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Investigating the Impact of Environmental Toxicology of Heavy Metals in Fish: A Study of Rivers of Pakistan

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ABSTRACT

The global concern of heavy metal toxicity has affected all nations, as the discharge of agricultural runoff and untreated industrial waste into water bodies, including rivers, leads to environmental toxicology. This increased level of heavy metals poses risks not only for marine life but also to those who consume them. While fish is an important protein source, consuming contaminated fish containing high levels of heavy metals can have severe adverse effects on human health. Therefore, it is crucial to address these pollution sources effectively in Pakistan, where a significant portion of the population relies on agriculture and fishing for their living. The country's rapid industrialization and urbanization have substantially increased pollutants in its rivers and other water bodies. The current body of research has indicated that the elevated levels of heavy metals in the ecosystem, including the Indus River, pose a significant threat to the local ecosystem and the well-being of marine life. Heavy metal pollution in Pakistani rivers originates from multiple sources, such as industrial effluents, agricultural runoff, and municipal waste. The unregulated discharge of industrial waste into rivers is a major contributor to heavy metal pollution in Pakistani rivers. Moreover, the excessive and uncontrolled use of fertilizers and pesticides in agriculture equally contributes to the contamination of rivers with heavy metals. The current study is a review article, which provides a comprehensive explanation of how environmental toxicology affects the ecosystem, especially concerning the rivers of Pakistan.

Keywords: contaminated fish, environmental toxicology, fish, river, heavy metals, uncontrolled pollution

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1. INTRODUCTION

Over the last few decades, water has become a matter of concern for the developing countries. Among many other organic and inorganic pollutants our rivers are getting contaminated with environmental toxicology, creating a harmful impact on the aquatic life. Particularly, this aquatic system has various uses, which are used for sawmills and sand mining, as well as, for daily life activities, such as bathing, washing, and sanitation [1]. Anthropogenic activities pose negative impact on natural water bodies. Heavy pollutants that are discharged from homes, businesses, and industries, may have a negative impact on the river's capacity to provide clear and fresh drinking water, which is essential to serve as a habitat for the ecosystems. Fish are commonly employed as bio-indicators to evaluate the contamination level in the aquatic environment [2]. Ngugi and Oyoo-Okoth [3] asserted that up to 80% of plant protein concentrates an organic form of Cr that can be substituted for fishmeal. The decline in fish populations and fisheries could have an adverse impact on the overall population growth and economic factors [4]. Since fish is a significant source of protein, it's critical to ensure its safety and superiority for better fish production. Since eating contaminated fish can have negative health effects, heavy metal contamination in fish has received extensive research on a global scale [5]. Since it contains omega-3 fatty acids, DHA, and EPA, fish offers a complete dietary package of energy, protein, amino acids, vitamins, and minerals. Moreover, fish has also been linked to positive health effects like protection against diabetes and cardiovascular diseases. Furthermore, fish's health benefits were negated (cancelled) by contamination, and consumers may experience health risks [6]. As it is used as food, Southeast Asian countries frequently cultivate the Indian major carp *Cirrhinus mrigala*, also known as the Mrigal fish [7]. Monitoring the amount of heavy metals in Mrigal fish is crucial because eating tainted Mrigal fish could be harmful to one's health [8]. According to scientific knowledge, the presence of toxic metals in aquatic ecosystems has detrimental properties on the organisms inhabiting them due to their persistent nature and tendency to accumulate. Sub-lethal effects resulting from heavy metal pollution or toxicology can significantly affect the long-term growth, reproductive capabilities, and overall survival of organisms in the ecosystem. [9] . The following metals are indicated below, which are poisonous for the fish species and ecosystem.

1.1. Cadmium

The aquatic environment and the crust of the Earth both contain significant concentrations of cadmium, a highly toxic heavy metal that has a detrimental effect on fish survival, development, and reproduction\Cd accumulation in fish tissues, particularly the kidneys, liver, and gills, which can result in a number of physiological and structural issues [10]. Fish are the primary predators in aquatic ecosystems, making them particularly susceptible to Cd pollution. The accumulation of Cd in their tissues may negatively affect their gills, liver, gonads, and other organs, which may cause problems with their metabolism, physiology, and reproduction, as well as, cause death [11]. Within aquatic environments that have been contaminated with cadmium (Cd), fish can experience stress due to the presence of ROS (reactive oxygen species) and RNS (ribonucleic acid enzymes) [12].

