Iran. J. Ichthyol. (2023) 10(2): 93-101
P-ISSN: 2383-1561; E-ISSN: 2383-0964

ORIGINAL ARTICLE

Study on Aluminium (Al) bioaccumulation in water, sediment, and fishes (*Labeo rohita*, *Hypophthalmichthys molitrix*, and *Oreochromis niloticus*) collected from River Sutlej, Pakistan

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Article history:
Accepted 22 May 2023

Abstract
Pollution of aquatic environment due to different heavy metals has become a global concern, raising health-related issues for humans, as well as aquatic flora and fauna. Many agricultural and industrial effluents are directly discharged into the rivers without any treatment. They deposit heavy metals in the sediments, water, and aquatic organisms. Keeping this environmental context in mind, the main goal of this study was to scrutinize the level of aluminium (Al) in water, sediments, and three fish species (*Labeo rohita*, *Hypophthalmichthys molitrix,* and *Oreochromis niloticus*). These samples were collected monthly from Sulemanki Headworks, River Sutlej, Punjab, Pakistan, from January to March in the year 2019. Water and sediment samples were collected from substations (upstream and downstream). Results demonstrated that the highest aluminium concentration was observed in upstream water and sediment samples ($223.83\pm3.45 mg\cdot L^{-1}$ and $417.25\pm3.59 \mu g\cdot g^{-1}$) than in downstream samples ($222.87\pm3.44 mg\cdot L^{-1}$ and $416.31\pm3.65 \mu g\cdot g^{-1}$). Among all fish organs, the liver had the highest accumulation of Al compared to muscle and gills. The order of accumulation in *Labeo rohita* was liver > gills > muscle, in *Hypophthalmichthys molitrix* the order was liver > gills > muscle, and in the *Oreochromis niloticus,* the order was liver > muscle > gills. This study suggests that River Sutlej should be properly monitored to safeguard water quality and protect aquatic life, ensuring the river's long-term health.

Keywords: Aquatic environment, Downstream, Effluents, Health, Heavy metals.

INTRODUCTION

Environmental pollution is one of the most serious problems that humans have faced in recent decades (Chaudhary et al. 2023a). It includes pollution of water, air, and land. However, water pollution is somewhat harder to measure than air and land pollution (Cachada et al. 2018). Water pollution is the pollution of water sources such as rivers, bays, oceans, estuaries, groundwater, lakes, and streams by industrial effluents (Shahi 2022). The discharging of untreated industrial wastes, which contain different types of heavy metals, causes contamination in both ground and surface water (McMahon et al. 2018). Heavy metals are metallic elements that have a higher density than water. (Chaudhary et al. 2023b). They enter the aquatic environment through industrial effluents and domestic sewage, where they have severe ecological and environmental impacts (Abedi et al. 2013). Agriculture is also a most noticeable polluting water reservoir element because different pollutants, including heavy metals, runoff through this (Bandpei et al. 2016). Heavy metals, particularly aluminium, are the world's third most abundant naturally occurring element. Approximately 8% of Earth's crust is made up of aluminium. It occurs naturally in water, medicine, air, and foods (I. Iqbal et al. 2022). Aluminium can enter natural streams through water treatment plants that use alum (aluminium sulphate) as a coagulant for suspended particles, acid rain, coal strip mining, and industrial effluents (Driscoll et al. 1980). Thus, aluminium is toxic to fish when it becomes available to organisms because of surface water acidification (Camargo et al. 2009). In aquatic ecosystems, heavy metal toxicity is usually measured in aquatic organisms, water, and sediment (Naz et al. 2022). The principal pathway of

Journal homepage: ijichthyol.org/ DOI: https://doi.org/10.22034/iji.v10i2.975/ DOR: https://dorl.net/dor/20.1001.1.23831561.2023.10.2.8.2

heavy metal input into the aquatic environment is the transfer of sediments from upstream to downstream in the river basin during high flow (Patel et al. 2018). Sediment analysis is more appropriate than water analysis for monitoring long-term metal deposition in ecosystems. Heavy metals from agricultural and industrial runoff drain into canals and rivers, ultimately collecting in sediments (Naz et al. 2021).

