Volume 4, Issue 3, 2026

Frontier in Medical & Health Research

ISSN: (e) 3007-1607 (p) 3007-1593

TO FIND HEAVY CONCENTRATION IN DIFFERENT ORGANS OF TWO DISTINCT FISH SPECIES FROM RIVER SWAT

[1]Naila Gulfam, [2]Shaista, [3]Muhammad Shakeel, [4]Anmol Salim, [5]Mehreen Niaz, [6]Faryal Saeed, [*7]Muhammad Saqib Khalil

[1]Jinnah College for Women University of Peshawar
[2]Jinnah College for Women University of Peshawar
[3]Institute of Biotechnology and Microbiology Bacha Khan University Charsadda
[4]Jinnah College for Women University of Peshawar
[5]Jinnah College for Women University of Peshawar
[6]Jinnah College for Women University of Peshawar
[*7]Sarhad Institute of Allied Health Sciences, Sarhad University of Science and Information Technology, KPK,Pakistan
[1]nailazoo@uop.edu.pk,[2]Chemistry554@uop.edu.pk, [3]drshakeel@bkuc.edu.pk, [4]annusalim@gmail.com, [5]mehreenniaz4911@gmail.com,[6]faryalsaeed792@gmail.com, [*7]saqib.siahs@suit.edu.pk

DOI: https://doi.org/10.5281/zenodo.22198104

Keywords:
Schizothorax Richardsonii, Oncorhynchus Mykiss, heavy metal, concentration, tssue, organs

Article History
Received on 22 Feb, 2026
Accepted on 28 March, 2026
Published on 31 March, 2026

Corresponding Author
*Muhammad Saqib Khalil

Abstract

This study aimed to assess the amount of heavy metal accumulation in two distinct fish species, Schizothorax richardsonii (Common snowtrout) and Oncorhynchus mykiss (Rainbow Trout), collected from the River Swat in Pakistan.The heavy metal contamination of freshwater fish is an important global public health danger. When accumulate up in fish, people who eat them run the risk of health problems, potentially causing damage to the nervous system, kidneys, and liver. Moreover, heavy metal toxicity can increase the risk of cancer and other diseases. This study aimed to assess the levels of chromium (Cr), copper (Cu), and cadmium (Cd) in two distinct fish species from the River Swat in Pakistan. Using an atomic absorption spectrometer at the Central Resource Laboratory, University of Peshawar, the concentrations of Cr, Cu, and Cd were determined in fish samples of Schizothorax richardsonii and Oncorhynchus mykiss. The research results showed that the levels of heavy metals (copper, chromium, and cadmium) in the fish sampled from River Swat are within the range permitted by the Food and Agricultural Organization of the United States (FAO/WHO) and the World Health Organization's (WHO) recommendations. This study indicates that no elements posing a threat to public health were encountered, thus not posing a short-term risk. Conclusion: From our study, it has been concluded that the heavy metal concentration of Cr, Cu, and Cd in Schizothorax Richardsonii and Oncorhynchus Mykiss was within the permissible limit, so these are safe for human consumption.

Frontier in Medical & Health Research

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INTRODUCTION

The word heavy metals has come to be synonymous with pollution and toxicity – and with good reason. The toxic heavy metals like lead, mercury and cadmium are very dangerous to human health and environment (Adnan *et al.*, 2024). In contrast, some trace elements like copper, zinc, iron and manganese are toxic for freshwater organisms at high concentrations but beneficial in low concentrations (Liu *et al.*, 2024). But heavy metals can be sequentially added to the environment, including the soil, sediment, underground water, and industry wastes (Yang *et al.*, 2024).

Millions of people rely on fish as an important source of nutrition, and they absorb toxins easily from their surroundings that can be harmful to human health. Urban pollution, agricultural runoff, and industrial waste discharge contribute to the accumulation of heavy metals in freshwater ecosystems (Biswas *et al.*, 2023), which can biomagnify and cause toxic effects in the organisms that are exposed to them (Akila *et al.*, 2022). Heavy-metal emissions have greatly increased due to human activities in recent decades, and the bioaccumulation of a particular fish species is influenced by factors such as feeding habit and body size (Jiang *et al.*, 2022). These concerns have been documented and there is a clear risk of bioaccumulation, biomagnification and food-chain transfer, and fish parasites are a big issue in aquatic habitats and can also be used as an indicator of disturbance in the habitat and decrease in water quality (Zaghloul *et al.*, 2022; Radwan *et al.*, 2022).

