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# Heavy metals contamination in water, sediments and fish of freshwater ecosystems in Pakistan

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## ABSTRACT

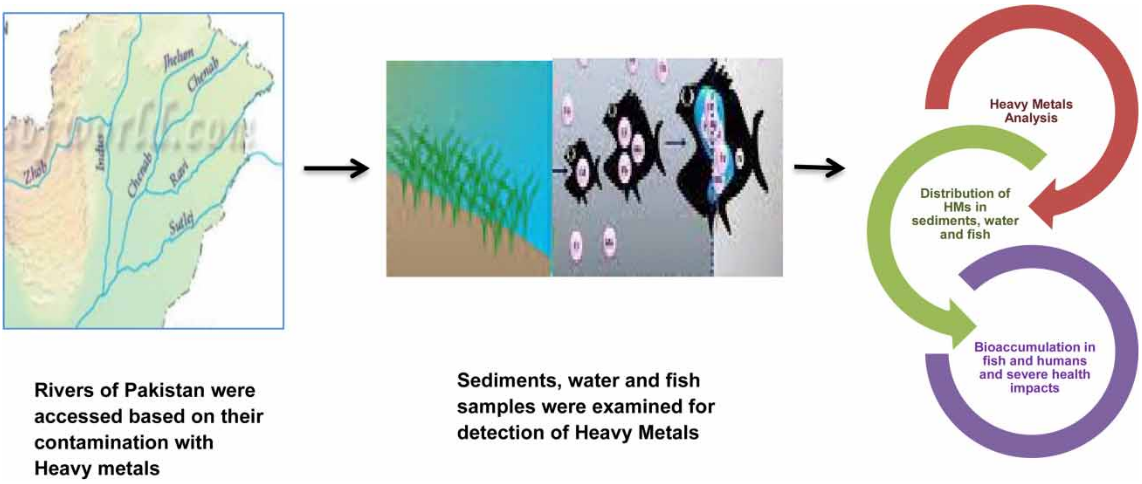
Freshwater ecosystems are being contaminated by heavy metal pollution. The primary source of contamination is wastewater discharged from urban, industrial, and agricultural facilities. The contaminated water contains hazardous amounts of heavy metals mixed in the freshwater ecosystem, causing deleterious impacts on marine life and humans. This review paper highlights the contamination of the freshwater ecosystem of Pakistan with heavy metals. Heavy metals' concentration in sediments, water, and fish were assessed in the food chain, and their relationship with sites and sources was explored. It was observed that heavy metals present in freshwater and sediments bio-accumulate into fish organs. It was also found that some parts of freshwaters such as the rivers Ravi, Chenab, Kabul, and Indus were highly contaminated, and they imposed negative impacts on fish and human health. The River Ravi, receiving a huge amount of industrial and sewage wastewater from urban centers and industries of Central Punjab, was highly contaminated compared to other rivers of Pakistan. The ecosystem health of River Indus was the best among all the rivers of Pakistan due to the enormous volume of water flow and less number of industrial units along with it. Freshwater fish of the rivers Indus, Chenab, and Jhelum are consumable for humans. The presence of heavy metals also causes social, environmental, and economic problems. Therefore, the wastewater should be treated before discharge into freshwater streams and rivers to lessen the harmful impacts of heavy metals on marine life and human beings.

**Key words:** fish, health, heavy metals, river, sediments, water

## HIGHLIGHTS

- The freshwater ecosystems of Pakistan are highly contaminated with heavy metals.
- The rivers Ravi and Kabul are highly contaminated because of discharge of industrial and sewage water.
- The rivers Chenab and Jhelum have moderate metal contamination at a few sites.
- The River Indus is very less contaminated with heavy metals.
- Contaminated fish from polluted rivers can badly impact human health.

## GRAPHICAL ABSTRACT




## INTRODUCTION

Environmental pollution is a major challenge in the recent era of modern society. Among different environmental contaminants, heavy metals are well known and are of greater concern due to their toxicity for living organisms and marine life. Heavy metals are a unique class of naturally occurring elements that persist in the environment for a long time and are not biodegradable (Kanamarlapudi *et al.* 2018). Heavy metals are the natural part of the Earth's crust. The sources of heavy metals into the environment could be natural or anthropogenic activities.

The naturally occurring heavy metals are already present in nature and become a part of the environment by weathering metal-bearing rocks and volcanic eruptions. In contrast, the anthropogenic sources of heavy metals include various industrial, mining, and agricultural practices (Dixit *et al.* 2015). Human mining and smelting operations, industry, irrigation, urban development, transportation, and fertilizers have released specific quantities of heavy metals, which have poisoned the land soil (Chaoua *et al.* 2019). However, heavy metals are persistent and pose a severe health impact on living biota. These toxic impacts of heavy metals could be acute or chronic, which is the real threat for living organisms (Bashir *et al.* 2017). Heavy metal concentration in the oceanic environment is an emerging issue due to anthropogenic activities and industrialization worldwide (Javed & Usmani 2016). Heavy metals enter oceans due to riverine influx, atmospheric deposition, and anthropogenic activities. Over the past decades, anthropogenic contributions to toxins such as heavy metals have grown into the aquatic ecosystem. These heavy metals appear to settle in the underlying sediments. As a result, well-contaminated residues are present in habitats, such as seaports or other existing coastal areas with continuing supplies. These heavy metals have potentially toxic effects and accumulate into biota exposed to the sediments.

## HEAVY METALS

Elements having densities more than 5.0 g/cm$^3$ and atomic masses higher than 20 are considered heavy metals (Gunatilake 2016; Al-Qodah *et al.* 2017; Li *et al.* 2019). Toxic heavy metals which pose hazardous effects are copper (Cu), chromium (Cr), zinc (Zn), cadmium (Cd), arsenic (As), nickel (Ni), cobalt (Co), mercury (Mg), lead (Pb) and so on (Gunatilake 2016; Kanamarlapudi *et al.* 2018). USEPA has designed a list of 13 metals (arsenic, antimony, chromium, cadmium, beryllium, lead, copper, zinc, selenium, mercury, nickel, thallium, and silver) which are considered toxic heavy metals (Ramos *et al.* 2002; Salman *et al.* 2015). Heavy metals are categorized into essential and non-essential based on biological systems. The essential heavy metals are essential for biological activities and required in the body of living organisms (human, animal, and plants) in the form of trace micronutrients such as nickel, iron, and zinc. While, the non-essential heavy metals are non-required elements for the biological system and act as toxins such as lead, cadmium, and mercury (Nies *et al.* 2004; Sharma & Agrawal 2005). The essentiality of heavy metals may vary for different groups of organisms like plants, animals, and microorganisms. However, heavy metals are naturally present in the environment and are considered the essential component for life due to their physiological and biochemical functions in biological systems. They also pose deteriorating impacts on health if they exceed a threshold level. According to Kim & Lee

(2017), the topmost toxic heavy metals are Hg, Pb, As, Cr, and Cd, which severely impact ecosystem health. Heavy metals also cause a disturbance in the microbial balance of the soil and affect the fertility of the soil (Barbieri 2016). Table 1 explains different sources of heavy metals and their potential impacts.

**Table 1** | Different sources of heavy metals and their impacts

| Heavy metals | Sources | Impacts | References |
|---|---|---|---|
| Pb (Lead) | • Acid batteries<br>• Old plumbing system<br>• Lead shots used for hunting<br>• Combustion of leaded gasoline<br>• Lead smelters<br>• Waste incinerations<br>• Ore and metals processing<br>• Utilities | • Effects air quality<br>• Effects freshwater<br>• Effects drinking water<br>• Food items<br>• Various health problems in human beings (Cardiovascular)<br>• Bioaccumulation<br>• Disturb soil function<br>• Effects the global balance<br>• Effect aquatic insect community | Zeitoun & Mehana (2014), Lidman *et al.* (2020), Iqbal (2012) |
| Hg (Mercury) | • Mining<br>• Urban discharge<br>• Agricultural materials<br>• Atmospheric deposition<br>• Combustion and industrial discharge<br>• Cosmetic materials<br>• Religious materials | • Contaminate the fish, sea food and wild life<br>• Cause various disorders in human health and different organs (Immunological, neurological, reproductive & embryonic toxicological effects<br>• Effects on plants and soil health<br>• Accumulation into food, plants, water and soil | Selin *et al.* (2010), Bhan & Sarkar (2005), Rice *et al.* (2014) |
| Zn (Zinc) | • Microplastic pollution in marine ecosystem adsorb heavy metals<br>• Traffic emissions<br>• Industrial emissions<br>• Hazardous waste sites<br>• Mining<br>• Smelting | • Contaminate surface water<br>• Bio-accumulated in fishes<br>• Increase acidity of water ecosystem<br>• Effects aquatic insect community<br>• Soil contamination<br>• $CO_2$ release by Zn production<br>• Hazardous for unborn/newborn | Brennecke *et al.* (2016), Zeitoun & Mehana (2014), Lidman *et al.* (2020) |
| Cu (Copper) | • Industrialization<br>• Moto oils<br>• Paints<br>• Copper IUDs<br>• Agricultural activities<br>• Mining<br>• Metal and electrical manufacturing<br>• Domestic use of pesticides<br>• Leather processing<br>• Automotive brake pads | • Ocean acidification<br>• Bioaccumulation<br>• Effects aquatic creature health (by damaging kidneys, nervous systems, and livers)<br>• Effects on human health<br>• Effects aquatic species<br>• Liver cirrhosis in children<br>• Multiple problems in human health (nausea, diarrhea, chest pain, irritation in respiratory tract) | Anant *et al.* (2018) |
| Cadmium (Cd) | • Excessive fertilization<br>• Incineration of municipal waste & sewage sludge incineration<br>• Metal mining<br>• Processing to ores<br>• Burning of fossils fuels. | • Cause various types of cancer<br>• Bioaccumulation in foods<br>• Air pollution<br>• Groundwater contamination<br>• Different health impacts (Bristling of bones) | Asati *et al.* (2016), Nawab *et al.* (2018a, 2018b), Zeitoun & Mehana (2014) |
| Ni (Nickel) | • Coal combustion<br>• Incineration of waste<br>• Mining activities | • Toxic to plants<br>• Toxic to living organisms | Nieminen *et al.* (2007), Cempel & Nikel (2006), |