Sediments, on the other hand, reduce the bioavailability of toxins by allowing them to settle at the bottom of the water sources (Naz et al. 2022). However, trace elements and metalloids get stuck in the sediments in different chemical forms (Islam et al. 2015). Hence, they become a fundamental problem for downstream water sources (Schleiss et al. 2016). In order to assess the extent of metal toxicity in the aquatic environment, it is necessary to understand the parameters of water, such as hardness, alkalinity, temperature, oxygen, and pH (Bhateria & Jain 2016). They also affect the growth parameters (weight and length) of fish. Fish is a widely consumed human protein source and an excellent dietary source of omega-3 fatty acids. It also contains unsaturated and polyunsaturated fats (Kralovec et al. 2012). Fish is also used as a bioindicator to assess metal pollution in the aquatic environment. It can take up heavy metals in four ways: gills, skin absorption, food consumption and nonedible particle consumption (Hussain et al. 2014). The absorbed metals accumulate in the different body organs, especially in the kidney, gills, muscles, and liver (Azaman et al. 2015). Accumulation of heavy metals may decrease fish metabolic activities and appetite, which inhibit development and growth (Naz et al. 2022). Thus, the fish is considered an early warning of environmental degradation (Kalaiyarasi et al. 2017).

Pakistan has a wide range of water resources, but anthropogenic activities have reduced water quality to the point that it is unsuitable for aquatic organisms and humans (Anjum et al. 2022). Rivers support diverse types of aquatic life and are a reliable source of fresh water. Nevertheless, local industries affect the riverine system by directly discharging effluents (Atique et al. 2020). Pollution first affects the river's physical condition and then destroys the community by disrupting the food chain. Because of this pollution, natural flora and fauna in rivers are under threat. So, the main aim of this study is to calculate the accumulation of Al in water, sediment, and fish (*Labeo rohita, Hypophthalmichthys molitrix* and *Oreochromis niloticus*) collected from River Sutlej.

MATERIALS AND METHODS

Study area: River Sutlej is the longest river in Punjab, Pakistan, and northern India. Sulemanki Headworks is located on the River Sutlej in Pakistan's Punjab province and is used for flood control and irrigation. Different industries, i.e., oil mills, paper mills, and sugar mills, are present in this region (Tabinda et al. 2013). Extensive industrialisation near the river introduced different types of heavy metals into the water. The present research was conducted at the public fishing site on Sulemanki Headworks, River Sutlej, Punjab, Pakistan, from January to March. The samples of rohu (*Labeo rohita rohita*), silver carp (*Hypophthalmichthys molitrix*), tilapia (*Oreochromis niloticus*), sediment, and water were collected monthly. The station was further divided into two substations, upstream and downstream. Water and sediment samples were collected from the substations. Water samples (n=15) were collected from just below the surface and a column (one metre below the surface) using the Kemmerer bottle and stored in quartz bottles. While sediment samples (n=15) were collected with the help of a PVC pipe from a depth of 5cm. Cans and polyethylene scoops were used for sample collection and storage. However, samples of three fish species, namely, *Labeo rohita*, *Hypophthalmichthys molitrix*, and *Oreochromis niloticus*, were collected by netting from the public fishing site. Six specimens of each fish species with an average weight of 900-1000g were collected randomly and preserved at 4ºC immediately after capture. For further analysis, all samples were put in cooling chest boxes during transportation to the departmental laboratory, UVAS, Pattoki. Physico-chemical parameters of water such as pH, total hardness ($mg \cdot L^{-1}$), dissolved oxygen ($mg \cdot L^{-1}$), water temperature (°C), and electrical conductivity ($mS \cdot cm^{-1}$) were recorded on the spot, while turbidity ($mg \cdot L^{-1}$) and alkalinity ($mg \cdot L^{-1}$) were measured in the departmental laboratory.

