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Cadmium Toxicity Accompanies Economic Loss to the Fish Farmers: A Review

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Abstract: **One of the greatest problems on the earth is pollution of Potentially Toxic Elements'. Discharges of improperly treated industrial wastewater comprises of Potentially Toxic Elements'. The existence of Potentially Toxic Elements in water is considered as a threat to the fish population because they accumulated heavy metals. Cadmium is a common Potentially Toxic Elements' having the potential for bioaccumulation. Cadmium metal in the form of particulate matters is released into the water body from various sources and settles down as sediments, which becomes important metal sink in an aquatic environment. When this sediment bound pollutants are taken by the aquatic organism, Cadmium enters into the food chains. This heavy metal is accumulated and biomagnified by aquatic organisms and transferred from the lower strata to the higher strata. Fish possess the potential properties of biomagnification and act as a bioaccumulator. When water is cadmium heavy metal polluted, Cadmium causes liver, intestine, kidney, nerve and brain damage in the fish, including hematological disorder, structural and pathomorphological alterations in various fish organs. Thus, such carcinogenic and toxic effect of Cadmium affects the fish population and results in economic loss to the fish farmers**

Keywords: **potentially toxic elements' pollution, bioaccumulation, biomagnification.**

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1. Introduction

Potentially toxic elements' (PTEs) pollution is one of the greatest problems in our world now-a-days. Due to industrialization and modernization an increase in pollution containing PTEs is observed.

Millions of tons of vastly contaminating effluents comprising PTEs are discharged into the aquatic bodies by various industries such as metal cleaning, electroplating, glass, battery manufacturing, tanning, textile, pickling and refining. Discharges of poorly treated industrial wastewater comprised of PTEs have cited serious ecological concerns. A number of studies included how growing population, industrialization and excessive use of natural sources generate water pollution problem and revealed that the rivers are the main victim of such pollution (Tiku et al., 2007; Kumar et al., 2009; Sharma, D., and Kansal, A., 2011).

The existence of PTEs in water is considered as a threat to human beings as heavy metals enters the food chain very easily. Cadmium (Cd) is harmful, toxic, heavy metal common PTEs and its compounds are environmental toxicants. They have the potential for bioaccumulation in the body (Wuetal.,2016) due to their high mobility and persistence (Wang, M., et al.,2024; Khan et al., 2020; Kula et al., 2008; Mohan et al., 2007;). They cause liver damage, lungs damage, renal damage, hypertension and anemia along with itai-itai disease when present in water above its 'permissible level' (Zhang and Reynolds, 2019; Kasuya, 2000; Bodek et al., 1998). In aquatic system, Cd is most readily absorbed by organisms directly from the water in its free ionic form (Perera et al., 2015) so aquatic organisms such as fish and amphibians are affected tremendously by wastewater. Fish is the source of many important nutrients but can accumulate heavy metals in their tissues (El- Moselhy et al., 2014). Several studies documented the toxicity of Cd in different fishes (Tian et al., 2020; Sundaresan, 2019). Interestingly, fish is positioned at the top level in a food pyramid of an aquatic ecosystem. Toxicity impacts on the behavioural parameters of fish and cause structural and pathomorphological alterations in the organs (Thophon et al., 2003). Therefore, fishes are considered as biomarkers in aquatic toxicity (Eissa et al., 2009). So, the effects of Cd in the fish body not only results in a decrease in their population but also lowers the quality of the meat. This review paper will describe the effect of cadmium toxicity in the different fish body.