(*Continued.*)

**Table 1** | Continued

| Heavy metals | Sources | Impacts | References |
|---|---|---|---|
| | • Smelters<br>• Traffic oil combustion for heat and electricity<br>• Non-ferrous metal production<br>• Metallurgical, chemical and food processing industries<br>• Tobacco smoking<br>• Kitchen utensils<br>• Stainless steel products<br>• Dental and orthopedic implants<br>• Wind-blown dust by weathered rocks and soil,<br>• Volcanic emissions, forest fires<br>• Vegetation | • Effects the ocean and fresh water ecosystem<br>• Effects phytoplankton<br>• Carcinogenic<br>• Effects soil fertility by altering mineral nutrition | Harasim & Filipek (2015) |
| Cr (Chromium) | • Electroplating industries<br>• Leather tanneries<br>• Textile industries<br>• Steel<br>• Industrial combustion<br>• Wood burning<br>• Reuse incineration<br>• fertilizers | • Effects soil fertility<br>• Effects plants growth<br>• Effects germination<br>• Effects yield<br>• Effects physiological processes in plants<br>• Bioaccumulation<br>• Effects human health<br>• Carcinogenic<br>• Effects surface water | Shanker *et al.* (2005), Da Conceicao Gomes *et al.* (2017) |
| As (Arsenic) | • Timber treatment<br>• Agricultural chemicals<br>• Glass production<br>• Metal alloys<br>• Pharmaceutical<br>• Mining<br>• Metal smelting<br>• Burning of fossil fuels<br>• Microplastic particles | • Air pollution<br>• Soil contamination<br>• Water contamination<br>• Inhibition of growth, photosynthesis and reproduction<br>• Lethality<br>• Behavioral changes in individuals<br>• Toxicity to rice seedling/growth | Garg & Singla (2011), Dong *et al.* (2020) |

## CONTAMINATION OF NATURAL WATER, SEDIMENTS AND FISH BY HEAVY METALS

Heavy metals such as zinc, cadmium, mercury, lead, and copper have serious hazardous impacts on the water ecosystem and its biota. As fishes are more sensitive to heavy metal pollution, they accumulate in their tissues and pose poisoning impacts on fish health (Authman *et al.* 2015). Heavy metals contamination is considered a poisoning agent for the health of fish. These metals can effectively influence a fish's vital operations and reproduction, weaken the immune system, and induce pathological changes. As such, fish are used as bio-indictors, playing an essential role in monitoring heavy metals pollution. Harmful devastating metals contaminate freshwater bodies, attacking aquatic species and constituting an ecological issue. The trophic level exchanging conceivably harmful and devastating metals in the natural human ways of life, particularly in fish, has significant ramifications for human wellbeing (Ali & Khan 2018a, 2018b). Heavy metals from industrial, agricultural, and mining activities discharged into rivers are trapped by sediments that pass and bio-magnify along the food chain. Heavy metals are persistent, non-biodegradable, non-soluble, and food chain energetic; they increase their concentration (bio-amplification) and the change in tropic level. Their toxic effect in aquatic systems is a primary focus of scientists due to their health risks to living organisms and human beings via the food chain. So these heavy metals cause severe diseases in fish and human beings (Nyairo *et al.* 2015). Heavy metals are generally viewed as unsafe because of their risk, persistency, and bio-accumulative nature.

Pakistan has numerous freshwater systems such as the Indus, Chenab, Ravi, Jhelum, Sutlej, and Kabul. These aquatic systems used to provide drinking water and healthy fish for centuries. But, in recent decades, due to rapid industrial growth and agricultural activities. These receive untreated sewerage, industrial wastes of big cities, and agricultural waste through countryside areas (Siraj *et al.* 2016). An examination was led in which samples of sediments, water, and fish were gathered from significant streams (Kabul, Chenab, Upper and Lower Indus) from all over Pakistan and dissected by inductively coupled plasma mass spectrometer (ICP–MS), inductively coupled plasma atomic emission spectroscopy (ICP–AES) and atomic fluorescence spectrometry (AFS), separately. Biological hazard investigation of silt uncovered that cadmium (Cd) poisoning represented hazard index as high in Chenab and upper Indus, significant in lower Indus, and moderate in Kabul. Fish tissue utilization for arsenic (As) surpassed security levels for anglers for entire streams, where as cadmium (Cd) surpassed at Chenab and Upper Indus, and lead (Pb) for Chenab anglers. The outcomes show all the metal contaminations from waterways at long last arrive at the Arabian, accordingly may represent a hazard to the marine environment at the national and worldwide scale (Nawab *et al.* 2018a, 2018b). A recent study in China on a huge grown-up populace has established an affiliation among blood level of lead (Pb) and expanded cardiovascular maladies domination (CVD) (Chen *et al.* 2017).

This review article aims to scrutinize the pollution level of rivers of Pakistan concerning heavy metals. This review article reviews available studies on heavy metal pollution in different rivers of Pakistan.

## HEAVY METALS IN RIVER WATER

Freshwater bodies of Pakistan are receiving heavy loads of untreated urban sewage, industrial effluents, and agricultural wastes, which are the main factors for increasing heavy metal pollution in rivers. Therefore, various studies focused on metal contamination of rivers of Pakistan.

Khan *et al.* (2004) evaluated the concentrations of heavy metals in river water in high and low flow seasons collected from the River Jhelum at Muzaffargarh. It was found that Pb, Cr, Ni, and Cd concentrations were higher than WHO limits for drinking water. Results indicated that this water was not fit for drinking, but Pb and Cd concentrations were within safe limits compared to US EPA standards for irrigation purposes. Heavy metals such as Zn and Mn's concentrations were lower than both the US EPA and WHO standards for drinking water. Iron (Fe) concentration under low flow season was very high and was a potential risk for humans. Copper (Cu) concentration was found higher than the limits for irrigation purposes even in the high flow season.

The time and space variations of the amount of heavy metals at 7 sampling sites in NullaAik, a major river affluent of the Chenab River, were identified by Qadir *et al.* (2008). Concentrations of Cr and Pb at all sampling sites were higher than National Environmental Quality Standard (NEQS) standards of Pakistan (at five sampling sites) and Cd in two sample sites. This water is used to irrigate people and livestock, which is very dangerous. NullaAik was heavily contaminated in the midstream compared with up and downstream. The disposal caused the high metal contamination in the middle of the NullaAik municipal waste and sewage from the Sialkot district.

The accumulation of heavy metal ions in water from the Kotri and Ghulam Muhammad dam in the Indus River was studied for a year by Arain *et al.* (2009). They found the concentrations of Fe to be 15.60–164 μg/l, Cr 238–1,383 μg/l, Mn11.20–418 μg/l, Cu 22–285 μg/l, Ni 2.14–72 μg/l, and Co 8.4–47.8 μg/l in water. Fe and Cu were found to be higher than WHO limits, while all other metal ions were within safe limits. It had been found that peak water flows in summer had been detected, hence fewer metal emissions due to its dilution. However, considerable pollution was due to reduced water flow in winter (December to February). The variation in metal ions according to the movement of water was observed. Strong metals were reduced in the summer due to the high water flow, while heavy metals accumulated during the winter due to low water flow. The concentration of iron and copper at all the sites concerning other metals was found to be very high than safe.

The water of River Chenab at Head Marala was also examined for heavy metal pollution. Heavy metal concentrations were found to be 0.08–0.24 ppm for Fe, 0.09–0.23 ppm for Zn, 0.1–0.36 ppm for Cu, and 0.01–0.3 ppm for Pb. Sources of these heavy metals were sewerage, industrial wastes, and mine-contaminated sediments (Iqbal *et al.* 2010).

