# Water Quality and Fish Health: Interaction with Toxic Substances

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## SUMMARY

Water quality is an important factor for the well-being of aquatic ecosystems, it also influences physiological, behavioral and biochemical activities of water animals including fish. Due to overpopulation, lack of awareness and lack of implementation of environmental laws, there is an increase in the variety of toxic compounds in water bodies whose adverse effects have been widely distributed among aquatic biotas. Fish, being fragile animals, is affected by changes in the physical and chemical constituents of the water. This chapter highlights the hazardous effects imposed by the influx of heavy metals, acid rain, pesticides, herbicides, petrochemicals, radioactive substances, plastics, microplastics and other industrial and domestic effluents and their byproducts on the wellbeing of fish. Toxic substances in aquatic environments result in a wide range of impacts on fish health and its survival. Various hazardous compounds and their metabolites cause stress responses, disrupt endocrine systems and impair growth and reproduction in fish populations. One of the major goals of the United Nations for the coming years is to ensure the safety and suitability of life under water indicating its importance for human health and sustainable development for a prosperous future. There is a need for hours to monitor water quality parameters furthermore, more rigorous monitoring and control of water quality standards to protect aquatic life from the escalating threat of environmental pollution.

## INTRODUCTION

Natural water chemistry is complex and varies from different water bodies depending on the equilibrium that maintains the chemical, physical and biological parameters of water along with its environment. Physical parameters include temperature, pH, turbidity, color, odor, taste, dissolved oxygen, total dissolved solids, total suspended solids, etc., while chemical parameters include, salinity, alkalinity, hardness of water, conductivity, level of chloride, nitrite, nitrate, phosphate, sulphate and heavy metals. Biological parameters are vital for accessing the health and ecological status of aquatic systems. Some of its key features involve biodiversity, algal bloom, biochemical oxygen demand, pathogens, microbial invertebrates and so on. Water quality is crucial not only for humans but also for the survival of aquatic fauna. Variations can cause disturbance and stress to fish on the onset of many diseases in humans (Vasistha & Ganguly, 2020).

Rapid urbanization and anthropogenic activities, for the sake of our comfort, cause water, air and soil pollution. Due to a lack of knowledge of its consequences and long-term effects, we take part in nature destruction resulting in drastic changes that have a negative impact on the aquatic and terrestrial ecosystems. Fish, being a fundamental component of the aquatic ecosystem, are very sensitive to changes in water quality. Changes in water quality and the presence of toxic substances in water can affect cellular and molecular damage along with altered physiological functions resulting in increased mortality.

As the earth is made of 70 % of water and fish as the primary source of protein, we will discuss the effects of some toxic substances including heavy metals, acid rain, pesticides, petroleum products, radiation, plastics and microplastics, and industrial wastes on fish health. To understand the interrelation between water quality and fish health, especially in the context of exposure to toxic substances, effective management and strategies should be devised.

## HEAVY METALS

Heavy metal is a group of metals or metalloids having high densities, atomic weight and atomic numbers. These are extremely toxic and have hazardous effects not only on humans but also on wildlife and aquatic fauna. Due to high densities, these are extremely difficult to eliminate. These are present in trace amounts on earth naturally but due to anthropogenic activities, their quantity rises gradually up to an alarming situation. Heavy metals that are extremely dangerous are mercury, lead, cadmium, chromium, and arsenic. Some of them are discussed below with its effects on fish (Ali et al., 2019).

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**Mercury (Hg)**

Mercury is one of the most concerned heavy metals in aquatic toxicology. In water, it is found in the form of elemental mercury, divalent mercury and methyl mercury. Due to low bioavailability and high volatility, it is rarely found in marine ecosystems. Microorganisms present in sediments of marine environment convert mercury in its lethal form i.e. methyl mercury. Bioaccumulation occurs in tissues of aquatic fauna due to ingestion of contaminated soil and its concentration surges in trophic food chain i.e. from bottom to the top of food chain (Al-Sulaiti et al., 2022) as described in Fig 1.