1.2. Lead (Pb)

Lead (Pb) is a compound that is found at low concentrations in the crust of the earth, predominantly as sulfide. The origins of lead emissions differ significantly based on their location and stages. However, on a country-wide scale, the primary contributors to airborne lead are the processing of ores and metals, as well as piston-engine aircraft that utilize leaded aviation fuel. Other significant contributors include waste incinerators, utilities, and manufacturers of lead-acid batteries. Generally, the air around lead smelters contains the most concentrated levels of lead. Depending on the dosage, lead (Pb), a heavy metal with toxic effects on health, can cause a wide range of negative effects. The developing central nervous system (CNS) is more susceptible to toxicity from Pb than other organ systems. Children are more susceptible to Pb toxicity when compared to adults because of the increased hand-to-mouth activity and intestinal absorption. In children and adults, it can cause several health problems, including renal failure, and coma, ultimately leading to death. Pb is considered a non-essential component, which is widely recognized due to its toxicity, which can lead to nephrotoxicity, neurotoxicity, and various detrimental impacts [13]. Trash fish used in the production of feed may have contributed to the high Pb levels found in fish feed and cultured tilapia. The results of the study indicated that the majority of the samples of raw, tank, and tap water from the lakes of Darbandikhan and Dokan, which were tested between June 2012 to May 2013, for a few water safety parameters had high levels of heavy metals like Cd and Pb, exceeding the thresholds advised by the WHO and FAO organizations.

1.3. Nickel

The chemical element nickel (Ni), which makes up about 3% of the Earth's crust, is naturally distributed in the air. Along with iron, cobalt, palladium, platinum, and five other elements, it is a part of group VIII B of the periodic table and a member of the transition series. Despite being common, nickel is harmful to living things. However, it is released into the air through fossil fuels and other various natural and anthropogenic activities. A study conducted [14] indicated that red blood cells (RBC) of *Cirrhinus mrigala* exposed to sub-lethal nickel concentrations showed a reduction in RBC count. It was also discovered that there was a correlation between nickel concentration and fish mortality. One of the natural sources of atmospheric nickel is wind-borne dust from soil and rock weathering, volcanic emissions, vegetation, and forest fires. Most anthropogenic sources of nickel in the environment are both stationary and mobile, including burning coal, diesel, and fuel oil as well as sewage, waste, and other materials [15]. Several prior studies have discussed the hazardous effects of Ni, which are highly reported in the urban atmosphere.

1.4. Copper

Copper is an essentially significant element, which is present in dietary products. Copper (Cu) acts as an enzyme that reduces the molecular oxygen by creating approximately a tolerable intake level. The majority of the organisms regulate copper, a vital element required for hemoglobin synthesis and for the functioning of numerous enzymes. However, research has shown that aquatic life, such as fish, invertebrates, and amphibians, can be extremely toxic to copper (Cu) and are all equally sensitive to chronic toxicity [16]. Organs of fish and mollusks frequently accumulate copper. Lamellae fusion has been associated with chronic copper exposure, whereas aneurysms and edema have been associated with short-term copper exposure [17]. Due to their direct exposure to water, fish gills are the initial organs to respond to environmental pollution, making them highly susceptible to the detrimental impacts of copper accumulation. Copper can also change the cellular makeup, glucose metabolism, and salt balance of fish. Due to fish efficiency bioaccumulators and heavy metals like copper can easily accumulate in their tissue, which could be harmful to human health [18] and others. The primary goal of conducting a histopathological study is to analyze cellular biomarkers that offer valuable insights into the condition of an organism. Notably, the study revealed notable necrotic and degenerative changes in the intestinal mucosa of *Oreochromis niloticus* and *Lates niloticus*. Additionally, it has been suggested in some sources that the consumption of toxic metals may contribute to the development of edema [19]. In a likewise manner, a higher level of Copper (Cu) was reported in the aquatic systems of Pakistan, which can cause bioaccumulation in plants and irrigated vegetables.