The lakes of Haleji and Keenjhar from the River Indus (Shafiq *et al.* 2011) were polluted by contaminated water. They had chosen four locations (surface, beach, 3–4 ft deep, and a position away from the coast) (about 75–80 meters). For two years, they sampled the contaminated water. All heavy metals were within the permissible limits. Only metallurgical waste, drugs, pesticides, and mines wastewater had found arsenic concentrations higher than the WHO threshold. Concentration of various heavy metal As 0–0.23, Cr 0–0.04, Cu 0–0.1, Fe 0.04–0.78, Pb 0–0.045, and Mn 0.015–0.255(ppm) were also reported. Siraj *et al.* (2016) identified the contamination of heavy metal in the waters of River Kabul, Pakistan. Heavy metal concentrations (μg/l) were found in the range of Zn 54.8–226.1, Ni 33.3–55.5,Cr 18.8–23.0, Cu 8–23.8, Cd16.7–57.7, Pb 3.7–70.8, Hg 13.1–38.5, and Mn 16.7–38.5, respectively. Sequence of metal accumulation was zinc>lead>nickel>cadmium> manganese>mercury>chromium>copper. Heavy metal sources were draining effluents from sewage, industrial sources, and agricultural runoff. Mercury concentration in water samples of all sites was higher than Pakistan's NEQS. Concentrations of all other heavy metals were within standards. Higher mercury levels can pose serious threats to aquatic and human life.

Shafi *et al.* (2018) investigated the effect of unprocessed mechanical and urban discharge on the River Ravi. It was examined by 11 polluted and non-polluted sites during the low stream season and investigated for substantial metals concentration and physicochemical parameters. The oxygen level fell beneath as far as possible for the spread of oceanic life such as fish other aquatic animals and as the waterway courses through Lahore up to BallokiHeadworks. Manganese (Mn) and lead (Pb) concentrations were more than the allowable limits for oceanic biological systems. The most elevated level of manganese (Mn), zinc (Zn), nickel (Ni), cadmium (Cd), and lead (Pb) identified in the stream was 20.0 μg/L, 70.0 μg/L, 190.0 μg/L, 2.0 μg/L, and 72.0 μg/L, respectively. Discoveries uncovered that streams at downstream locales of wastewater conveying channels could not provide an appropriate place for fish and other sea life because of their inadequate oxygen level.

Ali & Khan (2018a, 2018b) did an examination study intended to survey the convergences of the considerable metals in the silt, water, and distinctive freshwater fish in River Kabul, Pakistan. The normal convergences of the four significant metals followed the order: Ni >Pb> Cr>Cd. Expanding patterns in convergences of devastating concentrations of metals, particularly on lead (Pb) and cadmium (Cd) downstream, may become normal due to anthropogenic contamination all along the stream. More overwhelming metal targets at the central two locales, i.e. Nowshera and SarDaryab, could be required because of defilement of the stream water from mechanical effluents, household sewage, and farming spillover on these terminals. Unprocessed and polluted wastewaters from all the ventures from Peshawar were released into the Bara River, which flows into the Kabul. The concentration of heavy metals in Kabul at contrasting sampling sites is given in Table 2.

**Table 2** | Heavy metal concentration in water of River Kabul (Pakistan) at different sampling sites

| | Meta concentration (mg L$^{-1}$) | | | |
|---|---|---|---|---|
| **Site** | **Cr** | **Ni** | **Cd** | **Pb** |
| Warsak Dam | 0.28 ± 0.025 | 0.757 ± 0.465ab | 0.015 ± 0.005b | 0.337 ± 0.231 |
| SarDaryab | 0.157 ± 0.040 | 1.573 ± 0.716ab | 0.023 ± 0.008ab | 0.337 ± 0.193 |
| Nowshera | 0.480 ± 0.257 | 0.368 ± 0.294b | 0.038 ± 0.009a | 0.810 ± 0.197 |
| Jahangira | 0.23 ± 0.071 | 2.120 ± 0.799a | 0.037 ± 0.008a | 0.420 ± 0.277 |
| Average | 0.290 | 1.204 | 0.028 | 0.476 |

Results are shown as mean of three individual samples ± standard deviation (SD). Means in column followed by different letters are significantly at $p \leq .05$ (one-way ANOVA, Tukey Test).

From Table 2, it can be seen that the concentration of heavy metals in River Kabul depicted the following pattern: Ni>Pb>Cr>Cd. The concentration of Ni is highest (1.204 mg/L), followed by Pb (0.479 mg/L) then, Cr (0.290 mg/L) and Cd (0.476 mg/L). Saleem *et al.* (2019) collected water samples from three freshwater supplies of Pakistan in three seasons (pre-monsoon, rainstorm, and post-monsoon). The chosen metals like (Zn, Cd, Cr, Co, Fe, Cu, Ni, Mn, Pb, and Sr) and the physicochemical parameters (TSS, $Cl^-$, pH, DO, EC, TDS) were examined. Moderately higher concentrations were recorded in Co, Pb, and Sr, whereas; lower level metals were Cd, Mn, and Zn. Most metals revealed significantly higher amounts within the pre-monsoon period except cobalt (Co). These metals' normal level surpassed the international quality standards. Contamination appraisal focused on noteworthy contamination, primarily by Pb, Cr, Cd, and Ni. Assessment of wellbeing hazard demonstrated that Ni, Co, Cd, Cr, and Pb were related to large dangers (HQing>1), particularly in the children. The initial investigation of components showed anthropogenic commitments of Ni, Co, Cr, Cd, and Pb, whereas cluster investigation shows noteworthy spatial changeability. The most noteworthy metal contamination was found at locales close to the passages of the stores and/or close to the urbanized zones. The consideration uncovered that the most potent poisons of concern were Ni, Co, Cd, Cr, and Pb; hence, quick therapeutic measurements should be actualized to maintain sound oceanic biological systems.

## HEAVY METALS IN RIVER SEDIMENTS

Published data on heavy metal content in river sediments in Pakistan was minimal as many researchers focused on water and fish accumulation of heavy metals.

Ashraf *et al.* (1991) calculated heavy metal concentration in the sediments in three Indus River freshwater lakes. They observed that the concentration of Zn and As was high, respectively, on the Lloyd dam; Ni, Cd, Mn at the Terbella dam; while the concentration of Hg and Pb at the Chashma dam was high. They emphasized the need to further analyze the source and transport in the Indus River for the dispersal of heavy metals.

Sediments from various Indus River dams had been calculated for heavy metal content by Tariq *et al.* (1996). Strong arsenic (As) levels were observed in Lloyd dam sediments. Chashma dam sediments had high mercury (Hg) levels, while Guddu barrage sediments had high lead (Pb) levels. High sediment contamination was observed at locations near sewage sources and industrial effluents.

The assessment of heavy metal levels in sediments by Rauf *et al.* (2009a, 2009b) reflected the experience of metal input at this site. Higher than American EPA limits in Ravi sediments were observed in Cu (3.38–159.79 μg/g) and Cr (3.60–57.40 μg/g). Ravi River sediments contain heavy metals in the following series: Cu>Cr>Cd>Co. Cu was high in the main River Ravi and tributary samples, while Cr was high only in tributaries. The concentrations of Co and Cd were found to be safe. The Shahdara Bridge and neighboring tributary were heavily contaminated by urban and industrial waste from the Lahore District.

The effects of urban effluents in Ravi River sediments on heavy metal concentrations were studied by Shakir *et al.* (2013). Robust and low seasonal flow samples were obtained. In comparison with the acceptable standards of global, WHO, and EPA, the concentrations of most metals were high in water during low flows. Fit for drinking, leisure, and irrigation, water from the River Ravi had been considered unfit. Heavy metals were also anticipated to contaminate fish. Fe concentrations were found to be the largest (0.563–52.50 mg/L) and (91.85–384.15 mg/kg), while the concentrations of Cd in river water and sediments were the lowest (0.028–2.34 mg/kg). River Ravi contamination was majorly concerned with wastewater originating from municipal and industrial effluents. The lower portion of the River Ravi was not supposed to support marine fauna if no significant steps were taken immediately.

Idrees *et al.* (2017) calculated the standard deviation and heavy metals concentration in water sampled from three streams within the Charsadda locality. The concentrations of heavy metals such as Co, Cr, Cu, Mn, Ni, and Zn in three water samples were found within the extent of 0.241.13 mg/kg, 0.16–0.35 mg/kg, 0.01–0.08 mg/kg, 1.15–3.47 mg/kg, 0.38–1.59 mg/kg, 1.71–1.97 mg/kg and 0.22–1.49 mg/kg, respectively. Co and Mn levels exceed the recommended WHO (0.04 mg/L, 0.1 mg/L) limits. The Jindi and Swat streams were found to have exceeding levels of Co and Mn. These elevated levels may be due to anthropogenic interruptions, climatic statements, agrarian exercises, and untreated urban and mechanical losses. Another elevated concentration was Cr (0.05 mg/L) found in Kabul (0.35 mg/L). Tannery effluents were responsible for the abnormal metal levels. Mn concentration was too found higher than the WHO reasonable limit (0.1 mg/L).