2. Effect of Cadmium (Cd) toxicity on organism

An organism's consciousness comes from the environment. The 'Environment' word is derived from the French word 'Environer' which means 'to surround'. Hence environment is surroundings in which biotic and abiotic components are exist together. Biotic components are living things which have live. Examples of biotic components are man, animals, plants, microorganisms etc. Abiotic components are non-living things, they do not have life i.e. water, soil, sunlight, salinity, nutrient, precipitation etc. In the environment, biotic components live in Biosphere where they use all the resources of nature and work together. Biosphere, Atmosphere (air), Hydrosphere (water) and Lithosphere (soil) are the segments of earth. In earth-system, biogeochemical cycles help to regulate earth's climate and maintain a chemical balance, whereas homeostasis in nature maintains a balance in the ecosystem. Fast growing industrialization and urbanization increase anthropogenic activities which carelessly exploit earth's natural resources and increase environmental pollution. Natural resources are those resources which are provided by nature, have scientific interest, industrial and commercial use and also aesthetic and cultural values. Pollution is the introduction of harmful substances in our environment and is the universal problem created by organic pollutants, inorganic pollutants, gaseous pollutants, radioactive isotopes, organometallic compounds and heavy metals. Heavy metals are the metals, lanthanides, actinides and metalloids (elements having both non-metal and metal characteristic) whose atomic density is higher than 4000 kg/m3and relative atomic mass should be greater than 40. Example of heavy metals are cadmium (Cd), lead(Pb), mercury(Hg), zinc(Zn), arsenic(As), chromium(Cr), silver(Ag), iron(Fe), copper (Cu) and platinum(Pt) group elements (Duruibe ,J.O., et al.,2007; Nachana'a Timothy and Ezekiel Tagui Williams, 2019; Briffa, J., Sinagra, E., & Blundell, R., 2020). Potentially toxic metals are the important pollutants due to their toxicity (Velez and Montoro, 1998; Conacher and Mes, 1993). Cadmium (Cd) is a common PTE. Here the word Cadmium (Latin cadmia, Greek καδμεία) means "calamine". A cadmium-bearing mixture of minerals, which is named after the Greek mythological character, Κάδμος Cadmus, the founder of Thebes, was discovered by Friedrich Stromeyer and Karl Samuel Leberecht Hermann in Germany, as an impurity in zinc carbonate. Cadmium is a silver-white, blue-tinged, lustrous metal that melts at 321 °C and boils at 765°C. This divalent element has an atomic weight of 112.4 and an atomic number of 48. It is insoluble in water, although its chloride and sulphate salts are freely soluble (Windholz et al., 1976). Even though cadmium and its compounds may be toxic in certain forms and concentrations, the British Pharmaceutical Codex from 1907 states that cadmium iodide was used as a medication to treat "enlarged joints, scrofulous glands, and chilblains" (Dunglison, 1866). Cadmium is considered as one of the most toxic heavy metals. It is a nonessential element to all living organisms. Rivers and lake shores are the areas primarily affected by diluted cadmium waste from industrial facilities in big cities. Toxic cadmium metals in the form of particulate matter are released into the waterbody from various sources (like industrial effluents, agricultural runoff) and settle down as sediment which becomes important metal sink or reservoir in aquatic environment (Figure 1). This sediment bound pollutants and taken by aquatic organism, rooted aquatic macrophytes (Gurrieri, 1998). The cadmium-related contamination of the aquatic habitat has greatly increased in the last decades, resulting in an increase of cadmium deposits in tissues of aquatic organisms in all food chain systems (Giles, 1988).