Heavy metals enter the body of fish via the digestive system, body and gills (Praveena *et al.*, 2013), and chronic exposure can cause harmful effects such as reproductive tissue changes, immune system impairment and cancer (Lye *et al.*, 1998). Copper and iron are essential metals which are required in small quantities, and non-essential metals such as silver are toxic at low concentrations, are transported to aquatic ecosystems via both natural and anthropogenic routes (Abdo *et al.*, 2024). Fish as a food source are also a vehicle for heavy-metal contamination and may be at levels that can cause various health issues (Sunde, 2000). Heavy metals in aquatic environments are also likely to be present at low concentrations in the ambient environment but can accumulate significantly in aquatic organisms through multiple pathways, including binding to sediment (in particular carcinogenic ones as arsenic, lead and chromium) and as secondary pollutants in the aquatic system (Jeong *et al.*, 2023); cadmium, which is common in freshwater environments, causes oxidative stress and damages the larval and embryonic stages of fish (Santhosh *et al.*, 2024).

Swat valley is highly dependable on the Swat river and it has large number of fish species (Khan *et al.*, 2013). It suffers from water pollution due to industrial discharges, agricultural land use, agricultural run-off with pesticides and fertilisers, sewage pollution and dumping of solid wastes (Yousafzai & Hussain, 2018) which causes degradation of water quality, reduction of dissolved oxygen, loss of habitat and disruption of the wider ecosystem (Ahmad *et al.*, 2020). The culture of rainbow trout (*Oncorhynchus mykiss*) was brought to Swat valley in early 20th century but failed in a few attempts and was finally established by the establishment of a hatchery at Tangar village, Madyan (Yahya & Ali, 2002). Its flesh is palatable and rich in protein, low in carbohydrates, and the species grows very quickly, making it commercially important all over the world (Habibnia *et al.*, 2024; Abidin *et al.*, 2022).

The present study was conducted to determine the concentration of chromium, copper and cadmium

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ISSN: (e) 3007-1607 (p) 3007-1593

in various organs of two types of fish *Schizothorax richardsonii* (Common snowtrout) and *Oncorhynchus mykiss* (Rainbow trout)) obtained from the River Swat and compare the values obtained with the international permissible limits.

MATERIALS AND METHODS

Fish sample collection

Six samples of fish were obtained from different sections of the River Swat to determine the contamination and bioaccumulation of the selected selected common edible freshwater fish species. Gill nets fitted with cork lines or floats at the top and metal lines or sinkers with a bottom rope made of nylon thread were used as fishing gear by local fishermen. Samples were stored in ice box and taken to the laboratory for further analysis.

Fish identification

Taxonomic keys of Jayaram (1999), Talwar and Jhingran (1991), and Mirza and Sandhu (2001) were used for identification of fishes in the CRL laboratory complex, Peshawar. All fish were measured for confirmation of species identity, with morphometric measurements such as length, weight, eye diameter and number of barbels recorded.

Fish dissection

After the morphometric analysis the fishes were dissected and tissues samples obtained from gills, muscle, liver and intestine. The wet weight of tissues was recorded, washed with distilled water and kept in sterile polythene bags with proper labels in the freezer at −20 °C till further analysis.

Tissue digestion

Heavy metal content of the samples was determined by digestion of the samples at the Central Resource Laboratory (CRL), University of Peshawar. The tissue samples were then thawed and washed in distilled water prior to transferring them to clean 100 mL volumetric flasks. The process of digestion was done according to Van Loon (1980) and Du Preez and Steyn (1992), modified from Yousafzai and Shakoori (2006): 5 mL of nitric acid (55%) and 1 mL of perchloric acid (70%) were added to the flasks and left overnight, followed by a further 4 mL of perchloric acid (70%) and 5 mL of nitric acid (55%) the next day. The flasks were then placed on a hot plate under a Pyrex glass cover and heated to 200-250 °C until a clear, transparent solution was obtained, with the appearance of brown fumes followed by white vapour, which indicated digestion was complete. The digestion procedure, modified in this way, required about 30 minutes, whereas Van Loon (1980) required 3–4 hours. The samples were digested and then cooled, filtered through Whatman No. 42 filter paper and diluted to 100 mL with distilled water and kept in well-cleaned glass vials for further analysis of the metals.

Metal estimation

The heavy metal levels of Cadmium, Chromium and Copper in each tissue sample were measured by an atomic absorption spectrophotometer (Spectra AA 2000) at the CRL laboratory, Peshawar.