Ali & Khan (2018a, 2018b) distinguished overwhelming metal focuses on the residue of River Kabul at various testing destinations, as presented in Table 3. Groupings Pb, Cr, Cd, and Ni in the silt waterway were in the scope of on dry weight basis 23.3–88.7, 56.1–251.7, 1.8–4.0, and 5.5–29.0 mg $kg^{-1}$, separately. The normal convergences of 4 substantial concerning metals in the waterway residue followed the order: Ni>Cr>Pb>Cd. However, the groupings of metals did not show a predictable pattern of progress from the upstream side to the downstream site.

Table 3 depicts the heavy metal concentrations in the river Kabul, and it exhibited the following order: Ni>Cr>Pb>Cd. The concentration of Ni is highest (137.2 mg/L), followed by Cr (53.8 mg/L), then Pb (16.9 mg/L), and Cd (3.2 mg/L).

Javed *et al.* (2018) determined heavy metal concentrations by utilizing inductively coupled plasma-optical outflow spectrometry (ICP-OES). Samples were collected from the surface silt of Namal Lake. The metals were in the following order Al>Fe>Mn>V>Zn>Cr>Ni>Cu>As>Co>Pb>Cd. The noteworthy significant

**Table 3** | Heavy metal concentrations in sediments of River Kabul (Pakistan) at different sampling sites

| | Metal Concentration (mg kg$^{-1}$ dry weight) | | | |
|---|---|---|---|---|
| **Site** | **Cr** | **Ni** | **Cd** | **Pb** |
| Warsak Dam | 78.3 ± 36.5 | 61.3 ± 51.2b | 4.0 ± 0.45a | 24.0 ± 12.8 |
| SarDaryab | 25.0 ± 4.4 | 251.7 ± 62.1a | 3.3 ± 1.4ab | 5.5 ± 2.3 |
| Nowshera | 88.7 ± 72.9 | 56.1 ± 26.4b | 3.8 ± 0.65ab | 9.0 ± 11.4 |
| Jahangira | 23.3 ± 7.2 | 179.7 ± 67.1ab | 1.8 ± 0.23b | 29.0 ± 16.5 |
| Average | 53.8 | 137.2 | 3.2 | 16.9 |

Results are shown as mean of three individual samples ± standard deviation (SD). Means in a column followed by different letters are significantly different at $p \leq .05$ (One-way ANOVA, Turkey Test) by Ali & Khan (2018a, 2018b).

relationships were found among abundant metals As(69.0) > Ni(15.4) > Cu(10.0) > Cr(4.3) > Pb(3.66) > Zn(1.7). The outcomes from cluster examination, a relationship of abundant metals that the metals derived from characteristic and anthropogenic sources.

## HEAVY METALS IN RIVER FISH

Various researchers studied heavy metal concentrations in different freshwater species captured from the rivers of Pakistan.

Yousafzai *et al.* (2009) studied the heavy metal contamination of freshwater trout. The field of investigation consisted of the section of the Kabul River, which had now held waste, and the Kalpani filthy canal (having sewage from cities of Mardan, Risalpur, and some other towns). Intense metal ions ($Cr^{3+}$, $Zn^{2+}$, $Cu^{2+}$, $Ni^{2+}$, and $Pb^{2+}$) were analyzed in the liver tissues of sampled fish. Zn > Cu > Pb > Ni > Cr presented a concentration of heavy metals in fish liver.

For a year, Rauf *et al.* (2009a, 2009b) identified concentrations of Cr and Cd from River Ravi Siphan to Head Baloki in three species of freshwater fish (*Cirrhinus mrigala, Labeo rohita*, and *Catla catla*). The concentrations of Cd and Cr were found to be improved relative to other fish species in *C. catla*. Higher levels of Cd and Cr in the liver and lower gills of all sampled fish were recorded. Head Baloki fish were heavily contaminated relative to other areas.

Yousafzai *et al.* (2010) assessed Pb, Zn, Cr, Ni, and Cu concentrations in two freshwater omnivorous and carnivorous fishes, *Wallago attu* and *Labeo dyocheilus,* in the River Kabul, closely sampled from Nowshera. *L. dyocheilus* was found to accumulate 65% more heavy metals than *W. attu*. Metal accumulated in the same order in both fish species (Zn > Cr > Cu > Pb > Ni > Cd). Metal accumulation was high in the skin of *W. attu* and the liver of *Labeo*.

The effect of wastewater containing dangerous metals in the Ravi River was studied by Jabeen *et al*. and others (2012). The toxicity of water samples containing many heavy metals (Cr, Zn, Ba, As, Ni, and Al) were sampled from the Shahdara, Head Baloki, and Sidhnai dam *C. catla*, *C. mrigala*, and *L. rohita* were fish containing these heavy metals concentrations with significant seasonal variations. The abundance of zinc and aluminum was high in all sampling sites. In addition, the accumulation of heavy metals in the kidney was high compared to the liver relative to other species.

In another study, Naeem *et al.* (2011) showed the concentrations of heavy metals sampled from Ghazi, Ghat, Indus River in *Oreochromis niloticus* muscle tissue. The subsequent Zn > Cu > Mg > Mn orders revealed that Zn had the highest heavy metal concentration and Mn was the lowest. Cd was not found as the only heavy metal. The tolerable limits were found for all heavy metals.

Siraj *et al.* (2016) investigated heavy metals in the liver, gills, skin, and muscle tissues of the freshwater fish *W. attu* captured from Kabul, Pakistan. Metals were evaluated by atomic absorption spectrophotometer. The Zn concentration varied between 485 and 921 $\mu gg^{-1}$, whilst that of Ni (99.3–446.0), Cr (91.3–539.3), Cu (52.0–635.3), Pb (60.3–82.7), Fe (91.0–122.0), and Hg (74.0–103.0) $\mu gg^{-1}$ in.various tissues of *W. attu*. Higher levels in the skin followed the order like gills, muscles, and liver, respectively. The amount of zinc was greater in all tissues, and mercury concentration was lowest. The key target organ for metal accumulation was the skin, which depicts that metal entry into the fish body was due to direct exposure to metals.

Yousafzai *et al.* (2017) inspected and compared the overwhelming bioaccumulation of metals in *L. rohita* and *Cyprinus carpio* from Sardaryab, a tributary of the River Kabul. Nuclear retention spectrometry was used for diverse organs, counting gills, livers, and muscles. The metals of concern were Zn, Cr, Pb, and Cu. Lower metal levels were determined in both species' muscles and higher in livers. Cr and iron were profoundly concentrated metals within the gills and livers of both species. The concentration of $0.154 \pm 0.011$, $0.199 \pm 0.0079$, and $0.024 \pm 0.008$ μg/g of chromium was found within the gills, livers, and muscles of *C. carpio*, separately. Essentially, the gills, liver, and muscles of *L. rohita* contained $0.133 \pm 0.008$, $0.165 \pm 0.01$, and $0.019 \pm 0.006$ μg/g of Cr, separately. The highest level of iron was found in carp within the extent of $0.086 \pm 0.01$ μg/g in gills and $0.067 \pm 0.011$ μg/g in muscles, comparatively. Considering metals were present within the US prescribed recommended daily allowance (RDA) limits, no prompt hazard in utilization for humans was found. Information revealed that omnivorous bottom feeder *C. carpio* presented higher metals than *L. rohita*.

Iqbal *et al.* (2017) researched the Indus River, which runs from the Himalayas, the Karakorum to the Arabian Sea, irrigating the plains of Punjab, KPK, and Sindh. In the fish of the River Indus, the order of bioaccumulation was Fe>Zn>Ni>Cu>Pb>Cr with concentration values of 108.5>43.9>5.7>4.8>1.5>0.6 mg/kg, respectively.

Alamdar *et al.* (2017) studied Chenab, which goes through the Punjab region and is a significant stream that saturates horticultural fields. The levels for bio-accumulated metals in fish from Chenab was Zn>Cu>Mn>Co>As> Ni>Pb with normal concentrations of 45>4.99>3.1>1.43>1.12>0.34>0.31 mg/kg, respectively.

Iqbal *et al.* (2017) studied metal accumulation in two freshwater fish gathered from Indus Stream, Pakistan. Nuclear assimilation spectroscopy was used to analyze samples. Most noteworthy collected samples revealed high metal substances in winter and the least in summer. Within the body of *L. rohita*, the heavy metal range was under limits Fe>Zn>Ni>Cu>Pb>Cr>As, and the tissues with the most were liver>gills>skin>muscles. Bioaccumulation was distinctive among species. Fe was the most noteworthy, and As was the slightest amassed heavy metal in these fish species. Concentrations of Ni, Cr, Zn, Cu, and Fe in *W. attu* were higher at (83%), (50%), (26%), (64%), (2.95%), respectively as compared to *L. rohita*. Pb (67%) and As (22%) were higher in tissues of *L. rohita* compared to *W. attu*. Generally, 10% more metal accumulation was found in *W. attu* compared to *L. rohita*.

