Pollutants in Aquatic Environment

In many vertebrates (in vivo and in vitro), including fish, histological changes have been considered as a bio-indicator of toxicity stress (Revathy and Chitra, 2015). Histopathological changes are the outcome of a series of physiological changes that impact the target organs and mechanism of action (Ramesh et al., 2014). Changes in the liver, ovary, and kidney tissues of Heteropneustes fossilis were observed after exposure to Malathion (pesticide) (Deka and Mahanta, 2012). When the intestine of H. fossilis was exposed to a sublethal dose (1.42ppm) of chlorpyrifos, degeneration, atrophy of the villi structure, necrosis of the intestine's mucosal epithelium, and lymphoid follicle depletion were detected (Nazia et al., 2016). At 0.28 ppm, villi structures, focal regions of necrosis, and mucosal epithelium all vanished. Karthigayani et al. (2014) reported intestinal tissue disintegration after administering cypermethrin to Oreochromis mossambicus.

Bais and Lokhande (2012) also recorded degenerative change of mucosal epithelium necrosis in the intestine of *O. striatus* challenged to cadmium chloride. Degeneration of glomerulus, lymphocytes infiltration, cytoplasmic vacuolation, necrosis and blood congestion in kidney tissues of *Cyprinus carpio* after exposure to Sodium cyanide (David and Kartheek, 2014). Other investigations on the histological effects of pesticides in varying organs of fish include that of Rani and Venkataramana, (2012) who determined the effects of Malathion to *Glossogobius giuris*. Banaee et al. (2013) on Diazinon to Rainbow trout (*Oncorhynchus mykiss*), Karthigayani et al. (2014) on the effect of cypermethrin on *O. mossambicus*, Ullah et al. (2014) on Cypermethrin to *Tor putitora*, Pandey and Dubey (2015) on pentachlorophenol (PCP) to catfish (*Heteropneustes fossilis*).

Conclusion and Recommendations

Heavy metal contamination is a threat to water quality and public health, and it is becoming a global issue. Contaminated soil in cities can endanger the health of urban inhabitants. The intake of polluted food and water puts communities nearby at risk of heavy metal contamination. The consumption of contaminated fish is the primary pathway for heavy metal contamination in the food chain, eventually reaching the human body. The continuing accumulation of water quality is attributed to urbanization and the constant emission of industrialized effluents. It is found that heavy metal contaminants cause enormous economic loss by killing fish and leaving them unfit for human consumption, indicating a threat to fish biodiversity. Various ecotoxicological studies have indicated the negative effects of toxins on fish, such as haematological and histological changes, as well as anti-oxidant enzyme activities, and it is therefore recommended that biodegradable commodities be used. Environmentally friendly insecticides should be used in agricultural production as well. It is imperative that proper monitoring of river water quality be carried out on a constant basis. Appropriate measures, such as legislative provisions and other tools for effective environmental monitoring, should be implemented and used to safeguard and improve water quality.

References

Akinrotimi, O.A., Orlu, E.E., Gabriel, U.U. (2013) Haematological Responses of Tilapia guineensis treated with industrial effluents. *Applied Ecology and Environmental Science*, 1(1):10-13.

Akinwande, A.A., Abdulkadiri, J.O. and Adesina, B.T. (2016). Oxidative Stress and Antioxidant Response in the Giant African Catfish (*Heterobranchus bidorsalis* Geoffroy SaintHilaire, 1809) under Chronic Paraquat Exposure.

Alaa, G. M. O. (2014). Genotoxicity Tests and Their Contributions in Aquatic Environmental Research. *Journal of Environmental Protection*, 5(1):1391-1399.

Ali, D and Kumar, S. (2012). Study on the effect of chlorpyrifos on acetylcholinesterase and hematological response in *Channa punctatus*. *Bloch*, 3(5): 12-18.

Ali, J and Rani, V.J. (2009). Effect of Phosalone on Haematological Indices in the Tilapia, (*Oreochromis mossambicus). Turkish Journal of Vetenary Animal science*.

Ali, S and Muhammad, K. (2016) Acute Toxicity of Herbicide (Glyphosate) in *Clarias gariepinus* (Juveniles). *Toxicology Reports*, 3(1): 513–515.

Al-Sarar, A. S., Abobakr, Y., Bayoumi, A. E., Hussein, H. I and Ghothemi, A. (2012). Reproductive toxicity and histopathological changes induced by lambda cyhalothrin in male mice. *Environ Toxicology*, 29(1): 750-759.