Statistical analysis

The data were analysed statistically with SPSS Software. Note to author: I see that you have no complete, matching entries in your reference list in your thesis for Yousafzai and Shakoori (2006), Van Loon (1980), Du Preez/Due Freez and Steyn (1992), Jayaram (1999), Talwar and Jhingran (1991), or Mirza and Sandhu (2001); these are older, standard methods that are easy to forget when compiling a bibliography, so please locate them and enter full citations before submission.

RESULTS AND DISCUSSION

A certain amount of heavy metals can be preserved by certain aquatic organisms. While not being harmful or toxic, some heavy metals can enter the

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ISSN: (e) 3007-1607 (p) 3007-1593

food chain and have an effect on human health (Merlini, 1971). In general, toxicity develops whenever heavy metal concentrations rise over certain thresholds. In addition, the existence of heavy metals in water presents a threat to fish, human beings, and ecosystem safety when they enter the food chain at various stages. (Jain along with others, 2008; Sonmez and others, 2013).

Table 1: U.S Recommended daily dietary allowance (RDR 1989) supplied by a 100g of fish muscles per day as shown in the following

Metals	Concentration (mg)	Microgram (µg)
Zn	2.6	2600µg
Ni	0.01	10µg
Cr	0.05-0.20	50-200µg
Cu	2.0-3.0	2000-3000µg
Cd	0.014	14µg
Pb	0.3	300µg

***Oncorhynchus Mykiss* 1 (Rainbow trout)**

TABLES

Table 2 summarizes the concentration (mg/L) of Cd, Cr and Cu, in the intestine of *Oncorhynchus Mykiss* 1 (Rainbow trout) collected from river swat. .Mean concentration of Cd was 0.074.mg/L with standard deviation of 0.034 while mean value of Cr and Cu concentration was found to be 0.00mg/L and 2.961 mg/L .respectively with percentage RSD of 19.14 and 0.70 respectively. Intestine showed highest concentration of copper followed by cadmium while lest concentration of chromium was observed. After comparing the values it was found that these values range below the impermissible of USA.

Table 2: ***Heavy metal accumulation in the intestine of Oncorhynchus Mykiss 1 (Rainbow trout)***

Organ	Analyte	Mean	StdDev	%RSD
INTESTINE	Cd	0.074mg/L	0.0034	4.52
	Cr	0.00mg/L	0.0250	19.14
	Cu	2.961mg/L	0.0208	0.70

Table 3 Lists the levels of Cd, Cr, and Cu (in milligrams per liter) in the muscles of *Oncorhynchus Mykiss* 1 (Rainbow trout) that were taken from river swat .The mean value of the concentrations of Cr and Cu was determined to be 0.00mg/L And.0.439mg/L Respectively, with % RSD of 188.38 And 0.74 respectively, while the mean concentration of Cd was 0.050 Mg/L with a standard deviation of 0.0072. The highest copper concentrations were found in the muscles, but the lowest chromium content was found there. These readings fall below the USA's permitted limits, it was discovered after comparing the data.

Table 3: ***Heavy metal accumulation in the muscle of Oncorhynchus Mykiss 1 (Rainbow trout)***

Organ	Analyte	Mean	StdDev	%RSD
MUSCLE	Cd	0.050mg/L	0.0072	14.30
	Cr	0.00mg/L	0.0453	188.38

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	Cu	0.439mg/L	0.003	0.74

Tables 4 Describes the levels of Cd, Cr, and Cu (mg/L) found in the liver of *Oncorhynchus Mykiss* 1 (Rainbow trout) that were taken from river swat .The average concentration of Cd was determined to be 0.9 mg/L with a standard deviation of 0.0120 ,whereas the average concentrations of Cr and Cu were found to be 0.027 mg/Land 7.820 mg /L respectively, with percentage RSD of 124.85 and 0.50.The greatest quantity of copper was found in the liver followed by cadmium, and the lowest concentration of chromium .These numbers fall below what is considered to be acceptable in the United States, according on a comparison of the data.