Ali & Khan (2018a, 2018b) led an examination work to evaluate the convergences of copper (Cu) and zinc (Zn) at the site of Channagachua, of River Swat, Malakand division River Barandu and in the silt, water, and meat of freshwater fish. The selected destination of two rivers was examined for metals by nuclear ingestion spectrophotometer. The average concentration of zinc (Zn) and copper (Cu) in fish muscles at various areas of Swat were 0.57–2.38 and 1.28–3.95 mg $kg^{-1}$, separately, after relating fixations for River Barandu were 0.67–1.70 and 3.27–5.18 mg $kg^{-1}$ wet weight. The two metals demonstrated significantly lower bioaccumulation in fish muscles as this factor esteems lower than 1. The gills and liver exhibited more metal collections as compared to muscles. The possible hazard evaluation showed that these metals did not represent any toxicological danger.

Substantial metals in the various fish species of various testing destinations of Kabul have reported in Table 4.

Normal convergences of Pb, Ni, Cr, and Cd as shown by Table 4 in fish muscle tests in species of fish at various examining locales of the waterway went from 12.3 to 33.0, 33.2 to 109.2, 0.98 to 1.5, and 13.9 to 29.6 mg $kg^{-1}$ wet weight, separately. Fixations of metals in the fish samples, for the most part, had the order: Ni>Pb>Cr>Cd.

Lakes are the essential wellspring of business fisheries and hotspots for transient birds. Low convergences of abundant metals in lake fish make lakes more secure and simpler to oversee for biodiversity havens and ensured wetlands. Higher convergences of overwhelming metals in waterways present a danger to various trophic levels as well as human wellbeing because of the utilization of fish straightforwardly from the stream.

Hadyait *et al.* (2019) discovered heavy metals concentrations in muscles by conducting 72 fish tests of the eight chosen species, four marine (*Pampus chinensis*, *Otolithes ruber*, *Trachipteridae*, and *Oncorhynchus tshawytscha*) and four from freshwater (*L. rohita*, *Catla*, *Rita*, and *W. attu*). The fish samples were gathered from three superstores in Lahore, Pakistan. The readied fish tests were examined to assure Cr, Pb, and Cd focuses by utilizing the ICP-OES. It was discovered that Cd ($0.294 \pm 0.001$ mg/kg) focus was the most noteworthy in *L. rohita* gathered from Metro Superstore while the least level ($0.023 \pm 0.000$ mg/kg) was in the *O. shawytscha* of the equivalent superstore. Species savvy convergence of Cd shifts fundamentally. The centralization of Cr ($0.172 \pm 0.001$ mg/kg) was the most elevated in *O. shawytscha* gathered from the Main Fish Market of Lahore, while the least level ($0.002 \pm 0.001$ mg/kg) was in *L. ohita* gathered from Hyperstar superstore. The grouping of Pb

**Table 4** | Heavy metal concentrations (mean ± SD) in muscles of different fish species from River Kabul (Pakistan) at different sampling sites

| Site | Fish species | Heavy metal concentration (mg $kg^{-1}$ wet weight) in muscles | | | |
|---|---|---|---|---|---|
| | | Cr | Ni | Cd | Pb |
| Warsak dam | Clupisoma naziri | 15.7 ± 4.3 | 31.2 ± 19.9 | 1.3 ± 0.13 | 7.5 ± 4.9 |
| | Glyptothorax cavia | 13.3 ± 3.9 | 46.0 ± 11.0 | 1.7 ± 0.22 | 33.7 ± 16.5 |
| | G. punabensis | 8.0 ± 1.8 | 39.0 ± 24.4 | 1.3 ± 0.26 | 15.5 ± 11.8 |
| | Average | 12.3 | 38.7 | 1.4 | 18.9 |
| SarDaryab | Barilius vagra | 9.5 ± 4.0 | 98.3 ± 46.0 | 1.6 ± 0.29 | 16.2 ± 1.8 |
| | C. naziri | 13.7 ± 1.8 | 98.0 ± 42.0 | 1.1 ± 0.20 | 9.5 ± 10.0 |
| | G. cavia | 15.7 ± 6.2 | 116.3 ± 45.6 | 1.4 ± 0.36 | 16.2 ± 8.5 |
| | Tor putitora | 12.0 ± 4.0 | 94.5 ± 27.7 | 1.2 ± 0.18 | 13.7 ± 12.4 |
| | Average | 12.7 | 102.0 | 1.3 | 13.9 |
| Nowshera | C. mrigala | 40.2 ± 32.5 | 38.4 ± 12.2 | 2.0 ± 0.37 | 41.0 ± 23.8 |
| | C. naziri | 37.3 ± 37.5 | 19.8 ± 7.7 | 1.3 ± 0.70 | 18.3 ± 17.0 |
| | C. carpio | 38.7 ± 25.6 | 45.5 ± 47.6 | 1.0 ± 0.24 | 34.2 ± 23.5 |
| | Notopterus chitala | 15.8 ± 10.6 | 29.2 ± 22.0 | 1.6 ± 0.51 | 25.0 ± 17.4 |
| | Average | 33.0 | 33.2 | 1.5 | 29.6 |
| Jahangira | C. mrigala | 15.5 ± 7.7 | 106.2 ± 19.6 | 1.3 ± 0.32 | 19.5 ± 7.8 |
| | C. naziri | 16.2 ± 4.1 | 129.0 ± 35.3 | 0.90 ± 0.18 | 15.2 ± 15.7 |
| | C. carpio | 11.0 ± 1.5 | 122.5 ± 49.4 | 0.82 ± 0.10 | 26.7 ± 12.7 |
| | Schizothorax plagiostomus | 9.0 ± 4.4 | 79.0 ± 15.2 | 0.92 ± 0.55 | 20.3 ± 13.5 |
| | Average | 12.9 | 109.2 | 0.98 | 20.4 |

Results are shown as mean of three individual fish species ± standard deviation.

(0.057 ± 0.000 mg/kg) was the most elevated in *O. tshawytscha* gathered from Metro Superstore while the least (0.012 ± 0.001 mg/kg) in *O. ruber* of the equivalent superstore. The source's insightful t-test shows that: a) Cd fixations fluctuate altogether, while Cr and Pb foci differed non-essentially when marine and freshwater species were looked at: b) The scope of Cr (0.002–0.172 mg/kg) and Pb (0.011–0.057 mg/kg) was inside cutoff points and Cd (0.023–0.297 mg/kg) was greater than the WHO worldwide benchmarks (0.123 mg/kg for Pb, 0.050 mg/kg for Cd, and 0.1 mg/kg for Cr) in more fish types of primary Fish Market Lahore, Hyperstar and Metro store.

Nisa *et al.* (2019) discovered that presentation to heavy metals is a significant general wellbeing concern. The examination was an extensive experiment to decide the convergences of metals in expired freshwater turtles, and fish samples gathered from already decided inspecting destinations of the Chenab and Ravi waterways. Altogether, 35 expired turtles and fish liver samples were gathered and promptly put away at −20 °C for the initial investigation. Overwhelming metals centralizations of Cu, Cd, Zn (0.073, 0.0042, 0.169 mg/$L^{-1}$) in water tests from the Ravi, and 0.084, 0.145, and 0.0041 mg/$L^{-1}$ were gathered from the Chenab. Ni, Cr, Co, Pb concentration were lower 0.045, 0.121, 0.018, 0.06 mg/$L^{-1}$ in the Ravi, while at 0.045, 0.121, 0.018, 0.064 mg/$L^{-1}$ in the Chenab, they were fundamentally higher. The mean convergences in the liver samples for Ni and Cu shifted fundamentally ($P<0.01$) from the Ravi and Chenab. Despite the examining destinations, the average groupings of Pb and Cu recorded the most extreme in *K. smith* (3.85 ± 0.43 mg/$kg^{-1}$ and 26.54 ± 4.53 mg/$kg^{-1}$, separately), Ni, Cd, and Co in *L. punctata* and Zn in *K. tecta* (42.48 ± 4.06 mg/$Kg^{-1}$). The considered metals, Zn was recorded as generally bottomless (39.73 ± 2.28 mg $Kg^{-1}$), and Cd fixation was seen as least (0.188 ± 0.017 mg $Kg^{-1}$) in turtles samples gathered from all examining destinations

Ali & khan 2019 studied four metals in fish from Stream Swat, Stream Panjkora, and Stream Barandu. The least significant differences were analyzed by one-way ANOVA (Tukey test) in distinctive destinations of these streams. An increasing Ni bioaccumulation was discovered from upstream to downstream in the waterways of Barandu and Panjkora. The normal concentrations were 12.3–33.0 mg $kg^{-1}$ damp weight for Cr, 33.2–109.2 mg $kg^{-1}$ for Ni, 0.98–1.5 mg $kg^{-1}$ for Cd, and 13.9–29.6 mg $kg^{-1}$ for Pb in distinctive locales of Stream Kabul, Pakistan. Most elevated metal levels were within fish muscles at Batkhela, an urban and moderately contaminated location in Swat. A downstream location at Stream Panjkora, Khazana also reported elevated levels of Ni within fish muscles. At downstream levels of Barandu and Panjkora, there was consistently increased Ni concentration, which could be due to marble industry effluents and other sources of Ni. The most frequent higher concentration of Ni was investigated at Panjkora and Barandu, and Pb concentration was higher in Swat and Panjkora.