Water samples digestion: In the laboratory, 20mL of water was taken in a flask with 10mL of concentrated nitric acid (HNO_3) solution. After 5 min of stirring, the flask mouth was covered with cotton and placed on a hot plate in the Kjeldahl apparatus. The solution was heated until a colourless suspension was obtained. Then, the solution was cooled at room temperature and filtered through the Whatman filter paper. After filtration, the distilled water was added to make the volume up to 50mL and stored in a glass bottle at room temperature for further analysis (Sekhon & Singh 2013).

Sediment samples digestion: First, sediment samples were air-dried at room temperature. After careful air-drying, the samples were pulverised and sieved using a 2mm sieve. Then 2g powdered sediment sample was taken in a clean 20mL beaker, digested by aqua regia (HCL and HNO_3 in a 3:1 ratio) and placed in a Kjeldahl apparatus on a hot plate. A colourless suspension was obtained and filtered, and distilled water was added to make the volume up to 50mL. Then the samples were preserved in an Eppendorf tube at 4°C for further analysis (Alpers et al. 1994).

Fish samples digestion: The fish were dissected from anus to mouth, and vital organs, viz. muscles, liver, and gills, were separated. Before dissection, the weight and length of the fish were measured. After dissection, each organ was weighed and dried for 24h in an oven set to 65ºC. Subsequently, dry organs were burned in ashes in the furnace at 700-1000ºC for approximately 2h. Following this step, almost 2g of obtained ash content was mixed in a flask with 10mL of concentrated nitric acid and heated for 90 min until a colourless solution was obtained. In the last step, the solution was filtered, and deionized water was added to make the solution volume up to 50mL for further analysis (Rauf et al. 2009).

Determination of Aluminium (Al): Aluminium (Al) concentration in water, sediment, and fish organs (liver, muscle, and gills) was estimated by Hitachi Z-8230 Polarized Zeeman Atomic Absorption Spectrophotometer.

Statistical analysis: Achieved data were exposed to a one-way Analysis of Variance, and post hoc Duncan's multiple range test was applied at $p<0.05$ to test the significance level.

RESULTS

Physico-chemical parameters: Physico-chemical parameters of water, viz., pH, dissolved oxygen ($mg \cdot L^{-1}$), alkalinity ($mg \cdot L^{-1}$), water temperature (°C), turbidity ($mg \cdot L^{-1}$), total hardness ($mg \cdot L^{-1}$), and electrical conductivity ($mS \cdot cm^{-1}$) were recorded every month from January to March (Table 1). Dissolved oxygen was measured through a DO meter (Ohaus corporation, USA, model: ST300D), electrical conductivity was measured with the help of an EC meter (Adwa, Hungary, model: AD3000), and the temperature was measured with the help of a thermometer. In contrast, a multimeter measured pH and total hardness (HANNA, HI-198194). For alkalinity, a measured quantity of sulfuric acid is added to the water sample until three basic forms of alkalinity such as bicarbonate (HCO_3), carbonate (CO_3), and hydroxide (OH)) were transformed into carbonic acid. Table 1 contains all the water parameters measured from January to March.

Aluminium concentration in river water and sediment: The contamination level of aluminium (Al) in the water and bed sediment of the River Sutlej was analyzed, and their mean ±SD values were compared (Table 2). In water samples, the maximum aluminium (Al) concentration was observed in upstream samples ($227.54 \pm 1.10 mg \cdot L^{-1}$) in March, while a minimum in downstream samples ($218.43 \pm 0.90 mg \cdot L^{-1}$) in February. However, the highest aluminium concentration in bed sediment was noted in February ($421.46 \pm 0.42 \mu g \cdot g^{-1}$) from upstream samples and the lowest in January ($411.76 \pm 0.99 \mu g \cdot g^{-1}$) from downstream samples (Table 2). The mean value of Al accumulation observed in upstream water samples

Table 1. Physico-chemical parameters of water recorded from River Sutlej from January to March.

