1. INTRODUCTION

Water is abundant in the planet as a whole, but fresh potable water is not always available at the right time or the right place for human or ecosystem use and is, undoubtedly the most precious natural resource, vital to life (Karikari and Ansa, 2004; Ologbosere et al., 2016). Water Quality is one of the greatest issue of the world which is getting most exceedingly bad as the time is passing. Water quality is very much affected by the day to day activities of human being and also with industrial runoff. The most critical of the common impacts are topographical, hydrological and climatic, since these factor affect the water degradation level at most. Their impact is by and large most prominent when accessible water amounts are low and greatest use must be made of the restricted assets; for instance, high saltiness is an incessant issue in dry and waterfront territories (Shah, et al., 2016).

Aquatic degradation is mainly due to the discharge of organic and inorganic chemicals via anthropogenic activities. As a result, the water sources become unhealthy because of undesirable changes in physicochemical and biochemical conditions causing sudden and large scale mortality of fish population. The economically important fishes are highly affected by various pollutants including heavy metals. Therefore the fishes are often used as indicators of pollutants as they are the top aquatic food chain (Agah et al., 2009; Banu, 2016).
Pollution of fresh water bodies by industrial effluents leads to consequences like changes in colour, depletion of dissolved oxygen, pH imbalance, nutrient enrichment and eutrophication. Aquatic organisms inhabiting coastal waters are vulnerable to pollution load by chemicals because of the possibility of these chemicals to disseminate into drainage systems (Butler, 1966). The most harmful metallic pollutants are mercury, lead, zinc, cadmium and copper. The seriousness and persistence of heavy metals in water are compounded by the fact that they are generally water soluble, non-degradable, vigorous oxidizing agents and strongly bounded to many biochemicals especially polypeptides and proteins (Gurd and Wilcox, 1956).

The pollution of the environment with toxic substances has been increase in recent years as a result of the rapid growth of industries (Akpomie and Dawodu, 2015). Pollution of the aquatic environment is a serious and growing problem throughout the world. Increasing number of industrial, agricultural and commercial chemicals discharged into the aquatic environment have led to various deleterious effects on the aquatic organisms, including fish. Heavy metals contamination of aquatic ecosystem has attracted the attention of several investigators in both the developed and developing countries of the world (Olugbojo and Akinyemi, 2016).

Water pollution has a large set of adverse effects upon water bodies such as lakes, rivers, oceans, and underground water caused by human activities (James Salemcity et al., 2014). Water pollution
is the addition of something that changes its natural qualities (Coulson and Forbes, 1952). Polluted water becomes unsuitable for drinking purposes. If poisonous substances get dissolved in water it becomes unsuitable not only for aquatic life but also for agricultural operations. Rivers, lakes and ponds are used by people for bathing, washing clothes and even for drinking purposes (Kudesia, 1985).

Trace metal contamination is important due to its potential toxicity for the environment and human beings (Censi et al., 2006). The role of heavy and trace elements in the soil system is increasingly becoming an issue of global concern. Soil constitutes a crucial component of rural and urban environments and the sources of these contaminants in soil mainly include natural occurrence derived from parent materials and human activities (USDA, 2001). Anthropogenic inputs are associated with industrialization as atmospheric deposition, waste disposal, waste incineration, urban effluents, traffic emissions, fertilizer application and long-term application of wastewater in agricultural lands (Bilos et al., 2001; Koch and Rotard, 2001). Apart from the source of heavy metals, the physicochemical properties of soil also affect the concentration of heavy metals in soil (Nyamangara and Mzezewa, 1999; Roozbahani et al., 2015). All the toxicants and heavy metal present in the soil due to heavy rain it has reached nearby aquatic medium subsequently affect aquatic organisms.
Heavy metals are common pollutants of the aquatic environment because of their persistence and tendency to concentrate in aquatic organisms (Hoo et al., 2004; Srivastava and Verma, 2009). Most heavy metals released into the environment find their way into the aquatic system as a result of direct input, atmospheric deposition and erosion due to rainwater. Therefore, aquatic animals are often exposed to elevated levels of heavy metals (Hemlata and Neera, 2010).

Heavy metals are natural trace components of the aquatic environment, causing threat to the health of Indian ecosystem. High concentration of these metals is released into the aquatic environment as a result of leaching from bed rocks, atmospheric decomposition, water drainage, run off from river banks and discharge of urban and industrial waste waters (Rabee et al., 2011; Nazima and Bela, 2016).

Heavy metals are produced from a variety of natural and anthropogenic sources (Bauvais et al., 2015). In aquatic environments, heavy metal pollution results from direct atmospheric deposition, geologic weathering or through the discharge of agricultural, municipal, residential or industrial waste products, also via wastewater treatment plants (Damirak et al., 2006; Maier et al., 2015; Dhanakumar et al., 2015; Garcia et al., 2015).