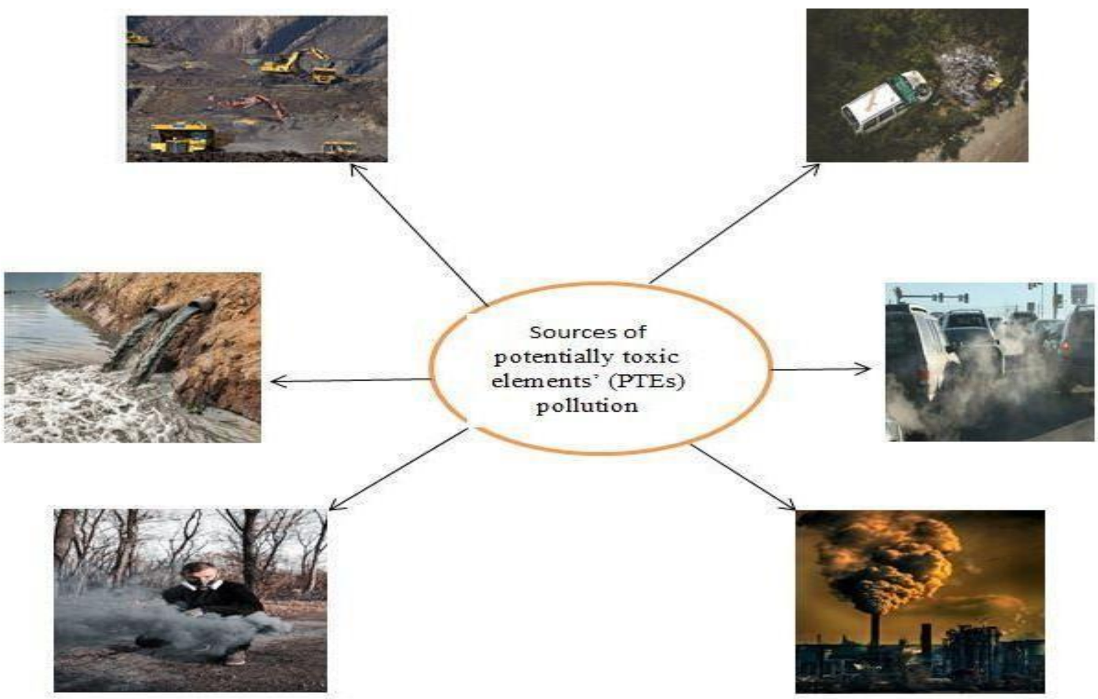

Figure1: Schematic diagram of sources of potentially toxic elements' (PTEs) pollution

Properties	• Density:8.69g/cm3,64th most abundant metal, Found frequently in combination with zinc • The only mineral found is Greenockite which is made up of cadmium and sulphur, • Silvery bluish tint metal
Uses	• Phosphate fertilizer, Pesticides, Nickel–Cadmium batteries , Glassware pigmentation, Corrosion-resistant plating, Stabilizer in plastic production, Nuclear reactors
Food source	• Shellfish, Mussels, Dried seaweed, Shrimps, Mushroom
Effects on humans	• Kidneys primarily affected causing nephrotoxicity, Infertility caused by are productive system failure • Calcium metabolism alterations, Bone fracture • Psychological disorders, Gastro intestinal disorders, Central nervous system complications, Immune system deficiencies, DNA impairment, Cancer • Itai-Itai disease, Osteoporosis, Renal dysfunction. • Reported to be genotoxic and ecotoxic in animals

Table1: Properties, uses, food sources and effects on humans of cadmium (G.W.C. Kaye and T.H. Laby, 1986; W.M. Haynes,2011s; IARC, 1993; G.Q. Yang et al.,1983)

Table1 shows the properties, uses and sources of cadmium in food and also the effects of cadmium on human bodies. Cadmium threshold levels refer to the maximum concentration of cadmium considered safe in environments before it becomes toxic. These limits vary depending on the different agencies. Table2 shows the Cadmium thresholds in different Compartment (ATSDR Toxicological Profile for Cadmium; Georgia, 2012).

Compartment	Agency	Description	Limits
Air	WHO	Air Quality Guide lines	5ng/m3
Workplace Air	OSHA	Legal limit over an 8-hour work day of cadmium in air	5μg/m3
Drinking-Water	EPA	Drinking water at this concentration for 10 days will not cause adverse effects in youths	0.04mg/L
	EPA	Drinking water at this concentration for a lifetime exposure does not caused verse effects	0.005mg/L
	WHO	Drinking water Quality Guide lines	0.003mg/L
Bottled Water	FDA	Bottled water threshold	0.005mg/L

Table2: Cadmium thresholds. (ATSDR Toxicological Profile for Cadmium; Georgia, 2012)