Sampling months	Physico-chemical parameters						
	Temperature (°C)	pH	Hardness ($mg \cdot L^{-1}$)	Dissolved oxygen ($mg \cdot L^{-1}$)	Alkalinity ($mg \cdot L^{-1}$)	Electrical conductivity ($\mu S \cdot cm^{-1}$)	Turbidity ($mg \cdot L^{-1}$)
January	16.54±0.45^{c}	6.77±0.11^{c}	160.56±0.45^{c}	4.77±0.22^{a}	230.88±4.10^{c}	263.22±2.67^{c}	65.48±1.23^{b}
February	17.98±0.02^{ba}	7.45±0.05^{a}	187.98±0.20^{b}	3.87±0.10^{b}	360.96±4.03^{b}	281.26±1.89^{a}	71.54±1.84^{a}
March	18.33±0.10^{ab}	7.03±0.03^{b}	193.73±0.02^{a}	3.17±0.03^{c}	388.26±3.34^{a}	270.10±3.95^{b}	61.42±1.17^{c}
Mean±SD	17.62±0.85	7.08±0.30	180.7±15.36	3.94±0.70	326.59±72.8	271.52±8.29	66.15±4.58

Superscripts (a, b, c) on different means in the column are significantly different at $P<0.05$.

Table 2. Aluminium concentration in water and sediment collected from two substations of River Sutlej.

Sampling months	Water		Sediment	
	Upstream ($mg \cdot L^{-1}$)	Downstream ($mg \cdot L^{-1}$)	Upstream ($\mu g \cdot g^{-1}$)	Downstream ($\mu g \cdot g^{-1}$)
January	224.17±0.17^{b}	224.32±0.32^{b}	416.92±1.00^{b}	411.76±0.99^{c}
February	219.78±1.00^{c}	218.43±0.90^{c}	421.46±0.42^{a}	419.83±0.98^{a}
March	227.54±1.10^{a}	225.90±0.07^{a}	413.37±1.01^{c}	417.34±0.34^{b}
Mean±SD	223.83±3.45	222.87±3.44	417.25±3.59	416.31±3.65

Means with similar letters in one column and overall means in a row are statistically similar at $P<0.05$.

Table 3. Concentration of aluminium (Al) in organs of *Labeo rohita* ($\mu g \cdot g^{-1}$), *Hypophthalmichthys molitrix* ($\mu g \cdot g^{-1}$) and *Oreochromis niloticus* ($\mu g \cdot g^{-1}$) collected from River Sutlej from January to March.

Sampling months	Organs								
	Labeo rohita ($\mu g \cdot g^{-1}$)			*Hypophthalmichthys molitrix* ($\mu g \cdot g^{-1}$)			*Oreochromis niloticus* ($\mu g \cdot g^{-1}$)		
Organ	Liver	Muscle	Gills	Liver	Muscle	Gills	Liver	Muscle	Gills
January	142.66±0.33^{a}	79.92±0.28^{a}	108.34±0.47^{a}	189.75±0.28^{a}	92.64±0.54^{b}	133.52±0.46^{c}	102.55±0.51^{c}	97.48±0.42^{a}	53.49±0.46^{b}
February	140.50±0.31^{b}	77.78±0.21^{c}	107.41±0.16^{b}	187.64±0.37^{c}	90.44±0.21^{c}	134.73±0.35^{a}	106.45±0.50^{b}	92.52±0.30^{c}	59.50±0.45^{a}
March	139.26±0.45^{c}	78.60±0.15^{b}	106.43±0.29^{c}	188.45±0.46^{b}	93.73±0.16^{a}	132.37±0.36^{b}	109.40±0.49^{a}	94.19±0.17^{b}	50.69±0.28^{c}
Mean±SD	140.80±1.52	78.77±0.95	107.39±0.87	188.62±0.98	92.27±1.48	133.54±1.07	106.14±3.00	94.73±2.20	54.56±3.91

Superscripts (a, b, c) on different means in the column are significantly different at $P<0.05$.