Tanning industry contributes significantly towards exports, employment generation and occupies an important role in the Indian economy while on the other hand; tannery wastes are ranked
as the highest pollutants among all the industrial wastes (Soyaslan and Karaguzel, 2008). Damage to the environment by the hazardous tannery effluent is becoming an acute problem in India (Taju et al., 2012). Tanneries generally pollute the environment and intensive industrial complexes generating large volumes of high concentration of wastewater. These wastes have historically been discharged into rivers and waterways. Most of the objectionable components of tannery effluent were formerly discharged directly into the nearby river or any aquatic medium. Tannery effluents are ranked as the highest pollutants among all the industrial wastes. It is estimated that in India alone about 2000-3000 tones of chromium escapes into the environment annually from tannery industries, with chromium concentrations ranging between 2000 and 5000 mg/L in the aqueous effluent compared to the recommended permissible limits of 2 mg/L (Atlaf et al., 2008).

Tannery industries produce great amount of effluents from different nature, most of them are highly pollutants. When toxic substances accumulate in the environment and in food chains, they can greatly interrupt biological processes. Non essential heavy metals are usually potent toxins and their bioaccumulation in living tissues leads to intoxication, decreased fertility, cellular and tissue damage, cell death and dysfunction of variety of organs. The presence of toxic and polluting heavy metals from industrial effluents, discharges from mines and their removal have received much attention in recent years.
The amount of heavy metals in the industrial waste waters often contains considerable and would endanger the public health and the environment if discharged without adequate treatment. Chromium, a potential pollutant, is well known for its mutagenic (Cheng and Dixon, 1998) and carcinogenic (Shumilla et al., 1999) effects in humans, animals and plants. Extensive use of chromium in tanning industries had resulted in chromium contaminated soil and ground water at production sites which pose a serious threat to human health, fish and other aquatic biodiversity (Turick et al., 1996; Nisha et al., 2016).

Manufacturing of leather, leather goods, leather boards and for produces numerous byproducts, solid wastes, high amount of wastewater containing different loads of pollutants and emissions into the air. The uncontrolled release of tannery effluents to natural water bodies increases health risks for human beings and environmental pollution. Effluents from raw hide processing tanneries which produce wet blue, crust leather or finished leather contain compounds of trivalent chromium and sulphides in most cases (Groganzh, 2002). Chromium compounds are used for ferrochrome production, electroplating, pigment production and tanning. These industries, the burning of fossil fuels and waste incineration are sources of chromium in air and water. Most of the liquid effluent from the chromium industries is trapped and disposed of in landfills and sewage sludges, the chromium being in the form of the insoluble trivalent hydroxide. The untreated
effluent containing particulates of chromium from the tanneries are discharged into fresh water bodies and also affected the aquatic organisms. Chromium is one of the highly toxic heavy metal to aquatic fauna (Sreenivasan and Krishnamoorthy, 2011).

The discharge of untreated tannery effluents is a long-time problem in the leather industries (Huq, 1998; Rasul et al., 2006). The export of tanned leathers is increasing following a decline of leather production in the developed world due to more stringent environmental controls. The increased number of tanneries causing environmental hazards as the untreated effluent used in the tanning process is released into the water resources (Asaduzzaman et al., 2014).

Chromium (Cr) and lead (Pb) are two of the many toxic metals in our environment. Chromium is used in chrome plating, pigments, tanning of animal skins, dyes and wood preservatives with a million ton being released to the environment annually. Wood preservative chromated-copper-arsenate (CCA) releases both chromium and arsenic to the environment. CCA readily leaches from wood; leading to the wide spread soil contamination by arsenic and chromium. The deleterious effects of CCA on public health have been well documented. In soil environment, arsenic and chromium predominantly exist as inorganic oxyanions. In soils, their mobility is heavily influenced by soil property. Arsenic V and Chromium III are less soluble and
more stable in the environment whereas arsenite (Arsenic III) and Chromium VI are highly soluble and mobile in the environment (Maria de Olivrira et al., 2014).

Chromium (VI) is one of the most hazardous pollutants released from industries like textile dyeing, chemicals and pigment production, wood preservation, tanning and electroplating (Agarwal et al., 2006). Chromium exists in several oxidation states ranging from -2 to +6, among which chromium (IV) and chromium (III) are the most significant because of their persistence and stability. Chromium (VI) finds its place in the priority list prepared by the Agency of Toxic Substances and Diseases Registry (ATSDR). Chromium compounds can lead to mutation and cancer, and inhibit enzymes and nucleic acid synthesis. In contrast, chromium (III) is less toxic and less mobile (Chaturvedi, 2011; Basu et al., 2014).