Table 4: ***Heavy metal accumulation in the liver of Oncorhynchus Mykiss 1 (Rainbow trout)***

Organ	Analyte	Mean	StdDev	%RSD
LIVER	Cd	0.97mg/L	0.0120	12.33
	Cr	0.027mg/L	0.0337	124.85
	Cu	7.820mg/L	0.0395	0.50

Table 5: Heavy metal accumulation in the gills of *Oncorhynchus Mykiss 1* (Rainbow trout)

Table 5 gives an overview of the levels of Cd, Cr, and Cu (in milligrams per liter) in the gills of *Oncorhynchus Mykiss 1* (Rainbow trout) that were taken from river swat .In contrast, the mean values of Cr and Cu concentrations were found to be 0.016mg/L And 0.861 mg/L. Respectively, with percentage RSD of 164.95And 1.90 respectively. The mean concentration of Cd was determined to be 0.070 Mg/L with a standard deviation of. 0.0097. Copper concentrations were highest in the gills followed by cadmium and chromium concentrations were lowest. These numbers fall below what is considered to be acceptable in the United States, according to a comparison of the figures.

Table 5: ***Heavy metal accumulation in the gills of Oncorhynchus Mykiss 1 (Rainbow trout)***

Organ	Analyte	Mean	StdDev	%RSD
GILLS	Cd	0.070mg/L	0.0097	13.79
	Cr	0.016mg/L	0.0260	164.95
	Cu	0.861mg/L	0.0165	1.90

***Oncorhynchus Mykiss* 2 (Rainbow trout)**

TABLES

Table 6 provides the essential information about the concentration level of Cd, Cr, and Cu in the intestine of *Oncorhynchus Mykiss* (Rainbow trout) collected from River Swat. The mean concentration of cadmium registers at 0.041mg/L, accompanied by a standard deviation of 0.0018 In contrast, chromium and copper levels reach 0.00 and 0.329mg/L respectively, with a percentage relative standard deviation of 36.59 and 1.11. The tests found that in the intestine the concentration of copper was significantly higher, followed by cadmium while chromium exhibiting the lowest concentration level. The levels of all three metals were within the safe limits set by USA.

Table 6: ***Heavy metal accumulation in the intestine of Oncorhynchus Mykiss (Rainbow trout) 2***

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Organ	Analyte	Mean	StdDev	%RSD
INTESTINE	Cd	0.041mg/L	0.0018	4.44
	Cr	0.00mg/L	0.0319	36.59
	Cu	0.329mg/L	0.0037	1.11

TABLE 7 summarizes the concentration (mg/L) of Cd, Cr and Cu, in the *Oncorhynchus Mykiss* 2 (Rainbow trout) muscle gathered from River Swat. Cadmium levels average 0.071mg/L, with a standard deviation of 0.0044. In contrast, chromium and copper levels reach 0.00 and 10.59mg/L respectively, with a percentage relative standard deviation of 42.45 and 0.90. The analysis revealed that the muscle contain the small amount of copper and a larger amount of cadmium and the amount of chromium is in between According to US guidelines the amount of these metals are safe posing no health risks.

Table 7: ***Heavy metal accumulation in the Muscle of Oncorhynchus Mykiss 2 (Rainbow trout)***

Organ	Analyte	Mean	StdDev	%RSD
MUSCLE	Cd	0.071mg/L	0.0044	6.19
	Cr	0.00mg/L	0.0220	42.45
	Cu	10.59mg/L	0.095	0.90

Table 8 illustrate the concentration of Cd, Cr,Cu in *Oncorhynchus Mykiss* 2 (Rainbow trout) 2 liver obtained from River Swat. The data reveals a mean concentration of cadmium at 0.077mg/L, with a standard deviation of 0.0141. Meanwhile, chromium and copper levels clocked in at 0.00 and 0.00348mg/L respectively, with a percentage relative standard deviation of 25.31 and 0.93. The liver showed the affinity of copper followed by cadmium with chromium displaying the lowest concentration .A comparative analysis showed that these values are safely below the Impermissible limits established by the United States.

Table 8: ***Heavy metal accumulation in the liver of Oncorhynchus Mykiss 2 (Rainbow trout)***

Organ	Analyte	Mean	StdDev	%RSD
LIVER	Cd	0.077mg/L	0.0141	18.42
	Cr	0.00mg/L	0.0292	25.31
	Cu	3.732mg/L	0.00348	0.93

Table 9 summarizes the concentration (mg/L) of Cd, Cr and Cu, in the Gills of *Oncorhynchus Mykiss* 2 (Rainbow trout) collected from River Swat. Mean concentration of Cd was 0.072 mg/L with standard deviation of 0.0080 while mean value of Cr and Cu concentration was found to be 0.029 and 1.582 respectively with percentage RSD of 176.66 and 0.19 respectively. Gills showed highest concentration of copper followed by cadmium while lest concentration of Cr was observed. After comparing the values it was found that these values range below the impermissible of USA.