was 223.83±3.45$mg \cdot L^{-1}$ and downstream was 222.88±3.44$mg \cdot L^{-1}$, while in river bed sediment, the mean of the noted value of upstream samples was 417.25±3.59$\mu g \cdot g^{-1}$ and downstream was 416.31±3.65$\mu g \cdot g^{-1}$. The overall observed results revealed that the mean concentration of Al in water and bed sediment is higher in upstream samples than in downstream samples. However, during this study, the maximum concentration of Al was recorded in water samples and the minimum in sediment samples (Table 2). Moreover, the values of aluminium accumulation in water and bed sediment of the river noted from the two stations are significantly ($P<0.05$) different from each other from January to March. Table 2, also shows the major monthly variations in data.

Aluminium concentration in fish organs: Aluminium (Al) was detected in organs, viz., liver, muscle, and gills of all three fish species (*Labeo rohita, Hypophthalmichthys molitrix,* and *Oreochromis niloticus*) collected from a public fishing site, Sulemanki Headworks, River Sutlej, from January to March. The results indicate that the highest aluminium concentration is present in all fish livers compared to muscle and gills. In descending order, the mean concentration of aluminium in *Labeo rohita* is liver (140.80±1.52$\mu g \cdot g^{-1}$) > gills (107.39±0.87 $\mu g \cdot g^{-1}$) > muscle (78.77±0.95$\mu g \cdot g^{-1}$) (Table 3), and in *Hypophthalmichthys molitrix* is, liver (188.62±0.98$\mu g \cdot g^{-1}$) > gills (133.54±1.07$\mu g \cdot g^{-1}$) > muscle (92.27±1.48$\mu g \cdot g^{-1}$) (Table 3). In *Oreochromis niloticus*, the mean Al concentration descending order is as follows: liver (106.14±3.00 $\mu g \cdot g^{-1}$) > muscle (94.73±2.20$\mu g \cdot g^{-1}$) > gills (54.56±3.91$\mu g \cdot g^{-1}$) (Table 3). Moreover, in *Labeo rohita* organs, maximum Al accumulation was observed in January in the liver (142.66±0.33 $\mu g \cdot g^{-1}$) and minimum in the muscle (77.78±0.21$\mu g \cdot g^{-1}$) in February (Table 3). In contrast, in *Oreochromis niloticus,* the highest concentration was recorded in the liver (109.40±0.49 $\mu g \cdot g^{-1}$) in March and lowest in the gills (50.69±0.28$\mu g \cdot g^{-1}$) in March (Table 5). However, during this study, the accumulation of aluminium (Al) was recorded high in silver carp (*Hypophthalmichthys molitrix*) than in rohu (*Labeo rohita*) and tilapia (*Oreochromis niloticus*). All the samples differed significantly at $P<0.05$ (Table 3).

DISCUSSION

In Pakistan, freshwater bodies are polluted due to industrial effluents, agricultural wastes, and untreated urban sewage, which are the leading causes of increasing heavy metal contamination in rivers. Therefore, the present study was conducted on the River Sutlej to check the aluminium (Al) concentration in bed sediment, water, and fish. Physicochemical parameters of water, viz., pH, temperature, electrical conductivity, dissolved oxygen, turbidity, total hardness, and alkalinity, are measured on a monthly basis. Natural factors and different anthropogenic activities influence these parameters in rivers (F. Iqbal et al. 2004). These parameters are also affected by the depth of the aquatic system. So, the water temperature may cause several changes in fish organs by metal deposition (Seiyaboh & Izah 2017). This study reported the maximum temperature in March and the minimum in January. The pH values were noted in the range of 6.77 to 7.03 throughout the study period. This pH range is suitable for fish survival and production (Ijaz et al. 2015). In contrast, the hardness of water is induced by the presence of calcium, iron, and magnesium ions, as well as aluminium and many other heavy metals (Ali et al. 2000). In this study, the noted water hardness values from the river Sutlej, Pakistan, varied from 160.56 to 193.73 ($mg \cdot L^{-1}$). Yousafzai et al. (2013) investigated a water hardness range of 175.2 to 182.8 ($mg \cdot L^{-1}$) from River Kabul, Pakistan. However, dissolved oxygen was noted to have a maximum in January (4.77±0.22$mg \cdot L^{-1}$) and a minimum in March (3.17±0.03$mg \cdot L^{-1}$). Dissolved oxygen shows a maximum value when the temperature is low because it is inversely proportional to photoperiods and water temperature (F. Iqbal et al. 2004). In March, the temperature was high (18.33℃) as compared to January (16.54℃) and February (17.98℃), and the dissolved oxygen value was low (3.17±0.03$mg \cdot L^{-1}$). Similar results were reported by Ali et al. (2000) from the union side of Chenab and Ravi River, Pakistan.