Chromium has found extensive use in tanning industry mainly because of the good quality of leather obtained. Wastewaters containing chromium are discharged into the environment, they pose a serious problem to the quality of the water. Removal of chromium from wastewaters is obligatory in order to avoid water pollution. Legislation by different governments, demands the concentration of chromium in discharges to be less than 0.05 mg L\(^{-1}\) irrespective of its oxidation state (Bishnoi et al., 2007). This has lead to the removal of
chromium from wastewaters before discharge. However the current methods being employed such as chemical precipitation are not feasible to reduce the concentration to the desired levels of 0.05 mg L$^{-1}$ chromium (Onyancha et al., 2008). Chromium exists primarily in Cr (III) and Cr (VI) oxidation states; the later, hexavalent species, being considered as more toxic in the environment due to its higher solubility and mobility. These species are known to be associated with a spectrum of DNA lesions occurring during Cr (VI) exposure (Reynolds et al., 2004). Teratogenic effects of Cr$^{6+}$ are more severe than Cr$^{3+}$. Cr$^{6+}$ is highly soluble and about 300 times more toxic than Cr$^{3+}$. On the other hand, Cr$^{3+}$ precipitates at the average pH of natural waters (Rehman et al., 2008).

Fishes are used as an excellent indicator of aquatic pollution due to their high sensitivity to environmental contaminants which may damage certain physiological and biochemical processes when contact with the organs of fishes (Puvaneswari and Jiyavudeen, 2015). Fish is widely consumed in many parts of the world because it has high protein content, low saturated fat and also contains omega fatty acids known to support good health (Ikem and Egiebor, 2005). Fish are constantly exposed to chemicals in polluted and contaminated waters. Fish have been found to be good indicators of heavy metal contamination in aquatic systems because they occupy different trophic levels and are of different sizes and ages (Burger et al., 2002; Tuzen and Soylak, 2007). Heavy metals are the most noxious pollutants
owing to their diverse effects. Some metals are soluble in water and readily absorbed into the living organisms. Metal ions of high toxicity are known to cause deleterious impact on organs and blood level in fish (Akahori et al., 1999; Karan et al., 1998; Vinodhini and Narayanan, 2008).

The gills are efficient tools for biomonitoring potential impacts (Ribeiro et al., 2005), because of their large surface area in contact with water and high permeability and plays a vital role in ionic regulation and gas exchange (Evans et al., 2005). Liver is a target organ and primary site of detoxification and is generally the major site of intense metabolism and is therefore prone to various disorders as a consequence of exposure to the toxins of extrinsic as well as intrinsic forms. Liver plays important role in metabolism to maintain energy level and structural stability of the body (Paliwal et al., 2009; Gaim et al., 2015). The liver primarily functions in the detoxification of metabolic products including wastes and toxicants in the environment (Joycelyn et al., 2010).

The kidney, together with the gills and intestine, are responsible for excretion and the maintenance of the homeostasis of the body fluids (Hinton et al., 1992; Evans, 1993) and, besides producing urine, act as an excretory route for the metabolites of a variety of xenobiotics to which the fish may be exposed (Hinton et al., 1992). Since a large volume of blood flows through the kidney, lesions found in this organ can be useful as signs of environmental pollution (Hinton and Lauren, 1990; Silva and Martinez, 2007).
The brain is highly vulnerable to oxidative stress due to its high metabolic rate, the reduced capacity for cellular regeneration, and numerous cellular oxidative stress targets like lipids, nucleic acids, and proteins. Generally, most molecules cannot cross the blood–brain barrier (BBB). But, due to large surface area, the NPs made of certain materials and with varying particle sizes can overcome this physical barrier and enter into the brain (Palaniappan and Pramod, 2011). Muscle rich in proteins, forms mechanical tissue intended for mobility and do not participate in metabolism (Sobha et al., 2007).

Biochemical parameters represent fine tools for evaluating the effects of contaminants and for environmental monitoring (Ahmad et al., 2004). The role of biochemical techniques to provide intimation an early warning of potentially damaging tissues and organs of stressed fish. In toxicological studies of acute exposure, changes in concentrations and enzymes activities often directly reflect cell damage in specific organs. Proteins are important organic constituent required for tissue binding, repair and under extreme conditions provide metabolic energy to meet the stress condition. The protein loss in tissues is probably to combat with the metabolic stress due to heavy metal exposure and may be due to cellular injury (Fatima et al., 2015).

Glycogen, a large and branched polymer of glucose, is the storage form of carbohydrate for virtually every organism from yeast to primates. The major glycogen stores in mammalian vertebrates exist
in liver and muscle, smaller amounts of glycogen being present in kidney, intestine and several other tissues. Classically, it is thought that the glycogen stored in liver, kidney and intestine can be made accessible to other organs by virtue of their possession of an enzyme glucose 6-phosphatase (Vornanen et al., 2011).

Lipids is a heterogeneous group of compounds having several important functions in the body such as being an efficient source of energy, constituents in cell membranes and nerve tissues, thermal and electrical insulators and acting as local hormones etc. (Murray et al., 2000; Hossam and Heba, 2013).

Enzymes are biochemical macromolecules that control metabolic processes of organisms, thus a slight variation in enzyme activities would affect the organism (Humtsoe et al., 2007). Common environmental contaminates such as metals pose serious risks to biochemical parameters and enzyme activities of fish (Gaim et al., 2015).