Factors responsible for intra-species differences with respect to mercury concentration in fish are body weight and length. Moreover, concentrations of mercury in fish tissues have a negative correlation with pH, dissolved oxygen, alkalinity, and total organic carbon but a positive correlation with ammonia, iron and nitrogen content in the water column (Glover et al., 2010).

Low concentration of mercury can cause behavioral, morphological, physiological, biochemical and genetic alterations. Mercury toxicity can have a wide range of impacts on individuals, species, life stages and can even lead to death (Morcillo et al., 2016). Embryonic and larval stages are most prone to mercury exposure, continuous exposure can cause malformation of organs, effect metabolic processes and survival skills. According to sub-chronic toxicity experiments conducted on *Pagrus major* (red seabream), if mercury concentrations exceed above 20 µg/L it causes reduction in hatching, increase mortality, and cause teratogenicity in both embryo and larvae (Zheng et al. 2019).

The oxidative stress that is induced in fish is one of the main causes of mercury toxicity. It causes an imbalance between the production of antioxidant defenses and reactive oxygen species (ROS) of cells which leads to oxidative damage to lipids, proteins and DNA (Brandão et al., 2015).

**Lead (Pb)**

Lead is a pervasive environmental pollutant and due to anthropogenic activities Pb pollution is increasing day by day, which results in acute and chronic neurological, circulatory, hematological, reproductive, gastrointestinal, immunological pathologies including behavioral, physiological and biochemical functions. Even low concentration of Pb accumulation is lethal for aquatic organisms (Kim & Kang, 2015).

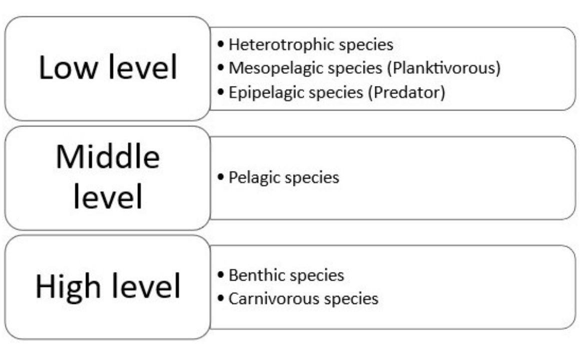


**Fig 1.** Relationship between mercury concentration and bioaccumulation in fishes based on water column

It forms a bond with oxygen and Sulphur in proteins and forms a stable complex which raises Pbs affinity for a particular protein. High affinity of lead can cause hypocalcemia due to inhibition of basolateral transport mechanisms of inocytes (a unique phenomenon where one or more viable cells actively enter into another cell, a process known as cell-in-cell) in gills epithelium resulting in disturbing ion regulation and electrochemical gradient (Paul et al., 2014). Lead poisoning primarily affects peripheral nervous system (PNS) and central nervous system (CNS). Cellular, intracellular and molecular mechanisms are involved in lead neurotoxicity resulting in neuronal apoptosis, oxidative stress interference with Ca (2+) dependent enzymes It also effects the function and structure of cell membrane, alterations in swimming behavior and response to environmental stimuli which rise concerns to oxidative stresses. Oxidative stress leads to damaged lipids, DNA and proteins.

Coupled disease pathogenesis and lead induced toxicity are significantly induced by this oxidative stress. Additionally, immunological parameters can be altered due to various stressors, and exposure to metal is strictly associated with modifications in the piscine immune system. Due to altered immune system, fish is more susceptible to infections and diseases (Nemsadze et al., 2009).

Population studies have revealed a relation between hypertension, cardiovascular disease and lead exposure. Primary organ targeted by lead toxicity is the vascular endothelium. Due to increased production of reactive oxygen species (ROS), downregulation of soluble guanylate cyclase and deactivation of endogenous nitric oxide (NO) leads to reduced availability of nitric oxide which impairs nitric oxide signaling (Afshan et al., 2014). Lead poisoning also effects development and reproduction of fish, causing reduced growth rate, abnormalities reduction in reproductive rate along with behavioral and morphological changes (Lee et al., 2014).