Toxicities of PTEs or heavy metals are well known. Heavy metals are toxic even at low concentration**.** Toxic behaviors of heavy metals appear due to tendency to form covalent bonds. Heavy metals bind covalently with organic groups and nonmetallic elements of cellular macro molecules and form lipophilic ions which generate toxic effects. There are four ways i.e., ingestion, inhalation, drinking and skin contact by which heavy metals can enter into the living organisms (V. Masindi and K. L. Muedi, 2018; C. H. Walkeretal., 2012). So, we can say heavy metals enter in our body through hair, food, water and bioaccumulate after a certain period of times. Heavy metals are nonbiodegradable therefore organisms can detoxify them using protein which hides the active elements of metal ions or by deposition of active elements in intracellular granules in an insoluble form to excrete in the organism's feces. When living organisms cannot detoxify heavy metals then the toxic natures of heavy metals are revealed. Bioaccumulation is dangerous because it is the accumulation over time of heavy metals in living organism that brings physiological and biological complications. Bioaccumulation occurs by inhalation or swallowing. For human there are some heavy metals which are necessary for life, known as essential elements and these essential elements are needed for different physiological and biochemical functions but when their amount is large, become toxic. Toxicity induced by heavy metals is associated with biomagnification and bioaccumulation. Biomagnification is the increase in concentration of heavy metals in the tissues of living organisms at successively higher levels in food chain (Briffa, J.et al., 2020). Through food chain heavy metals enter in our bodies and affect different body parts of human beings and also affect plant's bodies which are shown in Figure 2 and Figure 3

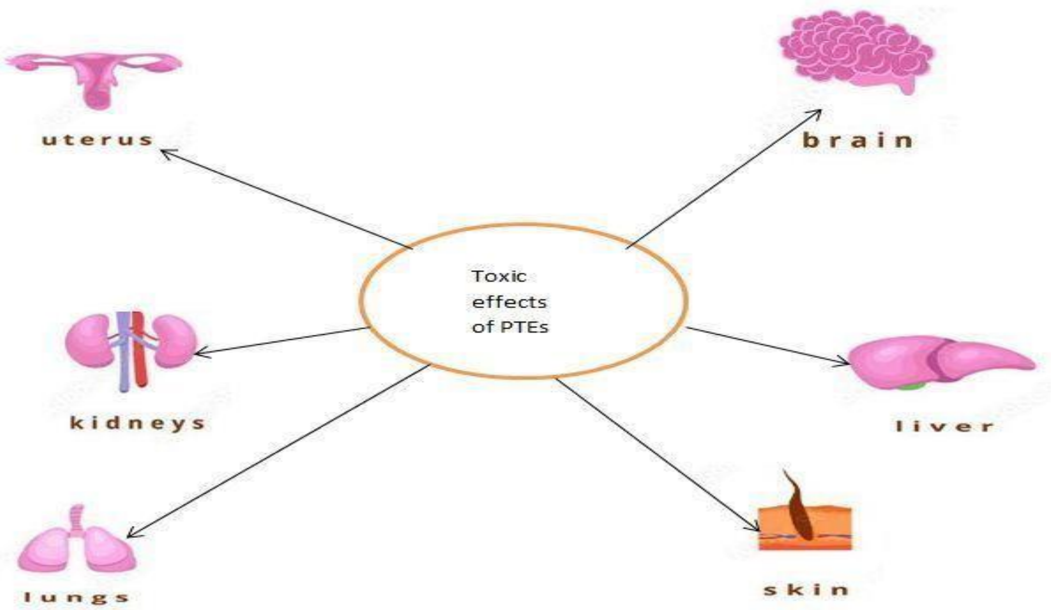

Figure2: Schematic diagram of PTEs or heavy metals effect on different human bodyparts