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Table 9: *Heavy metal accumulation in the Gills of Oncorhynchus Mykiss 2 (Rainbow trout)*

Organ	Analyte	Mean	StdDev	%RSD
GILLS	Cd	0.072mg/L	0.0080	11.07
	Cr	0.029mg/L	0.0516	176.66
	Cu	1.582mg/L	0.0029	0.19

***SCHIZOTHORAX RICHARDSONII 1* (COMMON SNOWTROUT) TABLES**

Table 10 Gives an overview of the levels of Cd, Cr, and Cu (in milligrams per liter) in the Intestine of *Schizothorax Richardsonii 1* (Common snowtrout) that were taken from River Swat. In contrast, the mean values of Cr and Cu concentrations were found to be 0.00 and 0.501mg/L Respectively, with percentage RSD of. 30.26 And 1.38 respectively. The mean concentration of Cd was determined to be 0.091mg/L with a standard deviation of 0.0057. Copper concentrations were highest in the intestine, followed by cadmium, and Cr concentrations were lowest. These numbers fall below what is considered to be acceptable in the United States, according to a comparison of the figures.

Table 10: *Heavy metal accumulation in the intestine of Schizothorax Richardsonii 1*

Organ	Analyte	Mean	StdDev	%RSD
INTESTINE	Cd	0.091mg/L	0.0057	6.29
	Cr	0.00mg/L	0.0260	30.26
	Cu	0.501mg/L	0.0069	1.38

Table 11 illustrate the concentration of Cd, Cr,Cu in *Schizothorax Richardsonii 1* (Common snowtrout) 1 Muscle obtained from River Swat. The data reveals a mean concentration of cadmium at 0.091mg/L, with a standard deviation of 0.0057. Meanwhile, chromium and copper levels Reaches at 0.00 and 0.501mg/L respectively, with a percentage relative standard deviation of 30.26 and 1.38. The muscle showed the affinity of copper followed by cadmium with chromium displaying the lowest concentration. A comparative analysis showed that these values are safely below the Impermissible limits established by the United States.

Table 11: *Heavy metal accumulation in the Muscle of Schizothorax Richardsonii 1 (Common snowtrout)*

Organ	Analyte	Mean	StdDev	%RSD
MUSCLE	Cd	0.095mg/L	0.0098	10.28
	Cr	0.00mg/L	0.0452	27.50
	Cu	0.343mg/L	0.0023	0.67

Table 12. Describes the levels of Cd, Cr, and Cu (mg/L) detected in the liver of *Schizothorax Richardsonii 1* (Common snowtrout) collected from river swat. The average Cd concentration was found to be 0.0 76 mg/L, with a standard deviation of 0.0097. The average concentrations of Cr and Cu were determin6ed to be 0.00 mg/L and 1.160 mg/L, respectively, with percentage RSD

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ISSN: (e) 3007-1607 (p) 3007-1593

values of 133.44 and 1.48. The liver contained the highest content of chromium, followed by copper and the lowest concentration of cadmium. These figures are lower than what is regarded acceptable in the United States based on data comparisons.

Table 12: ***Heavy metal accumulation in the Liver of Schizothorax Richardsonii 1 (Common snowtrout)***

Organ	Analyte	Mean	StdDev	%RSD
LIVER	Cd	0.076mg/L	0.0097	12.75
	Cr	0.00mg/L	0.0413	133.44
	Cu	1.160mg/L	0.0172	1.48

Table 13 summarizes the concentration (mg/L) of Cd, Cr and Cu, in the Gills of *Schizothorax Richardsonii 1* (Common snowtrout) fish collected from River Swat. Mean concentration of Cd was 228.8mg/L with standard deviation of 0.0080 while mean value of Cr and Cu concentration was found to be 0.052 mg/L and 1.131mg/L .respectively with percentage RSD of 64.16 and 1.25 respectively. Gills showed highest concentration of copper followed by cadmium while lest concentration of chromium was observed. After comparing the values it was found that these values range below the impermissible of USA.