**Cadmium (Cd)**

Cadmium (Cd), a toxic, ubiquitous and transition metal, is globally known as a major pollutant that travels up the food chain threatening health risks of aquatic fauna as well as humans. Cd is easy to accumulate, has great absorption and hard to find. However, it is enriched easily and transfers its toxicity through the food chain. Even low concentration of Cd can accumulate in sediments and algae and absorbed by aquatic fauna through food chain (Vu et al., 2017). When fish are exposed to Cd toxicity for a long period, it will be accumulated in different tissues, causing alteration in function and structure of gills, gonads, kidney and liver. Impairing vital functions like respiration, reproduction, osmoregulation and excretion (Cui et al., 2023).

Cd toxicity in fish also affect its immune system, reproductive and physiological mechanisms lead to suppress immune system, making them vulnerable to infections and diseases, reduced fertility, abnormal development of sperms and eggs and reduced hatching. Physiological mechanism is affected due to stress of Cd exposure, resulting in reduced growth and development of fish (Lee et al., 2023).

Recent studies revealed that it can induce epigenetic alterations leading chemical modification of DNA, chromatin and histone except DNA nucleotides sequence, microRNA, DNA methyltransferase, histone acetyltransferase, histone deacetylase and histone methyltransferase. Resulting in increased risk of diseases and development of different types of cancer (Hu et al., 2022). Gills are the first targets of Cd, by respiration Cd is built up in gill tissues. Absorbed Cd ions are carried by blood to different tissues and organs. Cd has the first toxic effect on structure of gill tissues that results in inflammation, apoptosis and necrosis, thus, the ability of gills to regulate osmotic pressure and ion transport is affected (Garcia-Santos et al., 2011).

Liver (detoxifying organ), turns heavy metals into less toxic substances, which are excreted from the body. When fish is exposed to Cd ions for long period of time, liver surpasses its detoxification capacity, which affects the functional and structural integrity of liver tissue (Wang et al., 2021). This damage primarily consists of nuclear deformation, nuclear membrane mitochondrial swelling and distortion, granular cytoplasm, endoplasmic reticulum expansion, cell edema, and cavitation. The liver's capacity to detoxify is greatly diminished when the tissue structure of the liver is compromised, which has an irreversible effect on development, reproduction, and survival (Liu et al., 2022). Cd toxicity affects the overall health of aquatic fauna which leads to a sharp decline in fish population resulting in disturbance of the whole ecosystem.

## ACID RAIN

Any type of precipitation that has high level of sulfuric acid and nitric acid is known as acid rain, also known as acid precipitation and acid deposition. There are two types of deposition i.e. dry deposition (snow fall, with smoke and fog) and wet deposition (rain). Dry deposition occurs mostly in those areas where these pollutants are produced while wet decomposition can occur at different areas that are even away from the source of pollution. Mainly it is caused by air pollution which is the result of anthropogenic activities particularly by burning (combustion) of fossil fuels.

When nitric oxide and Sulphur dioxide enters into air, their encounter with water droplets in clouds transformed them into nitric acid and Sulphuric acid, lowering the pH and making it acidic. Thus, lowering soil alkalinity, also disturbing the chemical balance of streams and lakes, increasing environmental stress on aquatic ecosystem and forests (Shammas et al., 2020).

Clear signs of acidification have been seen in lakes and streams due to less compatibility of buffering of acid than plants and soils. After acid rain, heavy metals leach out from soil and enter the water bodies, becoming prime source of water pollution and lowering of pH in water bodies. These acids inhibit normal consumption of salts and oxygen, causing suffocation and resulting in fish death. It also affects aquatic biota and disturbs the food chain as chemical concentration is increased rapidly in each trophic level. Low pH in water bodies cause reduction in reproductive rate, growth retardation, growth of sperms and eggs because they are fragile and sensitive and increased skeletal deformities in fishes. It also affects the organs that directly came in contact with water i.e. eyes, skin and gills making them vulnerable and less immune to diseases (Singh & Agarwal, 2007).