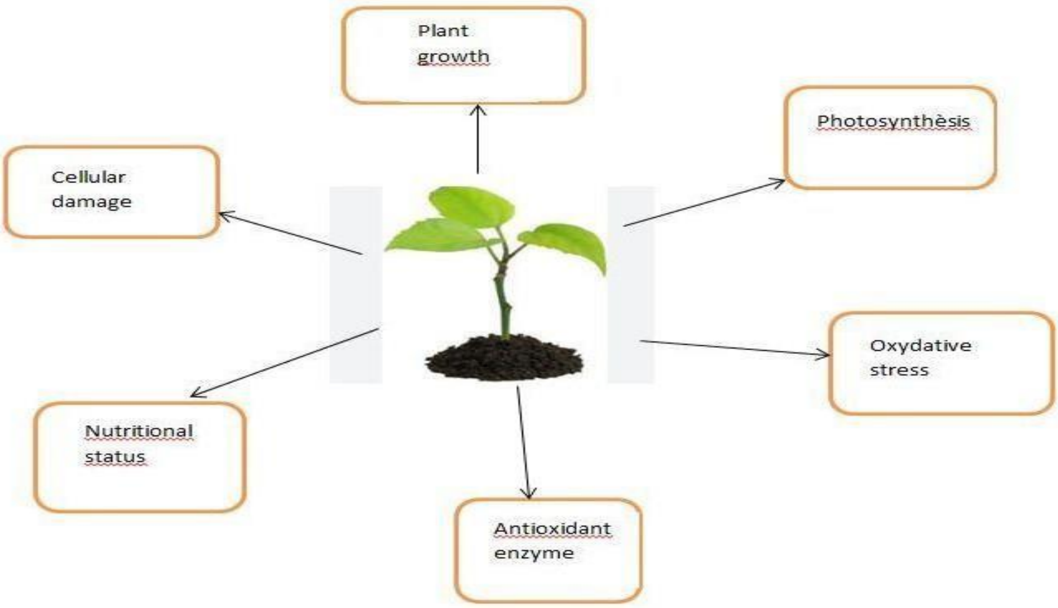

Figure3: Schematic diagram of PTEs effect on plants growth, photosynthesis, nutritional status, oxidative stress. Antioxidant enzyme and brings cellular damage

Interestingly, toxic effect of cadmium is not only found in animals but it is also observed in plants. Andresen and Kupper, 2013 observed the phytotoxic effects of cadmium in plants grown in cadmium contaminated soil. The effect of cadmium comprises genotoxicity, oxidative stress, inhibition of root metabolism and inhibition of photosynthetic apparatus.

3. Cadmium toxicity effects on fish and humans' health

Toxic heavy metals or PTEs are accumulated and biomagnified by aquatic organisms and transferred from lower strata to higher *via* food chain. Human exists at the top level of the food chain and obtains heavy metal burden from the food, especially fish. Fish possess the potential properties of biomagnification (Ayandiran *et al.*, 2009). As a good consumer, heavy metal affects fish. Exposure to heavy metal affects different organs, blood, heart, nerves and brain (Afshan *et al.*, 2014). There are several works which concern about the carcinogenic and toxic nature of cadmium and is suspected to cause carcinogenesis in animals and humans (Waalkes *et al.*, 1992). Earlier in 1969, after industrial development, maximum rivers received miscellaneous discharge from industrial and household effluents which affected quality of water and aquatic life (Verma and Shukla, 1969). Cadmium is an important heavy metal due to its toxic effects, and prolonged biological half-life (in case of human approx. 20 to 30 years), mainly stores in soft tissues like liver and kidney and low rate of elimination from the body. Health hazards related cadmium exposition revealed when Friberg, 1948 indicated the happening of proteinuria and emphysema in workers due to the dust of Cd. In 1960s, cadmium was launched into metal toxicology research for *Ouch-ouch* or *Itai-itai* disease, where Japanese women were affected by cadmium due to their cadmium contaminated diet.