The acid phosphatase and alkaline phosphatise are plasma membrane derived enzymes which play a pivotal role in the cytolysis and differentiation process (Davidson, 1949). They are present in almost all the tissues like liver, spleen, kidney, and reticulo endothelial cells and catalyse the liberation of inorganic phosphate from organic phosphate esters and help in maintaining buffer system in blood creating phosphate buffer system (Harper, 1990).
In fishes affected by toxicants the amino transferase enzyme activity is increased or decreased depending upon the tissues and time of exposure. Transaminase enzymes are relatively non-specific, with groups of amino acids with similar R groups (for example, the aromatic amino acids or the branched-chain amino acids). The equilibrium constant of a transaminase reaction is usually very close to one, reflecting the similarity in the free energies of the formation of ketoacids from amino acids. Transamination is much common than deamination in nature, since the deamination without a subsequent transfer to the amino group to another keto acid renders to coenzymes inactive. Most transaminase reactions involved aspartate or glutamate as one partner, with alanine also being rather common. Metabolic pathway mainly depending on enzyme activities may be affected due to the destruction under stress reflecting in the changes of enzyme activities (Ganguly et al., 1997).

The transaminases function at the junction between the carbohydrate and protein metabolism by inter converting the strategic compounds *viz.*, ketoglutarate, pyruvate and oxaloacetate on one hand and alanine, aspartate and glutamate on the other hand. A close relationship exists between the mitochondrial intensity and transamination levels and any modification in the organization of mitochondria might alter the enzyme associated with it. ALT and AST are enzymes frequently used in the diagnosis of damage caused by pollutants in various tissues such as liver, muscle and gills (De la Torre et al., 2000).
Antioxidant enzymes SOD, CAT and GPX are considered the first line of antioxidant defense and served as sensitive biomarkers of oxidative stress (Jiang et al., 2009). SOD is considered the first enzyme responsible for scavenging ROS and protecting cells from damage by free radicals process (Chien et al., 2003; El-Gawad et al., 2016). Malondialdehyde (MDA) is formed as an end product of lipid peroxidation, which is the initial step of cellular membrane damage caused by reactive oxygen species (ROS) (Pascual et al., 2003; El-Gawad et al., 2016).

Many pollutants can induce the formation of reactive oxygen species (ROS) such as hydrogen peroxide (H$_2$O$_2$), superoxide anion (O$_2^-$) and hydroxyl radical (·OH). Due to their high reactivity, these species may damage lipids, proteins, carbohydrates and nucleic acids (Ahmad et al., 2000; Modesto and Martinez, 2010). To neutralize ROS, animals have an antioxidant defense pathway constituted of antioxidant enzymes such as superoxide dismutase (Cu-Zn SOD), catalase (CAT) and glutathione peroxidase (Se-GPx), as well as non-enzymatic antioxidants such as glutathione (GSH). When the animal’s defenses are insufficient to neutralize ROS, oxidative damage may occur, and one of the most serious damages is membrane lipid peroxidation (Scandalios, 2005).
Oxidative stress is the primary cause of lipid peroxidation (Sarkar et al., 1998; Stohs et al., 2000) and alterations in membrane fluidity (Bagchi et al., 2000). Resistance development is related to increased activities of antioxidant enzymes, which are important in the protection against cadmium damage, inhibiting lipid peroxide formation (Almeida et al., 2002). Enhancement of TBARS is considered to be the indicator of the onset of oxidative stress from reduced species of molecular oxygen including hydrogen peroxide, superoxide radical and reactive hydrogen radical (Amalakumar et al., 2002). Lipid peroxidation is viewed as a complicated biochemical reaction involving free radicals, oxygen, metal ions and a host of other factors in the biological system (Jadhave et al., 1996). Lipid peroxidation has been used as a measure of xenobiotics induced oxidative stress which is originally defined as the equilibrium between peroxidants and antioxidants biological systems. Once this imbalance appears, cellular macromolecules may be damaged by the predominant free radicals. Lipid peroxidation is reported to increase on exposure to various xenobiotics (Kelly et al., 1998), thus becoming the important and necessary consequence of oxidative stress and it is involved in the pathophysiology of number of diseases and other natural degenerative conditions. The role of oxygen derived species in causing cell injury or death is increasingly recognized. Superoxide and hydroxyl radicals are involved in a large number of degenerative changes often associated with an increase in peroxidative processes and linked to low antioxidant concentration (Romero et al., 1998; Tamagno et al., 1998).
Acetylcholinesterase (AChE) is the main cholinesterasic form in all invertebrate and vertebrate tissues such as the brain (Rodrigues et al. 2011), muscles, blood cells and liver (Valbonesi et al. 2011). Acetylcholinesterase enzyme is found at neuromuscular junctions and cholinergic nervous system where its activity serves to terminate synaptic transmission. It degrades (through its hydrolytic activity) the neurotransmitter acetylcholine, producing choline and an acetate group in both vertebrates and invertebrates (Varo, et al. 2008; Rakhi, et al., 2013).