Nitrogen saturation has been seen due to elevated levels of nitrate in soil. These nitrate ions remove Mg and Ca ions from soil. Eutrophication is also caused by this excessive nitrogen. Nitrogen deposition is not only a source of toxicity in aquatic fauna but also cause of acidification. Acidifications liberate more aluminum from juvenile aquatic fauna and grass beds and gave chronic stress to these organisms e.g. shellfish have small size due to stress (Ahmadi, 2020).

Acid stress causes reproductive failure due to inadequate protein deposition and disrupted Ca metabolism in oocytes. It also causes gill membrane alteration, disturbed electrolyte homeostasis along with hypoxia. Acid stress causes lessened pH of blood due to presence of $H^+$ ions, which altered transepithelial potential and allows blood - water diffusion of $Na^+$ ions down an electrochemical gradient. Buffer mechanisms lowered the blood pH resulting in reduced hemoglobin transport (Fromm, 1980). Some fish species are also discovered that have high acid tolerance including *Sphagnum* species and *Lobella* species Decline in biodiversity of aquatic ecosystem has been seen due to these activities e.g. loss of sport fish population in Canada (Fatima et al., 2020).

## PESTICIDES

To overcome the shortcoming of food (food security) due to overpopulation, escalating increase in manufacturing and utilization of herbicides and pesticides have been seen since end of second world war. Pesticides may have synthetic or biological origin and are used to control pests, pathogens and weeds. It includes rodenticides, insecticides, larvicides, herbicides and etc. These efficiently increase the quantity and quality of crops economically. On basis of chemical composition, pesticides are further classified in four main groups which are following (Kadiru et al., 2022). All these have a wide range of toxic effects on different species of fishes and aquatic animals as described in Fig 2.

### Organochlorines

Organochlorines are known as the oldest group of pesticides that includes chlorinated, hydrophobic and organic compounds. Due to its toxic, bio-accumulative and persistent nature it is also known as persistent organic pollutants. Some common examples of OCPs include Dichlorodiphenyltrichloroethane (DDT), dieldrin, lindane and chlordane. Its mode of action is to disturb nervous system resulting in paralysis, convulsion and eventually death. It enters water bodies through various sources like agriculture runoff, leeching, discharge of wastewater from industries etc.

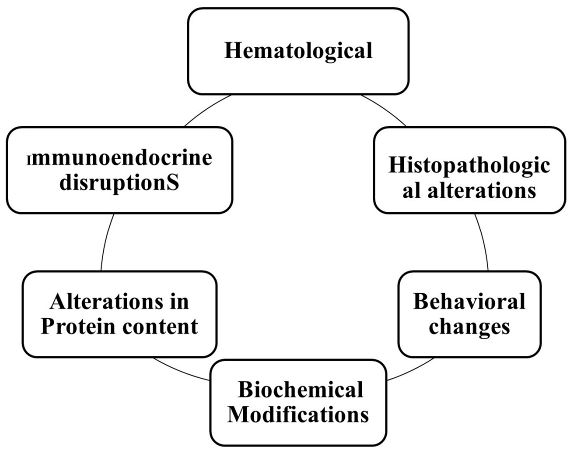


**Fig 2.** Effects of pesticides on fish

and accumulated in tissues of fish (Sultan et al., 2023). In fish it affects the physiological and metabolic mechanisms due to disruption in endocrine system. Genotoxicity, liver and kidney damage, oxidative stress, behavioral disorders and hematobiochemical complexities have also been seen (Rohani, 2023).