2. MECHANISM OF ACTION HEAVY METALS IN AQUATIC SYSTEMS OF PAKISTAN

Heavy metals, when present in high concentrations, pose toxicity to fish and other aquatic organisms. These substances can enter water bodies through various sources, including industrial wastewater, agricultural runoff, and atmospheric deposition. Upon entering the water, toxic metals have the potential to accumulate within fish tissues, leading to detrimental consequences. The toxicity of heavy metals in fish is mediated through complex biochemical, physiological, and behavioral processes. Oxidative stress is a significant mechanism underlying the toxic effects of heavy metals in fish. Metals such as cadmium, lead, and mercury can induce the production of ROS in fish tissues, leading to oxidative impairment to lipids, proteins, and, DNA. Consequently, this oxidative damage can cause cellular harm, disrupt physiological processes, and potentially result in cell death.

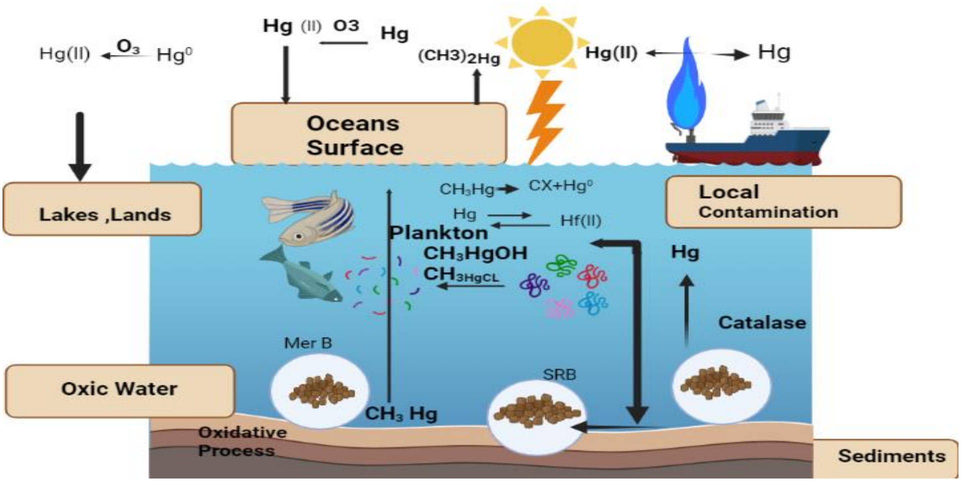

Figure 1. Heavy Metals' Mode of Action in Lakes and Ponds

For instance, [20] Yang, Hu [21] 's recent research on crucian carp found that exposure to cadmium interfered with the ion transport mechanisms in the fish's gills, impairing osmoregulation and acid-base balance. Furthermore, heavy metals can disrupt various biochemical pathways in fish production by interfering with their enzymatic functions. For instance, the enzyme acetylcholinesterase, which is essential for the proper functioning of fish nerves, can be inhibited by lead, as indicated by the recent investigation by [22] . (See Figure1).

3. HEAVY METAL EFFECT ON EMBRYONIC DEVELOPMENTAL OF FISH

According to [23], environmental pollutants, including waterborne metals have detrimental effects on fish embryos and larvae, which are considered the life stages with most vulnerable and toxic impacts. The presence of metals in the water can interfere with the development of fish embryos, potentially leading to adverse outcomes. Numerous studies have demonstrated that heavy metals can have a negative impact on developing fish production, especially in their embryonic and larval stages, causing high mortality rates, delayed hatching, abnormal body shape, and physical anomalies [24]. The effects resulting from heavy metal exposure encompass several detrimental outcomes, such as stunted growth rate, delayed and diminished hatching, reduced survival rates of embryos and larvae, and hatching that is both reduced and delayed. A recent study indicated that heavy metal toxicity specifically affects marine fish embryos and larvae, leading to reduced hatchability [25]. Much research has been conducted to investigate the toxic effects of these heavy metals on fish embryos and larvae, resulting in a substantial body of literature on this topic. For instance, zebrafish embryos exposed to cadmium concentrations similar to those tested in the current study from the gastrula stage onwards manifested a definite delay in hatching. Additionally, the newly emerged larvae had diminished swimming abilities [26].