Water born metals may alter the physiological and biochemical parameters in fish blood and tissues. The reaction and survival of aquatic animals depend not only on the biological state of the animals but also on the toxicity and time of exposure to the toxicant (Brungs, 1977). Hematological and biochemical profile in fish is proved to be a sensitive index for the evaluation of fish metabolism under metallic stress (Vinodhini and Narayanan, 2009). Hematological parameters that are used in veterinary and clinical medicines have been established as health indicators (Schutt et al., 1997). Quantity and quality of leucocyte cells, which are hematologic parameters are generally used to determine immune reactions and disease. Moreover, changes in leucocytes also occur when fish are stressed and environmental quality is altered (Tierney et al., 2004; Ponsen et al., 2009).

The use of hematological parameters as fish health indicators has been proposed by Hesser (1960). Hematology is used as an index of fish health status in a number of fish species to detect physiological
changes following different stress conditions like exposure to pollutants, diseases, metals, hypoxia, etc. (Blaxhall, 1972; Duthie and Tort, 1985). Therefore, hematological techniques are the most common method to determine the sub-lethal effects of the pollutants (Larsson et al., 1985; Alwan et al., 2009).

Haematological techniques are the most common method to determine the sub-lethal effects of the pollutants (Larsson et al., 1985). Thus, blood parameters such as RBC (Red Blood Cells), HGB (Haemoglobin), HCT (Haematocrit), MCV (Mean Cellular Volume), MCH (Mean Cellular Haemoglobin Concentration), trombocytes are the most common criteria used in the toxicity studies on fish. As an indicator of pollution, blood parameters are used in order to diagnose and describe the general health condition of some fish. Besides, this type of index reflects certain ecological changes in the environment (Roche and Boge, 1996; Selma and Hatice, 2004).

Histopathological assessment is a sensitive biomonitoring tool in toxicant impact assessment to indicate the effect of toxicants on fish health in polluted aquatic ecosystems. Histopathological assessment of fish tissue allows for early warning signs of disease and detection of long-term injury in cells, tissues, or organs. Structural changes in various tissues into the polluted ecosystem have also been acknowledged (Peuranen et al., 2000; Marchand et al., 2009).
The scanning electron microscope (SEM) uses a focused beam of high-energy electrons to generate a variety of signals at the surface of solid specimens. The signals that derive from electron-sample interactions reveal information about the sample including external morphology (texture), chemical composition, and crystalline structure and orientation of materials making up the sample. In most applications, data are collected over a selected area of the surface of the sample, and a 2-dimensional image is generated that displays spatial variations in these properties. Areas ranging from approximately 1 cm to 5 microns in width can be imaged in a scanning mode using conventional SEM techniques (magnification ranging from 20X to approximately 30,000X, spatial resolution of 50 to 100 nm). The SEM is also capable of performing analyses of selected point locations on the sample; this approach is especially useful in qualitatively or semi-quantitatively determining chemical compositions, crystalline structure, and crystal orientations. The design and function of the SEM is very similar to the electron probe micro analyzer and considerable overlap in capabilities exists between the two instruments (Egerton, 2005).

Transmission electron microscopy (TEM) has become a powerful tool for characterizing the structure of materials, both inorganic and organic. With inorganic solids, the characterization of interfaces or of defects at the atomic level has become almost routine. With organic materials, this often remains an elusive goal because the
radiation sensitivity of these materials limits their tolerable electron dose, which, in turn, results in a poor signal-to-noise ratio (SNR) and, thereby, limits resolution. With biological materials, an additional complication arises from the need to keep them in a hydrated state to ensure structural preservation (Kourkoutis et al., 2012).

Fish is generally appreciated as one of the healthiest and cheapest source of protein and it has amino acid compositions that are higher in cysteine than most other sources of protein (Ebrahimi and Taherianfard, 2011). *Channa striatus* is a commonly available freshwater fish found in India. It is an edible freshwater fish of great importance. Hence, it is prudent to study the effect of sublethal concentrations of heavy metal, chromium on protein, amino acid, glycogen, lipids, phosphatases, transaminases, antioxidants, lipid peroxidation, acetylcholine esterase, haematological parameters, histopathological, scanning and transmission electron microscopical studies in gill, liver, kidney, brain and muscle of freshwater fish *Channa striatus*.