### Organophosphates

Organophosphates (OPs) function as a contact, nervous and stomach poison. Widely used organophosphorus includes glyphosate, chlorpyrifos, malathion, parathion and diazinon. OPs inhibit cholinesterase (ChE), highly neurotoxic even sublethal dose affects the physiological impairment that includes reproductive, feeding and escaping predators (Sandoval-Herrera et al., 2019). Absence of ChE causes overstimulation of the nervous system, resulting in muscle contraction which affects respiratory failure, swimming performance and paralysis. OPs elevate oxidative stress that affects defense responses leading to cellular damage and elevated glycogenolysis protein catabolism. Besides, nuclear anomalies in eggs have also been seen (Rani & Singh, 2023).

Glyphosate is a common toxic herbicide which is used to kill unwanted plants by inhibiting 5- enolpyruvoylshikimate 3-phosphate synthase (EPSPS) enzyme, leads to disrupted mechanism of protein synthesis. It is highly soluble in water resulting in oxidative stress, inflammation, apoptosis, and immunosuppression in some fishes. Its accumulation affects skin, gills, and intestinal tissues. Oxidative stress is caused by imbalance in reactive oxygen metabolites that leads to metabolic, immunological, and physiological impairment in fish (Costas et al., 2022). Depending on different life stages, it has numerous effects on fish. Behavioral disruptions like foraging, swimming, escaping and mating have been observed. In addition to behavioral disruptions, it also effects physiological, endocrinal, and biochemical disruptions resulting in morphological abnormalities and increased death in embryos (Abdelmagid et al., 2023).

## PETROCHEMICALS

Complex assimilation of hydrocarbons, present on earth in any form (solid, liquid or gas) is called petroleum, also known as bitumen, crude oil, and natural gas. It is formed by decomposition of dead plants and animals including algae and zooplankton under high pressure and temperature, in anaerobic conditions for a longer period. Petroleum industry is a huge industry that have significant impact on both terrestrial and aquatic environment. It is extracted by drilling from underground surfaces and leakage has negative effect not only on humans but also on plant growth (Al-Rubaye et al., 2023).

Oil spills can occur during drilling wells and rigs, during transportation from bunker fuels or from tankers. Reasons for spilling may include pipeline vandalism, oil theft, systemic failure, accident or poor maintenance. Wind and water currents play a huge role in its distribution to ocean's surface by making a film slick. Resulting in weathering and making oil spillage heavier than water. Furthermore, some oil dispersed naturally while some forms emulsion with water making it persistent and hard to remove for an extended period. As a result, oxygen exchange rate became lower between water and air that leads to hypoxia, oxidative stress and cause death of aquatic fauna due to oxygen depletion (Grosell & Pasparakis, 2021).

Gas chromatography is used to determine the concentration of hydrocarbons in oil-spilled marine water, which is usually less than 1 ppm. In contrast, its concentration is exceeded to thousands ppm in sediments of polluted marine ecosystem. Fish is exposed to different hydrocarbons that are readily taken up and accumulated in its tissues and body fluids. Developing embryos are sensitive to polycyclic aromatic hydrocarbons which are ubiquitous environmental pollutants. Anthropogenic activities are also a source of producing PAHs that enter aquatic medium through industrial wastes discharge, urban runoff, atmospheric deposition and etc. (Cherr et al., 2017). After spilling, cleaning operations takes place which are source of habitat destruction of many aquatic fauna including coral reefs, fish, grass bed, mangroves and etc. resulting in reduced biodiversity in that area (Itaa et al., 2023).

Xenobiotics that are present in marine ecosystem stimulate an enzyme which are obliged for hydrocarbon metabolism that aids in transformation of aromatic hydrocarbons to water soluble compounds that helps in elimination of toxic hydrocarbons. Some aromatic hydrocarbons have negative effects on fish such as benzopyrene which are converted to mutagens causing neoplasia.

Hydrocarbon pollution is further increased by cleanup efforts. It affects fishes both externally and internally by inhaling, ingesting and irritation on eyes and skin making them vulnerable to diseases, predators, and parasites. It also induces behavioral, metabolic, reproductive, and morphological changes in fish (Grosell & Pasparakis, 2021).