3.1. Effect Fish Production

It has been noted that the buildup of toxic substances causes aquatic organisms, including fish, to experience a decline in growth and reproduction. Fish deformities can alter a fish's chances of surviving, thus, leading to the decline rate of growth, welfare, and external morphology, all of which can have a devastating impact on populations. Deformities of the vertebral column are among the most frequently described fish deformities in the literature [24]. Fish exposure to sub-lethal levels of metal mixtures can have detrimental effects on the overall fish growth and health. Metal mixtures can have a wide variety of effects on fish. Fish species' responses to food intake, food conversion efficiency, weight increments, and length increments, were discovered to be significantly different due to their exposure to metal mixtures, indicating significant effects on their growth [27]. In treated fish species, weight and fork/total lengths were found to be negatively correlated and statistically significant, while in control fish species, the correlation was positive but not statistically significant, [28, 29]. The study revealed a significant and positive correlation between weight gains, condition factors, and feed intake in both the treated and control fish species. This observation emphasized the link between fish condition and the quantity of feed consumed, which impacts the degree of weight gain. The study specifically focused on grower pond cultures of *Cirrhina mrigala*, *Labeo rohita*, and *Catla catla* [30] a long-term impact on growth, net fish production, and yield when fingerlings were exposed to lead (Pb) at sub-lethal concentrations. The study determined that the growth and yield of the fish species were adversely affected by sub-lethal lead exposure. This conclusion was based on observations of reduced weight gain, fork, and total length gains, as well as a decrease in net fish production [31, 32]. The study examined how the chemical properties of water can influence the growth capacity of *Ctenopharyngodon idella* and *Hypophthalmichthys molitrix* under sub-lethal stress as induced by a mixture of metals. The findings further also revealed that the growth of both fish species was significantly affected by the physico-chemical characteristics of the stressed media [31].

3.2. Removal of Heavy Metals

To keep the environment clean and boost human health, heavy metal ions must be successfully removed from wastewater. Numerous techniques, such as electrocoagulation, adsorption using synthetic and natural materials, the use of magnetic fields, sophisticated oxidation techniques, membranes, and others, have been developed to deal with this issue [33, 34]. According to Zhang and Hou [35], the sequential extraction method facilitates the understanding of metal movement in soil and groundwater. Physical remediation techniques, such as washing, soil extraction, solidification, and stabilization offer viable means of removing heavy metals from soil.

However, among the various methods available, adsorption is considered the maximum capable approach for the elimination of toxic metals. This is mainly because of its high effectiveness, broad pertinence, and its cost-effectiveness. Iron Magnesium oxides have become a commonly utilized adsorbent due to their simple preparation, abundant availability of raw materials, and minimal environmental impact. Regarding the deletion of these toxic metals from solutions, the main methods include ion exchange utilizing iron-manganese oxide nanomaterials and redox reactions. Further research is needed in these areas to enhance our understanding and optimize the utilization of these materials for effective removal of heavy metals [36]. Various physical techniques like ultrafiltration, coagulation, flocculation, adsorption, membrane filtration, and ion exchange are employed for heavy metal removal from water. Chemical strategies encompass neutralization, solvent extraction, chemical precipitation, and electrochemical treatment. A number of these methods are commonly adopted for the removal of heavy metals from water. These methods can be used individually or in combination depending on the specific situation and the types and levels of heavy metals, which are required to be removed. Each method has its own benefits and drawbacks and the choice of method would depend on a variety of factors including its cost, effectiveness, and environmental impact [37].

4. HEAVY METAL POLLUTION IN RIVERS OF PAKISTAN

According to the provided sources, the deterioration of the Indus River and other wetlands in Pakistan has resulted in heightened health hazards for the nearby communities. Although aquatic systems are vital sourcess of freshwater for the ecosystems that support all forms of life, their deteriorating water quality poses a severe threat to their long-term survival. Globally, rivers play a pivotal role as critical waterways, serving as the primary source of the water resources that are being utilized for agricultural, industrial, and domestic purposes [38, 39].