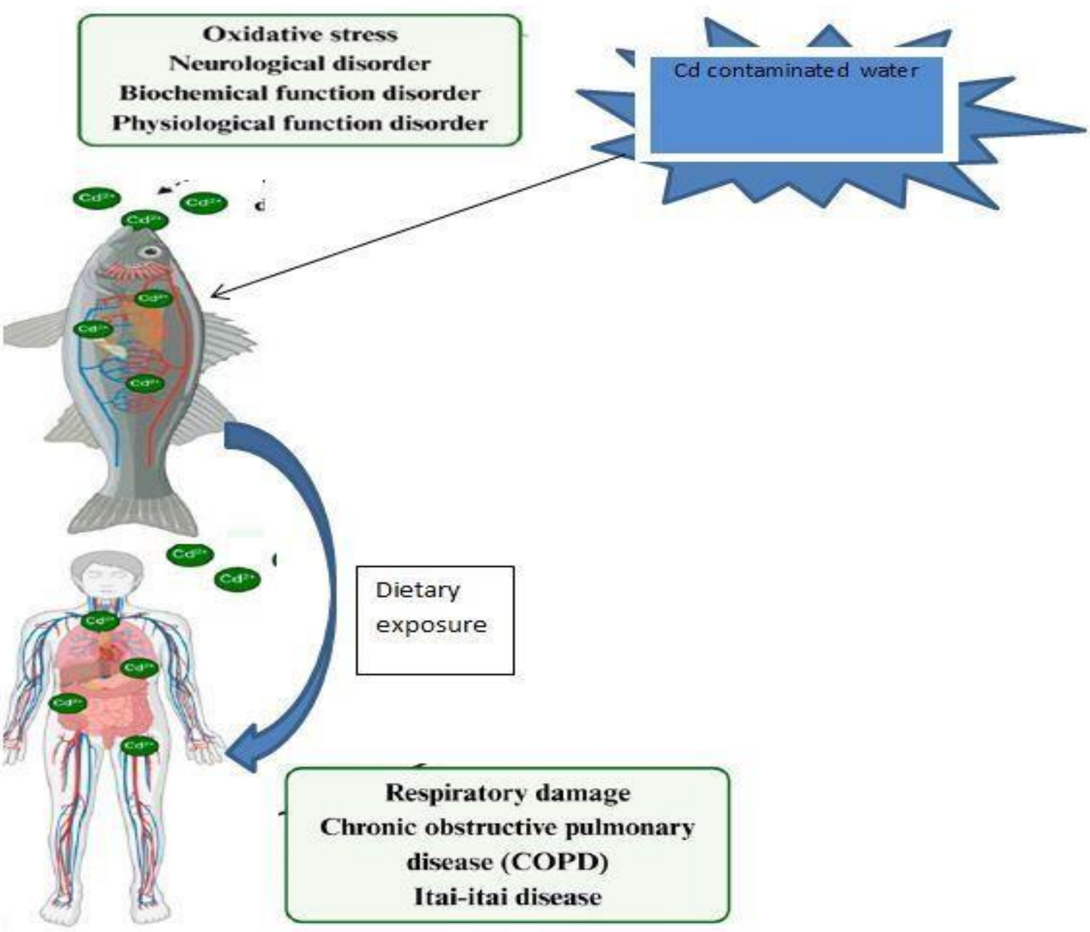

Figure 4: Schematic diagram of cadmium effects on Human beings due to their Cd contaminated diet.

Here Figure 4 Shows the cadmium effects on Human beings due to their Cd contaminated diet.

4. **Cadmium (Cd) toxicity effects on fish health and decrease fish population**

Due to nonstop anthropogenic activity from the past to ongoing agriculture and industrial operations, cadmium is enlisted as an extremely toxic element (Goering *et al.*, 1995). It has shown that the free cadmium ion is the most toxic and is the bioavailable form of the metal for numerous water bodies and animals (Sunda *et al.,* 1978; Foster and Morel, 1982; Borgmann *et al.,* 1991; Blust *et al.,* 1992; Huebert and Shay, 1992; Skowronski *et al.,* 1992).