## RADIOACTIVE SUBSTANCES

Emission of energy in the form of electromagnetic waves by sub-atomic particles that are high in energy and result in ionization is known as radiation. In today's world, almost everyone has a certain amount of radiation exposure, due to advancement in every field of life, radiation plays an important role in its medical imaging and fighting cancer. It has also dominated the field of protection. The world is yet to recover from sad incidents of Hiroshima and Nagasaki along with Chernobyl [on 6 and 9 August 1945 US detonated two atomic bombs over these two Japanese cities (Grossman, 2011)]. Usually, the main types of radiation include ionizing radiation and non-ionizing radiation. The main difference between the two types is the former can ionize atoms while the latter cannot. Crude examples include X-rays, gamma rays and microwaves and radio waves. The general effects of radiation include damage to the cells, increased risk for cancer, genetic mutations and most drastic is the disruption of the ecosystem. In terms of duration of exposure, it can cause nausea, vomiting, bone marrow changes and damage to the vital organs and long exposure includes genetic mutations and cancer (Michael et al., 2018).

It has been a widespread practice to dump radioactive waste into the ocean. Over the last half century. Radioactive waste usually includes radioactive reactors and solid or liquid radioactive waste, from the military or weaponry. Over time the amount of radiation in marine water is increasing. Numerous studies show that radioactive materials, both with short and long half-lives are absorbed by marine life and can be transmitted up in the food chain and have drastic effects on both marine and land life. Phytoplankton accept radioactive waste, as they are eaten by the larger animals, some waste also settle down in the ocean bed (Pradhoshini et al., 2023).

Usually, polonium is the radioactive material that is received by the marine life in the greatest amount as Polonium-210 is a naturally occurring radioactive in the oceans. Cesium-134 and Cesium-137 are also found in copious amounts. Studies have shown that these radioactive substances move with water currents and deposit sediments (Pinder et al., 2011).

Gills absorb radionuclides by ingesting contaminated phytoplankton, zooplankton, or prey. Its accumulation depends on the half-life of radioactive substance. It causes oxidative stress in fish that leads to increased ROS. Change in behavior patterns that involves feeding behavior, swimming patterns, locomotion, escaping prey and migration is also observed. Exposure to radiation alters the genetic makeup by damaging the DNA, leading to mutations in genes resulting in development of cancer, also causing cellular damage that further results in impaired growth and retarred development. Radioactive exposure affects the embryo because of elevated cell division, differentiation, and proliferation. Upon higher exposure and for longer periods, a significant increase in mortality was observed (Guirandy et al., 20219).

## PLASTICS AND MICROPLASTICS

In everyday life plastic is used widely in every aspect like in packaging of food, automobile products, construction, recreational items etc. because of its low cost, elasticity, low weight, and durability. Microplastics are microscopic plastic grains made from fragments of goods. Primary microplastics were used in cosmetics, cleansers, as drugs vector in medicine etc. On other hand, secondary nano plastics came into existence by degraded microplastics debris. These wastes enter the water bodies by winds or land runoff or lack of proper waste disposal areas (Kumar et al., 2020).

Microplastics are almost found in every aquatic setting because of the smaller size it is accessible to many aquatic faunae, especially fish. Due to their non meticulous feeding habits, deposit and filter feeders (omnivorous fishes) are more susceptible to MP ingestion than other fishes [herbivorous and carnivorous fishes (Bhuyan, 2022)].

Consequences of MP intake includes its accumulation in gastrointestinal tract resulting in damage and blockage to intestines, causing pseudofeces. It can transfer in fish body and exposed to distant tissues and organs through circulatory system causing inflammatory reaction, breathing issues, vascular inflammation, and cytotoxicity. It alters the metabolic enzymes by disrupting energy equilibrium (reducing or boosting consumption of energy, altering feeding behavior). MPs exposure can cause elevation of AChE activity and disrupt neurotransmitters (Prata et al., 2021).