Ali, Khan [40] ensuring the well-being of the aquatic ecosystem necessitated diligent monitoring of river water quality. Furthermore, evaluating the concentration of these toxic metals in fish species is of utmost importance because of their significant role in the human diet and the potential risks they pose to public health [41]. The River Shah Alam, located in Khyber Pakhtunkhwa, Pakistan, has faced pollution issues caused by the release of many toxic industrial sewages, agricultural runoff, and local mess from Peshawar and its surrounding areas. Previous studies have demonstrated that sub-lethal exposure to lead (Pb) can negatively impact the immune systems of tilapia fish (*Oreochromis mossambicus)*. By assessing the effects of these toxic metals, the study aimed to gain insights into the potential contamination and associated risks for the aquatic ecosystem and the fish inhabiting the river. The river systems in Pakistan have been adversely affected by the excessive discharge of metallic compounds, resulting in a decline in freshwater fisheries specifically in the river Ravi [42]. The release of effluents into lakes resulting from rapid urbanization and industrialization is a significant global issue, contributing to the presence of various toxic pollutants in the aquatic environment. Among these pollutants, heavy metals are particularly concerning due to their persistent nature and the potential for biological accumulation [43]. Water bodies like rivers, lakes, and oceans are frequently subjected to the disposal of heavy metals, which can subsequently accumulate in fish through multiple routes, including ingestion, skin contact, and gill absorption. As a result, fish can accumulate these traces of heavy metals at significantly higher levels than their concentrations in the surrounding water. The accumulation of heavy metals in fish through the process of bioaccumulation presented a potential hazard to both aquatic ecosystems and human well-being [44]. The increased concentrations of nickel (Ni) found in water samples taken from three rivers in District Charsadda, Khyber-Pakhtunkhwa, Pakistan, are attributed to the discharge of effluents originating from pharmaceutical industries [45]. The Faisalabad city, in Pakistan is a major contributor to this pollution, as it releases both industrial and municipal waste into the river through the Chakbandi drain. Consequently, the river exhibits high pollution levels, resulting in reduced water productivity and a significant increase in the bioaccumulation of pollutants in the muscle tissues of fish, particularly in the case of *Cirrhinus mrigala*. Elevated levels of heavy metals have detrimental effects on the overall well-being of fish, leading to disruptions in their normal physiological processes [46]. A recent investigation conducted on the Panjkora River yielded similar findings, demonstrating elevated concentrations of heavy metals in fish organs [47]. Factors such as age, sex, size, diet, and movement patterns can all contribute to metal accumulation in fish. Additionally, environmental factors like pH, temperature, calcium concentration, and water hardness can also impact metal accumulation. Unregulated disposal of industrial and agricultural waste, rapid urbanization, and population growth are the leading causes of water pollution [48] as per the citation, the Swat River is a significant source of water for the Swat district that begins in the mountains (glaciers) of Kalam before running longitudinally through the Swat district and entering the Dir district at Chakdara. In the study conducted along the River Swat, which harbors valuable fish species like *Oncorhynchus mykiss* and *Shizothorax esocinus*, the prime objective was to evaluate the presence of heavy metal contamination in different environmental components, such as water, sediments, algae, and fish tissues. The research revealed that *Graptophyllum reticulatum*, in particular, exhibited higher concentrations of heavy metals in its muscles, skin, liver, and gills as compared to *Cyprinus carpio*. The accumulation of these metals within fish cells poses a potential risk of fish mortality [49]. The release of untreated industrial wastewater into rivers and streams is a significant concern in Pakistan, leading to freshwater pollution. Shockingly, approximately 99% of industrial wastewater is discharged without undergoing any form of treatment [50]. A startling revelation was uncovered concerning the amount of lead (Pb) found in fish samples. The research results indicated that both 90% of the fish procured from the main market and every sample taken from retail shops, exceeded the international acceptable limit of 0.123g for lead content. This revelation is profoundly agonizing, as high lead concentrations in fish not only present health hazards to consumers but also to the fish farmers engaged in the cultivation process [51]. In this study, the bioaccumulation of lead (Pb) and cadmium (Cd) in the gills, swim bladders, and muscle tissues of *Tor putitora* fish species were examined. The species (fish) samples were collected from three sites in District Swabi, Khyber Pakhtunkhwa, Pakistan (Batakra, Ghazi, and Kund) between February and April 2016 [52]. (See Table 1)