Liu *et al.* (2020) examined the bioaccumulation and concentrations of metals in silt bed in freshwater fish tissues sampled from 5 areas on Swat Waterway, Pakistan. The WHO reported surpassed security values of Cd concentration within the downstream (30%) water samples, whereas the remaining chosen heavy metals did not cross security limits. The biological chance (Eri) for silt appeared to be a significant biological hazard ($80 \leq Eri < 160$) to over-the-top environmental hazard ($Eri > 320$) for Cd, Pb, and As. In contrast, at the downstream level, the potential environmental hazard (RI) appeared significant level ($190 \leq RI < 380$). Upstream parcel of stream presented lower levels compared to downstream. Moreover, the concentration order of heavy metals in fish tissues was in the order Zn>Cd>Pb>Cr>As>Cu>Ni. The chosen heavy metals in the think about a zone was inside the reasonable limits of all the fish tissue tests. The neighborhood anglers and tenants had no potential health concerns (non-carcinogenic <1 and carcinogenic). However, it may pose a health concern in the future due to the open dumping, untreated ceaseless wastewater stream from inns, machinery, and horticulture, directly tipping of civil waste. Downstream water was more contaminated as compared to the upstream. Suitable administration approaches to deal with heavy metals' aggregation in ecologies and administration of sea-going life ought to be the priority needs of the states around the world to protect delicate surroundings. Idrees *et al.* (2017) measured the standard deviation and average concentrations of heavy metals from three waterways destinations in fish species at Charsadda. In case of fishes, Zn, Co, Cr, Cu, Mn, Ni, and As level extended from 0.602–1.583 mg/kg, 0.23–0.25 mg/kg, 0.47–0.62 mg/kg, 0.035–0.074 mg/kg, 0.820–0.852 mg/kg, 4.165–4.244 mg/kg, 0.704–0.993 mg/kg and mg/kg individually. Despite the fact, Ni level was lower in water samples. It may be credited to moderate Ni concentration in fishes.

The results of water samples at Head Sulemanki are described in Table 5. 0.1410 ± 0.01674 mg/l of Fe was reported, while the amount of iron in *C. catla, W. attu*, and *T. nilotica* fish was 1.8751 ± 0.28851, 1.5285 ± 0.06232, and 2.4517 ± 0.53667, which showed that *T. nilotica* contained more Fe than the other two species of fishes. The amount of Ni in *T. nilotica* fish was more than the other two types of fish, and in the water sample, Ni was 0.0273 ± 0.00203 mg/l. While the amount of Cr, Cd, and Pb in these types of fishes were ordered as *W. attu*>*C. catla*>*T. nilotica*, *W. attu*>*T. nilotica*>*C. catla*, and *T. nilotica*>*C. catla*>*W. attu*. Analysis can be seen in Table 5.

**Table 5** | Descriptive analysis of heavy metals in three fish species

| Metals | N | C. catla $\bar{X} \pm S\bar{x}$ | W. attu $\bar{X} \pm S\bar{x}$ | T. nilotica $\bar{X} \pm S\bar{x}$ | Water $\bar{X} \pm S\bar{x}$ |
|---|---|---|---|---|---|
| Fe | 15 | 1.8751 ± 0.28851 | 1.5285 ± 0.06232 | 2.4517 ± 0.53667 | 0.1410 ± 0.01674 |
| Ni | 15 | 0.2531 ± 0.3244 | 0.2235 ± 0.02035 | 0.2663 ± 0.01552 | 0.0273 ± 0.00203 |
| Cr | 15 | 0.0351 ± 0.00391 | 0.0441 ± 0.00548 | 0.0273 ± 0.00260 | 0.0113 ± 0.00067 |
| Cd | 15 | 0.0600 ± 0.00926 | 0.0947 ± 0.02223 | 0.0778 ± 0.00847 | 0.0617 ± 0.00581 |
| Pb | 15 | 0.5435 ± 0.07696 | 0.5070 ± 0.03813 | 0.5663 ± 0.07015 | 0.0983 ± 0.00498 |

Aamir *et al.* (2020) led a study in various organs of *Sperata sarwari* to examine the collection of Cd, Hg, and As. The samples were collected from Head Taunsa, Indus River, Dera Gazi Khan, Pakistan. Cd aggregation (ppm) was accounted for most extreme in the kidney (83.05 ± 1.25) and liver (82.45 ± 0.85). The accumulation of Cd was found in the order kidney>liver>muscles>gills>skin (Figure 1).

The collection of arsenic (ppm) was most extreme in the kidney (0.63 ± 0.02) and gills (0.61 ± 0.02) of fish species. The arsenic accumulation was found in the specific order kidney>gills>liver>muscles>skin (Figure 2).

Aggregation of mercury (ppm) was discovered in body organs of fish and extreme levels found in the kidney (2.66 ± 0.02) and liver (2.55 ± 0.03) while less accumulated in the gills (1.93 ± 0.03) and muscles (1.44 ± 0.04). Aggregation was found in the accompanying order kidney>liver>muscles>gills>skin (Figure 3).

Ali *et al.* (2020) designed an experiment to determine the Pb, Cd, Cr, and Ni concentrations in the River Shah Alam, a major tributary of the Kabul River, Pakistan. Different samples from water, sediments, and fish parts were analyzed by atomic absorption spectrophotometry. Aggregation of heavy metals was examined in fish muscles, gills, skin, kidneys, and liver. The wet weight concentration of metals such as Cr, Ni, Cd, and Pb ranged between 30.5 ± 41.9 to 70.8 ± 12.1 mg $kg^{-1}$, 16.7 ± 10.2 to 103.5 ± 114.1 mg $kg^{-1}$, 1.1 ± 0.18 to 2.5 ± 0.21 mg $kg^{-1}$,

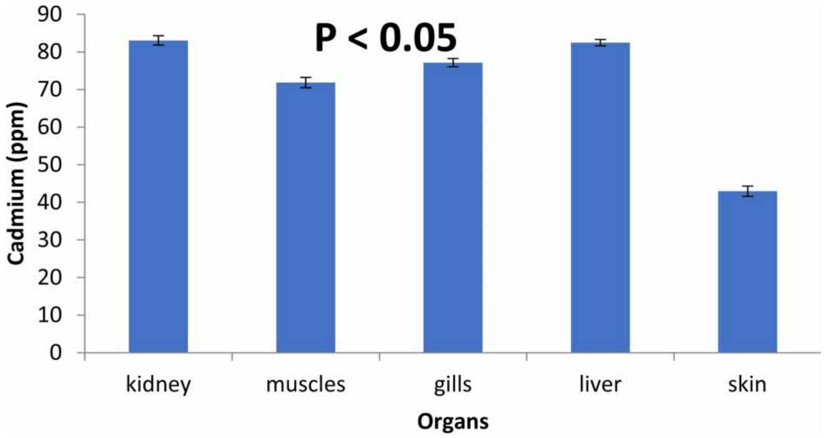



**Figure 1** | Accumulation of Cd in body organs of fish from Head Taunsa.

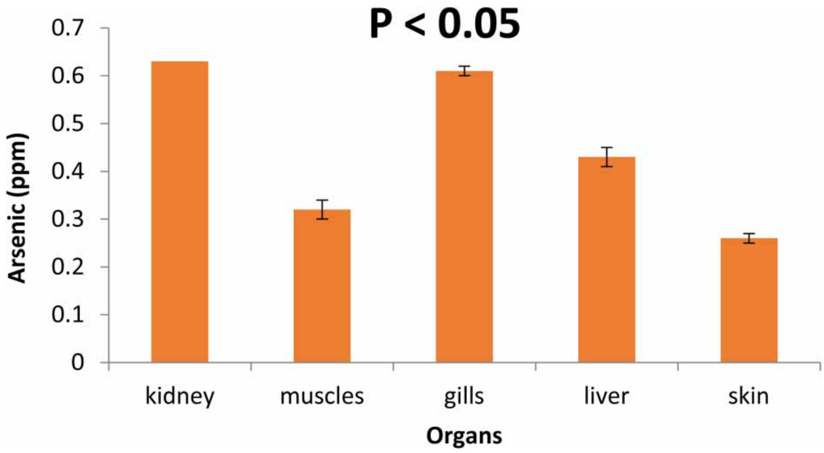



**Figure 2** | Accumulation of arsenic in body organs of fish from Head Taunsa.

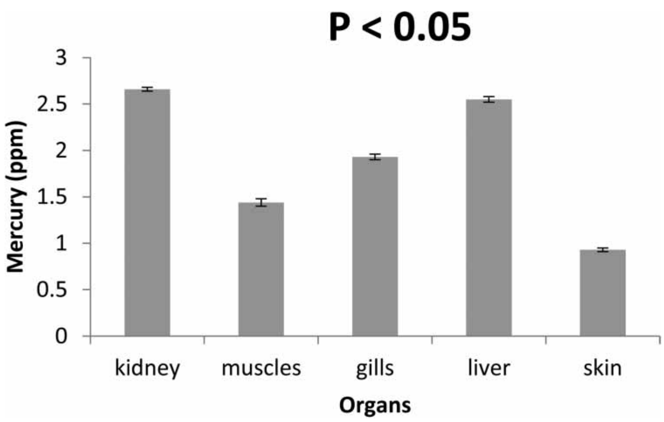



**Figure 3** | Accumulation of mercury in body organs of fish from Head Taunsa.

$29.7 \pm 18.3$ to $97.7 \pm 95.4$ mg kg$^{-1}$, respectively. Random variations and non-significant differences were observed in fish muscle samples and between species, respectively. The non-consistent trend was also observed across the studies for metal accumulation in five different tissues of *C. naziri and M. armatus*.