The survey of literature indicates that the toxicity studies have been extensively carried out in a number of fishes using a wide range of heavy metals. Distribution of heavy metals in water, sediments and fish tissue (*Heteropneustis fossilis*) in kali river (Maurya and Malik, 2016), bioaccumulation of trace metals in tissues of rohu fish for environmental risk assessment (Nazima and Bela, 2016),
use of fish as bio-indicator of the effects of heavy metals pollution (Authman et al., 2015), metabolic and antioxidant enzymatic activities in gill, liver and plasma of *Catla catla* during methyl parathion exposure (Abhijith et al., 2016), enhancement of antioxidant activity, non-specific immunity and growth performance of nile tilapia, *Oreochromis niloticus* by dietary fructooligosaccharide (El-Gawad et al., 2016), evaluation of antioxidant defence system during xenobiotic induced oxidative stress in freshwater fish *Oreochromis mossambicus* (Guptha et al., 2016), effects of chromium (VI) on the lipid peroxidation and antioxidant parameters in the gill and kidney tissues of catfish, *Clarias batrachus* (Madhavan and Elumalai, 2016), genotoxic and haematological biomarkers as an evidence of environmental contamination (Corredor-Santamaría et al., 2016), effect of clove extract pretreatment and drying conditions on lipid oxidation and sensory discrimination of dried omena (*Rastrineobola argentea*) fish (Slavin et al., 2016), histopathology biomarker responses in Asian sea bass, *Lates calcarifer* (Bloch) exposed to copper (Maharajan et al., 2016), scanning electron microscopy and Edax study of scales of genus *Puntius* (Thakur et al., 2016), scanning electron microscopic study of erythrocyte of *Heteropneustes fossilis* exposed to cadmium and copper (Paul and Ramanujam, 2016), effects of some heavy metals in different organs and some hepatic enzymes for European eel (*Anguilla anguilla*) (Mazrouh, 2016), heavy metal pollution, sources, toxic effects and techniques adopted for control (Ahmad et al., 2016), bioaccumulation
of trace metals in tissues of rohu fish for environmental risk assessment (Nazima and Bela, 2016), response of acid and alkaline phosphatase activities to copper exposure and recovery in freshwater fish *Carassius auratus gibelio var* (Jiang *et al.*, 2012), isolation, purification and characterization of acid phosphatase from *Scenedesmus obliquus* (Patil *et al.*, 2016), variations in acid phosphatase and alkaline phosphatase activities in liver and kidney of a fresh water fish *Labeo rohita* exposed to heavy metal concentrations (Mir *et al.*, 2016), novel alkaline phosphatase enzyme in acute lymphoblastic leukemia patients' serum (Aberomand *et al.*, 2016), effect of cadmium and lead exposure on tissue specific antioxidant response in *Spodoptera litura* (Suganya *et al.*, 2016), immunomodulatory effects of supercritical fluid CO extracts from freeze-dried powder of *Tenebrio molitor* larvae (yellow mealworm), (QingFeng and Yin, 2016), toxic effect of arsenic trioxide on biochemical response in freshwater fish *Cirrhinus mirgala* (Babu and Jothi Narendiran, 2016), the toxicity effect of detergent on enzymatic and protein activities of african mud catfish (*Clarias gariepinus*) (Nkpondion *et al.*, 2016), cadmium toxicity on biochemical constituents in the liver of fresh water fish *Cyprinus carpio* (Linn.) (Paritha Bhanu and Deepak, 2015).

Combined toxicological effects of pesticides: A fish multi-biomarker approach (Bacchetta *et al.*, 2014), development and characterization of a new gill cell line from air breathing fish *Channa striatus*
and its application in toxicology: Direct comparison to the acute fish toxicity (Abdul Majeed et al., 2014), the role of metallothionein and selenium in metal detoxification in the liver of deep-sea fish from the NW Mediterranean Sea (Siscar et al., 2014). Integrated reduction/oxidation reactions and sorption processes for Cr (VI) removal from aqueous solutions using Laminaria digitata macro-algae (Dittert et al., 2014), some physicochemical properties of sage (Salvia macrosiphon) seed gum (Ali Razavi et al., 2014), acute toxicity by water containing hexavalent or trivalent chromium in native Brazilian fish, Piaractus mesopotamicus: Anatomopathological alterations and mortality (Castro et al., 2014).

Effects of chromium on histological alterations of gill, liver, kidney of freshwater Teleost, Cyprinus carpio (Parvathi et al., 2011), histological and biochemical studies on some organs of two fish species (Gaber et al., 2014), heavy metals concentration in fish Mugil cephalus from Machilipatnam coast and possible health risks to fish consumers (Krishna et al., 2014), assessment of persistent organic pollutants accumulation and lipid peroxidation in two reproductive stages of wild silverside (Odontesthes bonariensis) (Silva Barni et al., 2014), the interrenal gland in males of the cichlid fish Cichlasoma dimerus: Relationship with stress and the establishment of social hierarchies (Morandini et al., 2014).