Table 1. Heavy Metal Pollution in River of Pakistan

Fish species/ Water samples	Location	Metals	Method	Effect	References
Cirrhina mrigala,	Baloki Headworks	Cd, Cr	Bioaccumulation in fish organ by flame atomic absorption spectrophotometer	Fish liver exhibited the highest tendency to accumulate both cadmium and chromium, while the accumulation of both metals was the minimum in fish gills.	[42]
Water samples	River Kabul	Cu,Cr, Ni, Pb, Cd	Bioaccumulation AAS	This affects the growth of the inhabitant fish population and in turn productivity of the river.	[53]
Cyprinus carpio,	Nandana River,	Cu, Cr, Fe, Ni, Pb	Bioaccumulation by flame atomic absorption spectrophotometer	Oxidative stress is brought on, which harms the cellular structure of body organs. No metal was discovered to individually present a risk to non-cancerous health.	[54]
Schizothorax plagiostomus	River Panjk	Cu, Pb, Cr, Ni, Cd	Bioaccumulation in fish organ by flame atomic absorption spectrophotometer	Bioaccumulation of nickel (Ni) in fish muscles, the elevated concentrations of Ni found in the fish samples may be attributed to the introduction of this metal into the river waters.	[55]
Schizothorax plagiostomus	River Swat	Pb, Cr, Ni, and Zn	Bioaccumulation atomic absorption spectrophotometer.	*Schizothorax plagiostomus* exhibits the highest accumulation of chromium (Cr) in both the gills and muscles	[56]
Glyptothorax punjabensis) Cyprinus carpio	Jindi, Khyali	Cr,Cu,Ni,Mn.Co	Goal Hazard Ratio Atomic absorption spectrophotometer, cancer risk at the target, and danger index.	The calculated cancer risk associated with nickel (Ni) for the given fish species exceeded the accepted risk level. Among the three fish species examined, Cyprinus carpio demonstrated the highest health risk, followed by *Glyptothorax punjabensis*.	[57]

Fish species/ Water samples	Location	Metals	Method	Effect	References
Tilapia nilotica, Wallago attu, Catla catla	Head Islam (Hasilpur),	Cu, Pb, Cr, Ni, Cd	Bioaccumulation Atomic absorption spectrophotometer	Vacuoles of varying sizes were observed in the affected liver cells, indicating cellular damage. Additionally, cell death, hemorrhage, and rupture of blood cells were observed between the hepatocytes, along with dilation in hepatoportal blood vessels	[58]
Cirrhina mrigala	Indus River	Zn,Ni,Cu	Atomic Absorption Spectrophotometer	The activity of CAT enzyme was higher in kidneys and gills of farm fish compared to the liver of hatchery fish. Variations in antioxidant defense system.	[59]
Schizothorax niger	River Jhelum	Cu^{2+}, Zn^{2+}, Pb^{2+} and Fe^{2+}	Bioaccumulation and biomagnification, Atomic Absorption Spectrophotometer	Fish can be harmful and toxic. In order to harm fish, Cu2+ can actively combine with other substances and elements like ammonia (NH3, Hg, and Zn2+). May result in a reduction in fish fertility.	[60]
Labeo calbasu	Chenab River.	Cr,PB,Zn	Spectrophotometer (model Spectra AA800).	In the liver of CF fish, the activity of superoxide dismutase (SOD), catalase (CAT), glutathione (GSH), and lipid peroxidase (LPO) was observed to be higher compared to HF fish ($P < 0.05$). Furthermore, the HF fish exhibited higher levels of Cr, Co, Cu, and Fe in their muscle tissues compared to CF fish. As fish muscles are a significant edible portion, these findings raise	[61]