Fish are suitable organisms used for monitoring the biological and chemical contamination in water (Henderson and Pickering, 1963). Effluents of different plants and industries, directly or indirectly release the cadmium metals as waste, which influences temperature, ionic strength, pH, complex ligands or presence of other metals (Nir *et al.,* 1989). Since metal toxicity affects every organism in our environment, so, Membane *et al.,* 2012 carried out an acute toxicity test of cadmium, zinc and lead metal separately and mixture of them on westslope cutthroat trout, shorthead sculpin, stone fly, may flies, caddis fly, hatchery rainbow trout and snail. After testing, they found 96 h median effect concentration (EC50) of cadmium to be 0.4 - 5329 μg/L and the relative resistance of taxa is nearly equal to for westslope cutthroat trout, rainbow trout and sculpin and this relative resistance is less than other taxa. Taylor, 1983 reported that at low concentration, cadmium is both toxic and persistent to hydrospheric life. Bioaccumulation of Cd is harmful for both marine and freshwater organisms. It has been stated that median concentration factors for both freshwater and marine organisms are less than hundred times and for fish species concentration factors are less than twenty times. So, for human beings, food is another source of cadmium. Because cadmium levels are high in fish, molluscans and crustaceans and mostly deposited in hepatopancreas (White and Rainbow, 1986; Naqvi *et al.,* 1993; Jorhem *et al.,* 1994).

Fish are known as metal indicators which assess environmental pollution in aquatic environment. Sundaresan, 2019 had shown cadmium chloride toxicity in kidney of freshwater fish Peters, *i.e.,* *Oreochromis mossambicus*. Exposure of cadmium chloride (8 ppm) for six days revealed changes in kidney as observed through electronic microscopy. Light microscopy and ultrastructure of kidney showed electron dense materials present in cytoplasm, blocking of junctional complex and other changes were also noticed. Thirumavalavan and Ganesan, 2013 stated that cadmium chloride caused histological changes in liver tissue of *Labeorohita,* when exposed to sublethal concentration of CdCl2 (1.87 ppm) for a period of 14 days at the interval of 7 and 14 days. Sawsan *et al.,* 2012 recorded the cadmium toxicity and bioaccumulation occurs in *Oreochromis nitoticus*(Tilapia fish) during intoxication at different concentrations (from 5 mg/L to 10 mg/L) for 7 days. It also focused on the adverse effects of cadmium on intestine, kidney and liver and revealed highest level of cadmium in cortex of the kidney and liver. In many studies nephrotoxic and hepatotoxic effects nature of cadmium are demonstrated (Templeton, 1990; Zalups and Ahmad, 2003). Prozialeck *et al.,* 2006 investigated that cadmium is found not only in liver and kidney but also in the lungs, testis and heart tissues.

It was stated that cadmium chloride toxicity effects on biochemical components like glycogen, glucose, lipid, free amino acid and total protein in *Catla catla,* so, it can cause damage to humans through biomagnification and/or bioaccumulation. After lethal and sublethal doses of exposure results revealed significant fall in all tissues and indicated the toxicant stress on organism (Sobha *et al.,* 2010). Tian *et al.,* 2020 depicted the developmental toxicity in thyroid endocrine disruption and subsequent transfer from parents to offspring due to cadmium chloride toxicity in zebra fish. Increasing exposure in cadmium may also cause increased cadmium concentration in liver, intestine, and caecum except kidney (Eaton, 1974). Gill and Pant (1985) reported that exposure to 0.63 and 0.84 mg/L CdCl2 (1/15th and1/20th of 96 h LC50) caused haematological disorders in *Puntius conchonius.* Exposure of cadmium caused hypochromia, cytoplasmic vacuolations, basophilic stippling of cytoplasm, deterioration of cellular membrane, schistocytosis and clumping of chromatin materials and extrusion of nuclei. Yilmaz et al., 2004 investigated the toxicity and effects of cadmium chloride (96 h LC50 value) on behavior of *Poecilia reticulates* (guppy fish) following the Finney's Probit Analysis method, 1971 and Behrens-Karbens method, 1931. Sengar *et al.,* 2018 showed the effects of cadmium chloride in the ovaries of *Heteropnuestes fossils* fish. Cadmium exposure caused enlarged oocytes, degeneration of outer layer of oocytes and many other changes in ovary. According to Baurand *et al*., 2014; Bo *et al*., 2015 they also act as bioaccumulator as they are able to accumulate great amount of heavy metal and other toxic contaminants. According to Radwan *et al*., 2010; El-Shenawy *et al*., 2012; Abdel-Halim *et al*.,2013; Zheng *et al*., 2013; Wang *et al*., 2014 production of free radical and antioxidant defense are always balanced. When antioxidant defense system in the body is lowered or faulty then high amount of free radicals is generated and cause oxidative stress. The cells are protected from damages caused by free radical through antioxidant defense system by restoring their level. Both enzymatic and non-enzymatic free radical inactivation and scavenging method involves in antioxidant defense system. A variety of contaminant exposures can change the antioxidant systems of aquatic organisms. In environmental monitoring system, it provides sensitive biochemical markers for exposure and toxicity. Antioxidant enzymes are such as, superoxide dismutase (SOD), catalase (CAT), glutathione S-transferases (GST), glutathione peroxidase (GPx) and lipid peroxidation (LPO) are usually studied. Changing of this antioxidant systems in fish body, bring different health hazards (Liu, Y.et al., 2022)