## SOCIAL IMPACTS OF HEAVY METAL POLLUTION

Pollution of heavy metals poses various societal problems. Heavy metals are known to contaminate neurodevelopment as they can cause reproductive damage that contributes to brain disorders, delays in development, disabilities in the education of children, and misbehaviors. Heavy metals are major contributors of neurobehavioral damage, which ultimately affects the IQ level of children and affects their academic attainment. Exposure to heavy metals during the perinatal and early childhood periods increases the risk of autism (Gorini *et al.* 2014). Due to their ubiquitous presence, heavy metals and other persistent organic chemicals could significantly affect the neurobiological processes and cause depressive symptoms (Berk *et al.* 2014). Heavy metals in freshwater ecosystems show that they can alter chemical communications between people, resulting in an 'info-disorder.' Disruption of information may influence animal behavior and social structure, changing the relationship intra-species and interspecies (Boyd 2010).

## HUMAN HEALTH PROBLEMS OF LIVING ORGANISMS DUE TO HEAVY METAL POLLUTION

Heavy metal pollution is becoming an environmental problem at the global level due to its adverse effects. These inorganic and toxic heavy metals are discarded into the freshwater ecosystem, soil, sediments, and the atmosphere due to human activities and rapidly growing urbanization. As a result, these heavy metals enter the environment surrounded by humans, plants, animals and microorganisms, and other living organisms. Once they enter into the environment, they contaminate and cycle in all the spheres of the environment, including the biosphere, lithosphere, hydrosphere, and atmosphere, which are interconnected.

Heavy metals become hazardous for human beings when they cannot be metabolized and accumulate into the soft tissue of the body. Although heavy metals are persistent, toxic, and inorganic, they can easily bind covalently with organic groups. Heavy metals form lipophilic ions and compounds with non-metallic elements like proteins generating toxic effects. Heavy metals can easily enter the human body via different pathways, including ingestion of contaminated water, food via the mouth, inhalation of polluted air, drinking contaminated water, and skin contact from the environment. Heavy metals cannot be broken down and are non-biodegradable, so when they enter the human body, they pose serious hazardous impacts. They are considered toxic and dangerous when bio-accumulated into the human body and cause biological and physiological complications (Figure 4).

There are various mechanisms of intoxication in the human body by heavy metals, which can be acute or chronic in nature. The toxicity of metals depends on dosage absorption, treatment route, and exposure time, i.e., chronic or acute exposure. Heavy metal intoxication's biochemical function involves binding, alternating their function, and causing damage to proteins and enzymes. Furthermore, heavy metals produce free radical neurotoxicity, promoting oxidative stress that damages lipids, proteins, and DNA molecules. These free radicals propagate adverse impacts on multiple organs, nervous system, and joints and carcinogenesis effects (Engwa

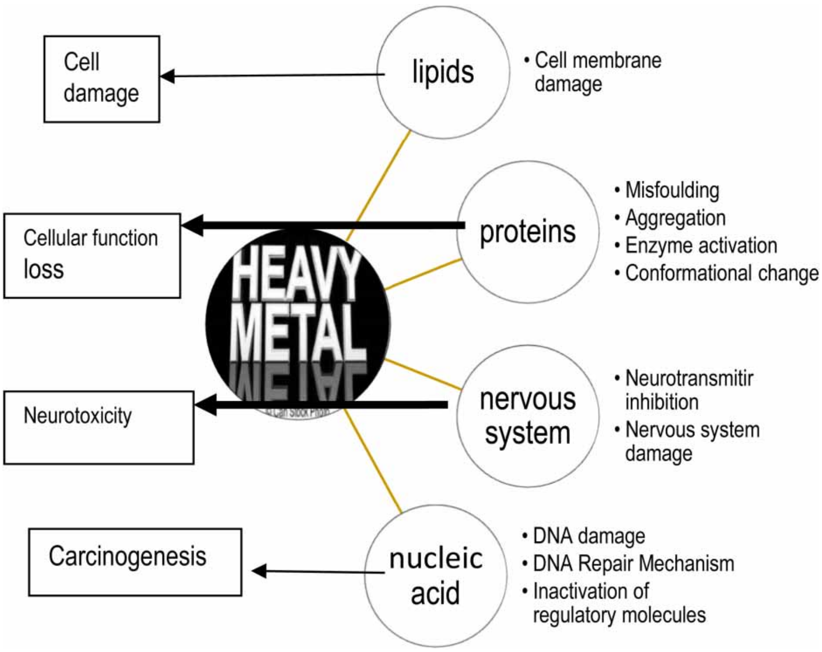



**Figure 4** | Effects of heavy metals on human health.

*et al.* 2019). These heavy metals raise serious concerns over their potential health effects on humans due to cell function loss, cellular changes, carcinogenesis, and neurotoxicity.

Since the sudden exposure's toxicity to considerable amounts of metals (such as occupational exposure) usually influences various organ regimes, its magnitude depends on the shape of the material, route, length of exposure, and a greater degree of an individual's sensitivity. As regards the health perspective, metal pathophysiology mainly depends on the generation of oxidative stress characterized by (a) the production of increased reactive oxygen species and reactive nitrogen species; (b) inhibiting or reducing the activity of enzymes that significantly contribute to intracellular antioxidant reservoirs and free-radical scavengers (Jan *et al.* 2015). Children are more vulnerable to contamination from heavy metals. Heavy metals subject children to negative effects. Breastfeeding is a neonate nutritional gold standard because human milk contains many essential compounds critical to proper growth. Milk is, however, also a bio-fluid that can absorb chemical pollutants and therefore have consequences for the immune system and the different bodies. The inclusion of heavy metallic arsenic, lead, cadmium, and mercury in milk is another concern, as these compounds are essential immunomodulators, which can contribute to disorders in cytokine development. The toxicants allow these compounds to be stimulated or suppressed. This may lead to complications with the child's wellbeing, such as allergy, endocrine disorders, delays in neurodevelopment, etc. (Pajewska-Szmyt *et al.* 2019). A pregnant woman's heavy metal intake often has significant consequences for the child's weight (Shirai *et al.* 2010). For both mother and infant wellbeing, the effects of heavy metals during pregnancy are significant. Heavy metal ingestion by diet has metallic effects of poisoning, including low birth weight, body size, muscle growth, a low level of IQ, and infant weight (Neeti & Prakash 2013). Heavy metal concentrations increase in each successive predatory stage due to bio-magnifications, so the occupational exposure to heavy metals of mothers leads to abnormal growth and development. The unprotected mom is confronted with early-pregnancy miscarriage, accidental abortion, genetic defect, congenital malformation, intrauterine growth, and premature delivery (Vimalraj *et al.* 2017).

Similarly, cosmetics repeatedly applied directly to the human skin cause unfavorable impacts on human health. The most common heavy metals in cosmetics include lead, mercury, cadmium, arsenic, nickel, and aluminum, which have negative implications on the health system. Metals in cosmetics may be retained and directly reacted to or ingested into the blood via the skin, accumulated through the bloodstream, and adverse effects in different organ systems. Mostly, topical effects such as allergic contact dermatitis and systematic effects due to metals exposure occur in the human body (Borowska & Brzóska 2015). Therefore, cosmetics products containing heavy metals can be carcinogenic and cause detrimental effects on public health. The heavy metals in cosmetics products cause allergies, irritation, and harmful impacts on human health (Kaličanin & Velimirović 2016). So, beauty products have adverse impacts on the skin, nails, hair (hair dye quality), and body because they contain toxic heavy metals (Alam *et al.* 2019). Different heavy metals and their impacts on human health are discussed below in Table 6.