Fish species/ Water samples	Location	Metals	Method	Effect	References
				concerns about the potential health risks for consumers.	
Labeo rohita	Head Balloki	Hg	Atomic fluorescence spectrometer.	Metal buildup results in oxidative stress that is toxic and causes genotoxicity as well as the usual changes in SOD, CAT, and MDA levels.	[62]
Cyprinus carpio	Rawal Lake,	Cd, Co, Cr, Cu, Fe	Flame atomic absorption spectrophotometer	Carcinogenic and non-carcinogenic effects in fish	[63]
Cyprinus carpio)	Indus River in Mianwali	(Mn, Pb, Zn, Hg and Cr	Coupled plasma optical emission spectroscopy.	The fish demonstrated higher bioaccumulation of essential metals such as zinc (Zn) compared to toxic metals like lead (Pb). However, the elevated concentrations of manganese (Mn), mercury (Hg), and chromium (Cr) in fish muscles could potentially pose health risks to individuals consuming these fish	[64]
Labeo rohita	River Kabul	Cr,Fe	Atomic Absorption Spectrophotometer	The metals that were most concentrated in both species' gills and livers were chromium and iron.	[65]
Salmo trutta fario	River Swat.	Hg	Using the hydride generation method, an atomic absorption spectrometer (GBC 932 plus).	The fishing community encountered various health problems, including muscle pain, headaches, visual impairment, high arterial blood pressure, anemia, and kidney dysfunction.	[66]

Fish species/ Water samples	Location	Metals	Method	Effect	References
Sarda orientalis	Pakistan (northern Arabian Sea)	Zn Mn,Cu Cd	Atomic Absorption Spectrophotometer	A serious threat to human health is posed by metal contamination in marine fish.	[67]
OREOCHROMIS NILOTICUS,	Tarukri Drain	Cd,Fe, Pb, Ni, Zn	Atomic Absorption Spectrophotometer, Bioaccumulation	The kidney, liver, and muscles all had the highest concentrations of heavy metals cause a variety of harms to fish, and its consumers may also be at risk for health problems.	[68]
MASTACEMBELUS ARMATUS	Shah Alam	Cr, Ni, Pb,Cd	AAS	Fish exposed to heavy metals experience pathological changes and a disruption in the release of reproductive hormones. Fish exposed to Cr experience biochemical, haematological, and behavioural changes.	[40]
CYPRINUS CARPIO)	SHAHPUR DAM	Pb, Cu, Cr, Fe, Ni)	Atomic absorption spectrophotometer, cancer risk, and hazard index (HI) (CR)	Oxidative stress was assessed using the catalase (CAT), glutathione S-transferase (GST), and reduced glutathione (GSH) activities in the liver and gill of Cyprinus carpio. DNA damage	[54]
C. IDELLA	HEAD PUNJNAD	Cd,Hg	Atomic absorption spectrometer made by Zeeman (Z-5000, Hitachi Japan).	Damage to the kidney can result in chronic toxicity, which can also cause body tumours, liver dysfunction, poor chances for reproduction, loss of routine kidney functions, and hypertension.	[69]

5. CONCLUSION

This study crucially highlighted that the presence of heavy metals creating environmental toxicology has severely impacted the ecosystem by raising several significant environmental concerns that demand immediate attention. Water bodies, such as rivers, become contaminated due to the release of untreated industrial waste and agricultural runoff containing heavy metals. Fish play a pivotal role in the food chain and can potentially become a source of heavy metal exposure for both aquatic creatures and people who consume them. Addressing this problem requires collaboration among the public, private, and local communities to highlight the need to necessitate to develop sources, which will decrease the industrial effluents and increase fish production. The government should enforce stringent regulations and implement robust monitoring mechanisms to ensure that industries adhere to environmental standards and refrain from releasing hazardous waste into water bodies. In conclusion, the heavy metal analysis conducted in this study addressed the complex issue of contamination of environmental toxicology in Pakistani rivers. Moreover, using the fish sample, it was highlighted that a comprehensive approach involving various stakeholders was required to sustain the fish production and ecosystem. Additionally, it was indicated that by working together, the sustainable utilization of natural resources can be ensured to promote the well-being of the communities. Industrial growth, coupled with poor waste management strategies, has led to a significant degradation in the quality of water bodies. Hence, several key contaminants, including untreated industrial effluents, municipal waste, agricultural runoff, and improperly disposed-of domestic waste, all of which have turned the aquatic systems into repositories of pollutants, increasing the nature of heavy metals and toxins.

In particular, toxic heavy metals and microplastics have been identified as severe threats to both aquatic ecosystems and human health. Their presence has not only disrupted the riverine ecology but also entered the food chain, affecting people and other organisms at higher trophic levels. Moreover, the high levels of organic pollutants have depleted oxygen levels in the water, leading to massive fish die-offs and the destruction of aquatic biodiversity.

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