Ameur, W. B., Lapuente, J., El Megdiche, Y., Barhoumia, B., Trabelsi, S., Camps, L., Serret, J., Ramos-López, D., GonzalezLinares, J., Driss, M.R., Borràs, M. (2012). Oxidative stress, genotoxicity and histopathology biomarker responses in mullet (*Mugil cephalus*) and sea bass (*Dicentrarchus labrax*) liver from Bizerte Lagoon (Tunisia). *Mar Poll Bull*., 64(2):

Ani, L.C., Nwamba, H.O., Ejilibe, C.O. and Nwani, C. D. (2017). Acute toxicity of glyphosate-based herbicide glycot on Juvenile African catfish *Clarias gariepinus* (Burchell 1822).

Annett, R; Hamid, R. H and Alice, H. (2014). Impact of glyphosate and glyphosate-based herbicides on the freshwater environment. *Journal of Applied Toxicology*, 34(1):458-567.

Banaee, M., Sureda, A., Mirvagefei, A.R. and Ahmadi, K. (2013). Histopathological Alterations Induced by Diazinon in Rainbow trout (*Oncorhynchus mykiss*). *International Journal of Enviromental Research*, 7(3): 735-744.

Banjo, A.D, Aina, S.A and Rije, O.I. (2010). Farmers Knowledge and Perception Towards Herbicides and Pesticide usage in Fadama area of Okun-owa, Ogun State of Nigeria. *African Journal of Basic and Applied Sciences*, 2(5-6): 188944.

Banjo, A.D., Aina, S.A and Rije, O.I. (2010). Farmers knowledge and perception towards herbicides and pesticide usage in Fadama area of Okun-owa, Ogun State of Nigeria.

Erhunmwunse, N.O., Ogbeide, O.S., Tongo, I., Enuneku, A.A and Adebayo, P.O (2018) Acute Toxicity of Glyphosate-based Isopropylamine formulation to Juvenile African catfish (*Clarias gariepinus*). *Nigerian Journal of Basic and Applied Science*, 26(2): 97-101.

Etonihu, A. C.; Aminu, B. A.; Ambo, A. I.; Etonihu, K. I. (2011). Iodine content and pesticide residues of some Nigerian food grains. *Continental Journal of Agricultural Science*, 5(1):

Ezemonye, L.; Ikpetsu, T. and Tongo, I. (2009). Distribution of propoxurin in water, sediment and fish from Warri River, Niger Delta, Nigeria. *Turkish Journal of Biochemistry*, 34(3):

Ezemonye, L.I.N., Ikpesu, T O. and Ileshie, I. (2008). Distribution of Diazinon in Water, Sediment andFish from Warri River, Niger Deltal Nigeria. *Jordan Journal of Biological Sciences*, 1(2): 31 – 37.

Ezenwosu, S. U., Emmanuel, I. N., Gregory, E. Odo., Ogonna, C. A., Obiageli, C. E., Gladys, U. O and John, F. E. (2020). Lambda-Cyhalothrin induced hepato-nephro toxicity potentials and post treatment recovery in *Clarias garipinus*. *African Journal of Biochemistry Research*, 14(1):18-26.

Ezike, C. O; Felix, O. E; Nicholas, C. U and Godwin, E. O. (2019). Haematology, Oxidative Stress and Micronuclei Frequency of *Clarias gariepinus* Exposed to Glyphosate based Herbicide Glycot GBHG. *International Journal of Advanced Fisheries and Aquatic Science*, 4(1): 106-121.

Faheem, M and Lone, K. P. (2017). Oxidative stress and histopathologic biomarkers of exposure to bisphenol-A in the freshwater fish, (*Ctenopharyngodon idella*). *Brazilian Journal of Pharmeutical Sciences*, 53(3): 1-9.

FAO/WHO, (2018). Pesticide residues in food 201 8 Joint FAO/WHO Meeting on Pesticide Residues. Pp. 234-256.

FAO/WHO, (2018). Pesticide residues in food 201 8 Joint FAO/WHO Meeting on Pesticide Residues. Pp. 234-256.

Gabriel, U.U., Uedeme-Naa, B., Akinrotimi, O.A. (2011) Pollutant induced altered behaviours in fish: A review of selected literature. *J Technol Education Nigeria*, 16(1): 9-23.

George, A. D., Akinrotimi, O. A and Nwokoma UK. (2017). Haematological Changes in African Catfish (*Clarias gariepinus*) Exposed to Mixture of Atrazine and Metolachlor in the Laboratory. *Journal of FisheriesSciences.com*, 11(3):