Heavy metals are toxic even in small quantities because they disturb the ecosystem by accumulating in organisms and causing toxic effects on biota. Water and bed sediments are suitable for assessing the accumulation of metals in the aquatic environment (Tabinda et al. 2013). In this study, water and bed sediment samples were collected on two substations (upstream and downstream) of River Sutlej, and their mean (±SD) values were compared. According to the results, the highest amount of aluminium (Al) concentration was observed in upstream water and sediment samples than in downstream samples. Our findings agree with the results of Tabinda et al. (2013), who collected sediment, water, and fish samples from the River Sutlej at Sulemanki headworks during summer and winter. They reported a higher concentration of heavy metals in river water than in fish and sediment. Likewise, Wogu & Okaka (2011) investigated nine heavy metals from the River Warri in Nigeria, which continuously receives urban sewage, agricultural waste and industrial effluents. They observed higher concentrations of Mn, Ni, Cd, and Cr in water, which indicates that River water is harmful to aquatic organisms and humans. Our results are also in line with Shanbehzadeh et al. (2014). They reported different heavy metals (Zn, Ni, Pb, Fe, Cu, Cd, and Cr) accumulation in sediment and water samples collected from upstream and downstream of the River Tembi. Likewise, Diagomanolin et al. (2004) observed higher concentrations of Cu, Cr, and Ni in upstream water samples than in downstream water samples collected from the Karoon Waterway River, Iran. (Yehia & Sebaee 2012) also recorded five heavy metals in water and bed sediment collected from the River Nile, Egypt.

Fish gills, muscles, and liver are considered important organs that are highly damaged by heavy metal pollution. This study detected aluminium (Al) in all fish specimen's organs (liver, muscle, and gills). According to the findings, the accumulation of Al differs depending on species-specific aspects, including feeding habits, age and size. Al concentration was recorded higher in filter feeder fish such as *Hypophthalmichthys molitrix* and lower in omnivore fishes such as *Oreochromis niloticus* and *Labeo rohita*. In organs, the noted values showed that aluminium accumulation is higher in the liver than in muscles and gills. Waheed et al. (2013) have reported similar accumulation patterns in the liver, muscle, and gills of six fish species collected from the River Chenab, Pakistan. The liver shows a higher arsenic concentration as compared to muscle and gills. El-Moselhy et al. (2014) also collected different fish from the Red Sea and observed higher metal concentrations in the liver (Zn, Mn, Pb, Cu, Fe) compared with muscle and gills. Similarly, Jabeen et al. (2012) determined the concentration of arsenic, aluminium, zinc, barium, nickel, and chromium in herbivorous (*Cirrhina mrigala, Labeo rohita*, and *Catla catla*) and carnivorous (*Wallago attu, Mystus sperata*, and *Rita rita*) fish species collected from the River Ravi, Pakistan. They found a higher concentration of aluminium (Al) in the livers of herbivorous and carnivorous fish species than other metals. Ahmed et al. (2016) also noted a higher accumulation of heavy metal in the skin and liver than in muscles and gills. Mohammadi Rouzbahani (2017) identified the liver and gills as target organs for heavy metal accumulation in two fish species collected from the Persian Gulf, Iran. However, several researchers reported different heavy metals in fish procured from different rivers (Tabinda et al. 2013; Islam et al. 2015; Naz et al. 2022).