## ENVIRONMENTAL PROBLEMS

Heavy metals are released from different natural and anthropogenic sources, and after their origin from the Earth, they ultimately again enter into the environment as a byproduct/pollutant (Bashir *et al.* 2017). They enter into different environment domains such as soil, water, sediment, and atmosphere. Environmental pollution due to heavy metals is emerging rapidly, and it is a matter of concern due to its devastating impacts on nature (Cimboláková *et al.* 2019). The stipulated levels of heavy metals concentration have deleterious effects on the ecosystem and biota health. The transport of heavy metals into groundwater from toxic waste sites is a significant environmental concern. Heavy metals, such as Pb, Hg, and As, enter groundwater aquifers and contaminate them if they exceed the threshold level. Similarly, a higher concentration of heavy metals in freshwater also pollutes it and alters freshwater chemistry. The presence of heavy metals in waterways could significantly increase due to the interaction of some other materials, such as clay particles and dissolved organic matter. The presence of heavy metals and other inorganic contaminants deteriorates water quality and makes it unfit for human consumption (Brraich & Jangu 2015). The predominant sources of heavy metal pollution such as industrialization and urbanization worsen the water even for agricultural practices. The use or application of that water (containing heavy metals) into an agricultural area, bio-accumulated into crops, either contaminates the crops or enter the food web by bio-magnifications. However, due to such practices, mainly the residents of areas such as Lahore, Pakistan, consume vegetables/crops irrigated with contaminated water. So, ultimately, these heavy metals enter

**Table 6** | Different heavy metals and their toxicity

| Heavy metals | Rout of entry | Health effects – Acute | Health effects – Chronic | References |
|---|---|---|---|---|
| Lead | • Ingestion<br>• Inhalation<br>• Skin contact<br>• Drinking water | • Loss of appetite, headache, hypertension, abdominal pain, renal dysfunction, fatigue, sleeplessness, arthritis, hallucinations, vertigo<br>• Inflammation<br>• Muscle contraction<br>• Intracellular movement | • Mental retardation,<br>• Birth defects, psychosis, autism, allergies, dyslexia, weight loss, hyperactivity, paralysis, muscular weakness, brain damage, kidney damage, death | Jaishankar *et al.* (2014), Engwa *et al.* (2019), Matta & Gjyli (2016), Jha *et al.* (2020) |
| Mercury | • Inhalation<br>• Ingestion<br>• Absorption by skin contact | • Lung damage, vomiting, diarrhea, nausea, skin rashes, increased heart rate or blood pressure<br>• Depression<br>• Fatigue, headache, hair loss | • Brain disorder<br>• Nervous system disorder<br>• Shyness, tremors, memory problems, irritability, and changes in vision or hearing | Jaishankar *et al.* (2014), Matta & Gjyli (2016). |
| Iron | • Ingestion<br>• Hemeoxygenase<br>• Along with other essential nutrients | • Gastrointestinal bleeding, vomiting and diarrhea<br>• Shocks, hypotension, lethargy, tachycardia, hepatic necrosis, metabolic acidosis<br>• Ulceration<br>• Death | • Cancer<br>• Siderosis<br>• DNA damage<br>• Effects on colon<br>• Pulmonary problems | Jaishankar *et al.* (2014), Engwa *et al.* (2019), Jha *et al.* (2020) |
| Cadmium | • Dermal exposure<br>• Ingestion<br>• Inhalation | • Stomach irritation, vomiting, diarrhea<br>• Chill<br>• Fever<br>• Muscle ache<br>• Cadmium blues | • Kidney disease, fragile bones, and lung damage<br>• Renal disinfection<br>• Morphopathological changes in the kidneys<br>• Pulmonary edema<br>• Premature birth and weight loss during pregnancy | Engwa *et al.* (2019), Jha *et al.* (2020) |
| Chromium | • Ingestion (Lungs)<br>• Inhalation(Gastrointestinal tract)<br>• Skin contact (Less) | • Severe redness swelling<br>• Disturb hemoglobin<br>• Irritation<br>• Ulcer on nasal septum<br>• Damage sperm and male reproductive system | • Cardiovascular, respiratory, hematological, gastrointestinal,<br>• Renal,<br>• Hepatic, neurological **Effects** possibly death<br>• Carcinogenic<br>• Alterations in replication and transcription of DNA<br>• DNA damage | Engwa *et al.* (2019), Teklay (2016), Jha *et al.* (2020). |
| • Arsenic | • Ingestion (water & food)<br>• Breathing<br>• Dermal contact | • Reduction in the production of erythrocytes and leukocytes, damage to blood vessels, nausea vomiting, abnormal heartbeat, pricking | • Arsenicosis<br>• Skin lesions, peripheral vascular disease,<br>• Pulmonary disease cardiovascular diseases,<br>• Weakness<br>• Neurological problems,<br>• Diabetes mellitus | Engwa *et al.* (2019), Matta & Gjyli (2016) |

(*Continued.*)

**Table 6** | Continued

| Heavy metals | Rout of entry | Health effects: Acute | Health effects: Chronic | References |
|---|---|---|---|---|
| | | sensations in the hands and legs | • Certain types of cancers<br>• Lethal toxicity | |
| • Aluminum | • Vaccination<br>• Dialysis<br>• Infusion<br>• Inhalation<br>• Ingestion<br>• Skin contact | • Irritation<br>• Metal fume fever<br>• Headache<br>• Chest tightens<br>• Cough | • Kidney damage<br>• Bone damage<br>• Brain damage<br>• Lung problems,<br>• Anemia,<br>• Impaired iron absorption,<br>• Nervous system problems<br>• Cyst<br>• Reproductive and developmental effects<br>• Breast cancer<br>• Crohn's disease, inflammatory bowel diseases,<br>• Alzheimer's disease | Igbokwe *et al.* (2019) |

the food chain and cause negative impacts on human health. Consuming polluted groundwater also affects human health by affecting different organs and functions of the body such as the kidneys, liver, and brain. The concentration of heavy metals into groundwater increases by seepage and geological and mining activity, leading to geo-accumulation, bio-accumulation, and bio-concentration with heavy metals such as zinc, copper, and lead eventually affects the health of living organisms. Along with urbanization and industrialization, agricultural activities and tanneries also cause the release of heavy metals such as arsenic (As) into groundwater, which poses toxic effects to human health, such as arsenic being carcinogenic. Similarly, the addition of heavy metals into surface water and sediments also has bio-toxic effects on biota and alters water quality. The quality of any water depends upon its sources and origin, which could alter the physio-chemical properties of water. Moreover, the wetland ecosystem, a transitional zone between the upland and aquatic ecosystem, could also alter its quality by receiving polluted water. For example, the wetland receiving polluted water with a heavy load of nutrients could alter the chemistry of the wetland and may cause eutrophication. Likewise, the heavy metals accumulated into sediments directly impose toxic impacts on benthic organisms and many other organisms by entering into the food web. The biota of these ecosystems is also affected by their bio-toxic impacts on fishes and plants. The plants are also very susceptible, although they require nutrients for growth, an excessive amount of heavy pollutants could impede their growth, germination, reproduction, and some other functions (Oancea *et al.* 2005). Heavy metals also act as oxidative stressors for plant growth. The heavy metals behave like hormones, induce substances, alter plants' physiology and productivity, and sometimes cause mutations in plants and animals. Heavy metals are important environmental pollutants that cause toxic effects on plants and pose dangerous threats to the agro-ecosystem. Furthermore, heavy metals accumulate into the soil and alter its chemistry by affecting microbial activities and processes and negatively impacting soil fertility (Singh & Kalamdhad 2011). The emissions of heavy metals into the atmosphere directly impact air quality. The air quality deteriorated by the release of heavy metals causes health impacts in human beings by direct inhalation of air and some other indirect means such as settling heavy metals down on soil surface and ultimately affects the water, plant, and animals as well. Further, the addition of heavy metals such as Pb and Zn into rainwater makes the water acidic and contaminated, which could dissolve into catchment and water storage tanks (Huston *et al.* 2009). The addition of heavy metals into rainwater makes it acidic in nature, which may cause soil contamination and erosion of building materials and deteriorate them more quickly.

## ECONOMIC IMPLICATION

Along with eco-toxicity (soil water, air, plants, wildlife, and domestic animals), heavy metal pollution also causes many economic losses and has become a severe issue in recent years. Heavy metals released from different sources transfer into and then contaminate the terrestrial and aquatic ecosystem, where they further deteriorate living organisms. Pollution due to heavy metals could alter the structure and functions of any ecosystem. In a terrestrial ecosystem, insects play crucial ecological roles in maintaining ecosystem services such as food provisioning, plant pollination, dung burial, pest control, and wildlife nutrition. So, the accumulation of heavy metals in insects could change their morphology and physiology such as bees, butterflies, ants, and wasps. Eco-toxicological effects of heavy metals on useful insects might directly affect food security, agricultural economy, and human welfare (Skaldina & Sorvari 2019). The accumulation of heavy metals concentration into the soil could affect the enzyme activity of microorganisms. The accumulation of heavy metals affects the agricultural soil and crops (paddy crops like rice), increasing danger (Hu *et al.* 2014). The risk of food security increases by accumulating heavy metals into crops (wheat, rice, maize), as they also affect rice production (Ezekiel 2015).

Remediation of heavy metals requires special attention to protect soil quality, air quality, water quality, human health, animal health, and all spheres together. However, developed physical and chemical-heavy metal remediation technologies demand costs that are not feasible, time-consuming, and release additional waste to the environment (Masindi & Muedi 2018).

## CONCLUSION

Heavy metal contamination in River Ravi and River Kabul is high due to a huge amount of untreated discharge of industrial and sewage water from urban centers and industrial fields. As a result, the ecosystem health of both of these rivers is degrading day by day. River Chenab and River Jhelum have moderate metal contamination at a few sites. River Indus is much less contaminated. Contaminated fish from polluted rivers can badly impact human health.

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## DATA AVAILABILITY STATEMENT

All relevant data are included in the paper or its Supplementary Information.

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