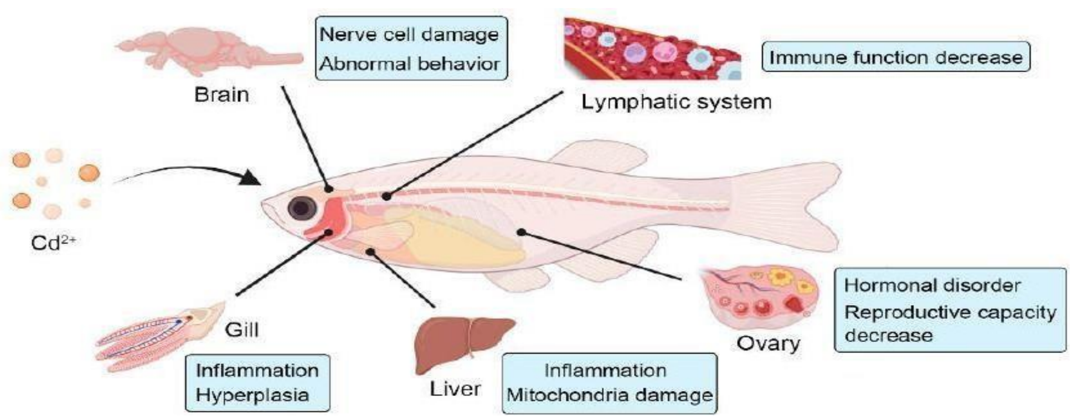

Figure5: Schematic diagram of toxic effects of Cadmium (Cd) on fish organ (Liu, Y. etal.,2022)

5.Conclusion

Aquatic food chain includes phytoplankton – zooplankton- small fish- large fish- birds or humans. Since cadmium (Cd) metal in the form of particulate matter is released into the water body from various sources (like industrial effluents, agricultural runoff) and settles down as sediment and becomes an important metal sink in an aquatic environment. Therefore, when these sediment-bound pollutants are taken by aquatic organisms or rooted aquatic macrophytes, heavy metal, cadmium enters into the food chain. This heavy metal is accumulated and biomagnified by aquatic organisms and transferred from lower strata to higher strata via food chain. Humans exist at the top level of the food chain and obtains heavy metal burden from the food, especially fish due to their potential properties for biomagnification. As a good consumer, they accumulate great amount of heavy metal or other toxic contaminants. A variety of contaminant exposures can change the antioxidant systems of the fish. These changes bring about different health hazards. Cadmium (Cd) toxicity causes structural and pathomorphological alterations in various fish organs and impacts on the behavioural parameters of the fish. So, fish are considered as biomarkers in aquatic toxic environment. Cadmium (Cd) has adverse effects on intestine, kidney, liver nerve and brain. It also causes hematological disorders and numerous changes in the ovary. Hence, this carcinogenic and toxic element decreases fish population. As a result, there is a high economic loss faced by fish farmers. Hence, monitoring is needed to find the cadmium concentration in fish tissue for minimizing economic loss and save the public health. Since aquatic organisms including fish are under the serious threat due to the environmental contamination. So, it is very important to monitor aquatic environmental quality and we need effective methods for purification and recycling of wastewater polluted by PTE ions to provide alternative.

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