CONCLUSION

It is concluded that aluminium (Al) has been detected in the water, sediments, and organs (liver, muscle, and gills) of fishes (*Labeo rohita, Hypophthalmichthys molitrix*, and *Oreochromis niloticus*) collected monthly from January to March at Sulemanki Headworks, River Sutlej, Punjab, Pakistan. The upstream water and sediment samples were found to be more contaminated than the downstream samples. In all organs of fishes, aluminum was detected, but the highest concentration was noted in the liver. These findings indicate the negative impact of industrial activities near the Sutlej River, which pose a significant threat to aquatic life and can lead to serious health problems for humans who consume these fish. Thus, it is crucial to take serious preventive measures to limit anthropogenic activities in River Sutlej in order to protect the environment and public health.

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Iran. J. Ichthyol. (2023) 10(2): 93-101
P-ISSN: 2383-1561; E-ISSN: 2383-0964
http://www.ijichthyol.org

doi: 10.22034/iji.v10i2.975
dor: 20.1001.1.23831561.2023.10.2.8.2

مقاله کامل

مطالعه تجمع زیستی آلومینیوم (Al) در آب، رسوبات و ماهیان (*Labeo rohita*، *Hypophthalmichthys molitrix* و *Oreochromis niloticus*) جمع‌آوری شده از رودخانه ستلج، پاکستان

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چکیده: آلودگی محیط آبی ناشی از فلزات سنگین مختلف به یک نگرانی جهانی تبدیل شده است و مسائل مربوط به سلامتی انسان و همچنین گیاهان و جانوران آبزی ایجاد کرده است. بسیاری از پساب‌های کشاورزی و صنعتی بدون تصفیه مستقیم به رودخانه ها ریخته می‌شود. آن‌ها فلزات سنگین را در رسوبات، آب و موجودات آبزی رسوب می‌دهند. با در نظر گرفتن این زمینه محیطی، هدف اصلی این مطالعه بررسی دقیق سطح آلومینیوم (Al) در آب، رسوبات و سه گونه ماهی (*Labeo rohita*، *Hypophthalmichthys molitrix* و *Oreochromis niloticus*) بود. این نمونه‌ها به‌صورت ماهانه از رودخانه ستلج، پنجاب، پاکستان، از ژانویه تا مارس سال ۲۰۱۹ جمع‌آوری شدند. نمونه‌های آب و رسوب از ایستگاه‌ها (بالادست و پایین‌دست) جمع‌آوری شد. نتایج نشان داد که بالاترین غلظت آلومینیوم در نمونه‌های آب و رسوب بالادست (۲۲۳/۸۳±۳/۴۵ میلی‌گرم بر لیتر و ۴۱۷/۲۵±۳/۵۹ میکروگرم بر گرم) نسبت به نمونه‌های پایین‌دست (۲۲۲/۸۷±۳/۴۴ میلی‌گرم بر لیتر و ۴۱۶/۳۱±۳/۶۵ میکروگرم بر گرم) مشاهده شد. در بین تمام اندام‌های ماهی، کبد بیشترین تجمع Al را در مقایسه با ماهیچه و آبشش داشت. ترتیب تجمع در *Labeo rohita* کبد > آبشش > عضله، در *Hypophthalmichthys molitrix* ترتیب کبد > آبشش > عضله و در *Oreochromis niloticus*، ترتیب کبد > ماهیچه > آبشش بود. این مطالعه نشان می‌دهد که رودخانه ستلج باید به‌درستی نظارت شود تا از کیفیت آب م و حیات آبزیان محافظت شود و از سلامت طولانی مدت رودخانه اطمینان حاصل گردد.

کلمات‌کلیدی: محیط آبی، پایین‌دست، پساب، سلامت، فلزات سنگین.