Concentrations of prioritized pharmaceuticals in effluents from fifty large wastewater treatment plants in the US and implications for risk estimation (Kostich et al., 2014), effects of arsenate, chromate,

Efficiency of combined ceramic microfiltration and biosorbent based treatment of high organic loading composite wastewater: An approach for agricultural reuse (Bhattacharya *et al.*, 2013), Preparation and characterization of nano chitosan for the treatment of wastewaters (Sivakami *et al.*, 2013), removal of hexavalent chromium ions by *Yarrowia lipolytica* cells modified with phyto-inspired FeO/Fe₃O₄ nanoparticles (Rao *et al.*, 2013), antioxidant response, CYP450 system, and histopathological changes in the liver of nitrobenzene-treated drakes (Xing *et al.*, 2013), potential use of novel modified fishbone for anchoring hazardous metal ions from their solutions (Zayeda, 2013), mutual promotion mechanism for adsorption of coexisting Cr(III) and Cr(VI) onto titanate nanotubes (Liu *et al.*, 2013), comparative study of sorption kinetics and equilibrium of chromium(VI) on charcoals prepared
from different low-cost materials (Varga et al., 2013), adsorption and desorption characteristics of imidazole-modifiedsilica for chromium(VI) (Wang et al., 2013), effect of heavy metals on the histopathology of gills and brain of fresh water fish Catla catla (Jagannath Bose et al., 2013),

Mechanisms of kidney toxicity for chromium-and arsenic-based preservatives: Potential involvement of a pro-oxidative pathway (Matos et al., 2013), antidotal impact of extra virgin olive oil against genotoxicity, cytotoxicity and immunotoxicity induced by hexavalent chromium (Khalil et al., 2013), morphological and histological studies on freshwater prawn Macrobrachium rosenbergii irradiated with $^{60}$Co gamma radiation (Stalina et al., 2013), gill histopathological and oxidative stress evaluation in native fish captured in Portuguese northwestern rivers (Pereira et al., 2013), accumulation, histopathological effects and response of biochemical markers in the spleens and head kidneys of common carp exposed to atrazine and chlorpyrifos (Wang et al., 2013), inhibition of carbon steel corrosion in CO$_2$-saturated brine using some newly surfactants based on palm oil: Experimental and theoretical investigations (Abd El-Lateef et al., 2013), in vitro interceptive and reparative effects of myo-inositol against copper-induced oxidative damage and antioxidant system disturbance in primary cultured fish enterocytes (Jiang et al., 2013), the relationship of cytotoxic and genotoxic damage with blood aluminum levels and oxidative stress induced by this metal in common carp (Cyprinus carpio) erythrocytes
(Medina et al., 2013), antioxidant activity of Cod (*Gadus morhua*) protein hydrolysates: *In vitro* assays and evaluation in 5% fish oil-in-water emulsion (Sabeena Farvin et al., 2014).

Chromium(VI) reactions of polysaccharide biopolymers (Chi Lin and Li Wang, 2012), transmission electron microscopic study of renal haemopoietic tissues of *Channa punctatus* (Bloch) experimentally infected with two species of aeromonads (Rajarshi and Sumit, 2012), rapid removal of chromium from aqueous solution using novel prawn shell activated carbon (Arulkumar et al., 2012), spectroscopic study for understanding the speciation of chromium on palm shell based adsorbents and their application for the remediation of chrome plating effluents (Kushwaha et al., 2012), chromate reduction on humic acid derived from a peat soil – Exploration of the activated sites on HAs for chromate removal (Huang et al., 2012).

Cadmium-induced oxidative stress and histological damage in the myocardium, determination of hypoxia and dietary copper mediated sub-lethal toxicity in carp, *Cyprinus carpio*, at different levels of biological organisation (Mustafa et al., 2012), Biotreatment of Cr(VI) contaminated waters by sulphate reducing bacteria fed with ethanol (Pagnanelli et al., 2012), long-term exposure to hexavalent chromium inhibits expression of tumor suppressor genes in cultured cells and in mice (Fan et al., 2012), removal of hexavalent chromium by heat inactivated fungal biomass of *Termitomyces clypeatus*: Surface characterization
and mechanism of biosorption (Ramrakhiani et al., 2011), biosorptive uptake of Cr(VI) from aqueous solutions by *Parthenium hysterophorus* weed: Equilibrium, kinetics and thermodynamic studies (Venugopal and Mohanty, 2011), selective transport and removal of Cr(VI) through polymer inclusion membrane containing 5-(4-phenoxyphenyl)-6H-1,3,4-thiadiazin-2-amine as a carrier (Saf et al., 2011), the effects of heavy metals exposure on reproductive systems of cyprinid fish from kor river (Ebrahimi and Taherianfard, 2011), assessment of heavy metal pollution in tigis river sediment (Rabee et al., 2011), developmental and reproductive characteristics of western mosquitofish (*Gambusia affinis*) exposed to paper mill effluent (Hou et al., 2011), organic–inorganic hybrid of chitosan/organoclay bionanocomposites for hexavalent chromium uptake (Pandey and Mishra, 2011).

Biosorption of chromium (VI) by coconut coir: Spectroscopic investigation on the reaction mechanism of chromium (VI) with lignocellulosic material (Shen et al., 2010), cytotoxicity of chromium ions connected with induction of oxidative stress (Vasylkiv et al., 2010), a simple but accurate method for histological reconstruction of the large-sized brain tissue of the human that is applicable to construction of digitized brain database (Fukuda et al., 2010), nephroprotective action of tocotrienol-rich fraction (TRF) from palm oil against potassium dichromate (K₂Cr₂O₇) induced acute renal injury in rats (Rashid Khan et al., 2010).