It also induces oxidative stress, which in addition to inflammation and irritation cause damage to DNA that leads to development of cancer. It induces oxidative stress even with smaller size of microplastics e.g in *Serranus scriba* from Tunisian coast. The presence of LDPE microplastic in *Sparus aurata* elevates activation of antioxidant enzymes leading to pro-inflammation in gut. Microplastics accumulation causes harmful effects to both adults and at initial stages of development resulting in behavioral and physiological effects (Bajt, 2021).

## DOMESTIC WASTE

Domestic wastewater is separated into two types, i.e. grey and black water. Grey water is mainly associated with all wastewaters except coming from toilets, it contains few but persistent chemicals, while wastewater coming from toilets falls into black water category which is rich in phosphorus, nitrogen and organic content. Approximately 75% of domestic wastewater comes from residential buildings or households, while the remainder 25 % is from commercial areas, office buildings and public facilities (Widyarani et al., 2022).

Most rigorous contamination arises from rapidly urbanized zones, where intensive exploitation of groundwater for industrial and domestic applications occurs, eventually leading to a significant downward gradient. Surfeit evidence proposes that anthropogenic activities incorporate domestic, industrial, intensive farming, and livestock wastewater discharge are accountable for increase in nitrate concentration of waterbodies (Cao et al., 2022). This enters the water bodies through direct discharge, runs off due to rain or floods or from inadequately treated water plants.

Nutrient pollution led to the emergence of toxic algal blooms, which release toxins that kill fish and other aquatic fauna. These poisons can lead to a variety of health issues, including skin irritation. liver, gills and nervous damage issues that eventually lead to mortality. Furthermore, eutrophication can also cause decline in water quality, compromising fish immune system and making them more prone to diseases e.g. vibriosis, parasitic infections and bacterial diseases. It also disrupts a lake ecosystem's food web, resulting in changes in the distribution and abundance of fish species and their potential prey (Kies, 2024).

The negative consequences of malfunctioning or inefficient Wastewater treatment plants have been seen at several organizational levels, resulting in metabolic and behavioral alterations in aquatic fauna. Around the world, these effects include losses in fish diversity and abundance, as well as modification, which can result in persistent estrogenic effects or even the collapse of fish populations and communities (Prinzio et al., 2024). Domestic wastewater is rich in certain nutrients, especially Nitrogen, Sulphur and Phosphorus. It can therefore have positive impacts on meat composition and weight gain in fish (Fig 3).

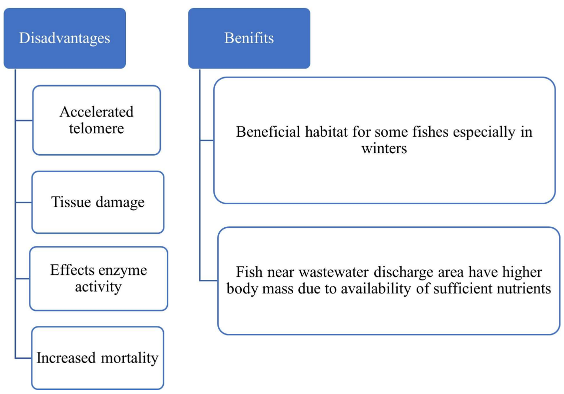


**Fig 3.** Disadvantages and benefits of untreated domestic wastewater on Fishes

## CONCLUSION

The presence of toxic substances in water imposes wide array of effects on fish health it also disturbs the delicate balance required to sustain aquatic ecosystems. Heavy metals, insecticides, and industrial contaminants impair fish physiological systems, impacting growth, reproduction, and survival. Untreated industrial and domestic wastewater should be avoided to directly thrown in water bodies unless it is treated. Continuous monitoring should be done to ensure the treatment of wastewater and quality of treatment plants. Management and conservation should be done to prevent aquatic toxicity and maintain overall ecological balance and sustainability. Enhanced efforts in environmental protection and pollution control are required to protect aquatic life from the pervasive risks posed by environmental toxins.

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