Application of Brazilian-pine fruit coat as a biosorbent to removal of Cr(VI) from aqueous solution-Kinetics and equilibrium study (Vaghetti *et al.*, 2008), acute toxicity impacts of hexavalent chromium on behavior and histopathology of gill, kidney and liver of the freshwater fish, *Channa punctatus* (Bloch) (Mishra and Mohanty, 2008), a new route to synthesis of sulphonato-salen-chromium(III) hydrotalcites: highly selective catalysts for oxidation of benzyl alcohol to benzaldehyde (Wu *et al.*, 2008).

Enzymatic responses to metal exposures in a freshwater fish *Oreochromis niloticus* (Atli and Canli, 2007), long-term safety evaluation of a novel oxygen-coordinated niacin-bound chromium(III) complex (Shara *et al.*, 2007), a role for transforming growth factor-β apoptotic signaling pathway in liver injury induced by ingestion of
water contaminated with high levels of Cr(VI) (Rafael et al., 2007),
determination of metals in fish and mussel species by inductively coupled
plasma atomic emission spectrometry (Turkmen and Ciminli, 2007),
detection of micronucleus and abnormal nucleus in erythrocytes from
the gill and kidney of *Labeo bata* cultivated in sewage-fed fish farms
(Talapatra and Banerjee, 2007), responses of metallothionein and
reduced glutathione in a freshwater fish *Oreochromis niloticus* on
metal exposures (Atli and Canli, 2008), biochemical, physiological and
histological changes in the neotropical fish *Prochilodus lineatus* exposed
to diesel oil (Simonato et al., 2008), effect of clomazone herbicide on
biochemical and histological aspects of silver catfish (*Rhamdia quelen*)
and recovery pattern (Crestani et al., 2007), determination and comparison
of heavy metals in selected seafood, water, vegetation and sediments
by inductively coupled plasma optical emission spectrometry from
an industrialized and pristine waterway in Southwest Louisiana
(Hamilton et al., 2008), histopathology of lambda-cyhalothrin
on tissues (gill, kidney, liver and intestine) of *Cirrhinus mrigala*
(Velmurugan et al., 2007), reproductive toxicity of chromium in adult
bonnet monkeys (*Macaca radiata* Geoffrey), reversible oxidative stress
in the semen (Subramanian et al., 2006), safety and toxicological evaluation
of a novel niacin-bound chromium(III) complex (Shara et al., 2005),
multiple biomarker response in rainbow trout during exposure to
hexavalent chromium (Roberts and Oris, 2004),
The fish *Channa striatus* is chosen for the present study for the following reasons:

1. *Channa striatus* is a commonly available freshwater fish.

2. It is an edible freshwater fish of great economic importance.

3. It is one among the freshwater organisms exposed to heavy meals.

The chromium is selected for the present study for the following reasons:

1. Chromium is one of the most dangerous occupational, industrial and environmental toxins.

2. It is found in drinking water, atmospheric air and even in food.

3. Chromium is an essential element in the trivalent form of less concentration for metabolic activity but the concentration is increased act as a non-beneficial element, because of its high toxicity, non-biodegradable and persistent in nature.

4. The mobility of chromium in the aquatic ecosystem is influenced by various organic and inorganic complexing agents.

5. Chromium is a toxic metal that interact metabolically with nutritionally essential metals.

6. Chromium causes significant metabolic alterations and injuries of biological systems at different levels.

7. It has high potential to accumulate in tissue through food chain and directly through water in man, mammals as well as in aquatic organisms including fish.
The present study was designed with the following objectives.

1. To find out the sublethal concentration of chromium for 30 days.

2. To study the changes in protein, amino acid, glycogen and lipid levels in gill, liver, kidney, brain and muscle of the fish *Channa striatus* exposed to sublethal concentrations of chromium for 10, 20 and 30 days.

3. To estimate transaminases and phosphatases activities in gill, liver, kidney, brain and muscle of the fish *Channa striatus* exposed to sublethal concentrations of chromium for 10, 20 and 30 days.

4. To estimate enzymatic (SOD and CAT), non-enzymatic (GSH) activities and lipid peroxidation levels in gill, liver, kidney, brain and muscle of the fish *Channa striatus* exposed to sublethal concentrations of chromium for 10, 20 and 30 days.

5. To estimate acetylcholine esterase and acetylcholine activity in brain of the fish *Channa striatus* exposed to sublethal concentrations of chromium for 10, 20 and 30 days.

6. To examine the haematological parameters in blood of the fish *Channa striatus* exposed to sublethal concentrations of chromium for 10, 20 and 30 days.

7. To examine histopathological alterations in gill, liver, kidney, brain and muscle of the fish *Channa striatus* exposed to sublethal concentrations of chromium for 10, 20 and 30 days.

8. To examine scanning and transmission electron microscopical changes in gill, liver, kidney, brain and muscle of the fish *Channa striatus* exposed to high sublethal concentration of chromium for 30 days.