Table 13: ***Heavy metal accumulation in the Gills of Schizothorax Richardsonii 1 (Common snowtrout)***

Organ	Analyte	Mean	StdDev	%RSD
GILLs	Cd	0.143mg/L	0.0080	5.60
	Cr	0.052mg/L	0.0337	64.16
	Cu	1.131mg/L	0.0141	1.25

***SCHIZOTHORAX RICHARDSONII 2* (COMMON SNOWTROUT) TABLE**

Table 14 Gives the crucial details regarding the concentration of Cd, Cr, and Cu in the intestine of *Schizothorax Richardsonii 2* (Common snowtrout) fish taken from the River Swat. The cadmium concentration is 0.071 mg/L on average, with a 0.0040 standard deviation. Conversely, the levels of chromium and copper are 0.00 mg/L and 0.407 mg/L, respectively, with a percentage relative standard deviation of 160.11 and 0.44. According to the tests, copper was identified in the intestine at a substantially higher concentration, followed by cadmium while chromium showing the lowest concentration. All three metal levels were within the USA's safe standards.

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Table 14: *Heavy metal accumulation in the intestine of Schizothorax Richardsonii 2 (Common snowtrout)*

Organ	Analyte	Mean	StdDev	%RSD
INTESTINE	Cd	0.071mg/L	0.0040	5.64
	Cr	0.00mg/L	0.0426	160.11
	Cu	0.407mg/L	0.0018	0.44

Table 15 Lists the amounts of Cd, Cr, and Cu (in milligrams per linear liter) found in *Schizothorax Richardsonii 2* (Common snowtrout) fish muscle collected from the River Swat. The average amount of cadmium is 0.083 mg/L, with a 0.0029 standard deviation. On the other hand, the levels of chromium and copper are 0.012 mg/L and 0.323 mg/L, respectively, with a relative standard deviation of 355.50 and 2.07 percent. According to the analysis, the muscle has a tiny amount of copper, a high amount of cadmium, and a medium amount of chromium. The amount of these metals is safe and poses no health hazards, according to US guidelines.

Table 15: Heavy metal accumulation in the muscle of *Schizothorax Richardsonii 2* (Common snowtrout)

Organ	Analyte	Mean	StdDev	%RSD
MUSCLES	Cd	0.083mg/L	0.0029	3.48
	Cr	0.012mg/L	0.0440	355.50
	Cu	0.323mg/L	0.0067	2.07

Table 16 Show the concentrations of Cd, Cr, and Cu in *Schizothorax Richardsonii 2* (Common snowtrout) fish liver collected from the Swat River. The findings show a mean cadmium content of 0.097 mg/L with a standard deviation of 0.0122. Meanwhile, chromium and copper levels were measured at 0.00 and 1.139 mg/L, respectively, with percentage relative standard deviations of 14.11 and 0.35. The liver revealed copper affinity, followed by cadmium, with chromium having the lowest quantity. A comparative research revealed that these values are well below the Impermissible limits set by the US.

Table 16: *Heavy metals accumulation in the Liver of Schizothorax Richardsonii 2 (Common snowtrout)*

Organ	Analyte	Mean	StdDev	%RSD
LIVER	Cd	0.097mg/L	0.0122	12.51
	Cr	0.00mg/L	0.0156	14.11
	Cu	1.139mg/L	0.0039	0.35

Table 17 Describes the concentrations (mg/L) of Cd, Cr, and Cu in the gills of *Schizothorax Richardsonii 2* (Common snowtrout) obtained from the Swat River. The mean Cd concentration was 0.535 mg/L with a standard deviation of 0.0082, but the mean Cr and Cu concentrations were 0.225mg/L and 2.874mg/L, respectively, with percentage RSDs of 23.27 and 0.33. Gills had the highest concentration of copper, followed by cadmium, and the lowest concentration of Cr was discovered. After comparing the values, it was

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ISSN: (e) 3007-1607 (p) 3007-1593

discovered that they are below the USA's permitted limit.

Table 17: ***Heavy metals accumulation in the Gills of Schizothorax Richardsonii 2 (Common snowtrout)***

Organ	Analyte	Mean	StdDev	%RSD
GILLS	Cd	0.535mg/L	0.0082	1.53
	Cr	0.225mg/L	0.0523	23.27
	Cu	2.874mg/L	0.0095	0.33

DISCUSSION

Some aquatic organisms can accumulate a detectable level of heavy metals without any apparent negative effects, but as the metals are transferred from one trophic level to another, they can reach the human diet and cause damage to fish, human beings, and ecosystems, as long as they cross a certain threshold (Jain *et al.*, 2008; Sonmez *et al.*, 2013).

Copper levels in all four organs studied (intestine, muscle, liver and gills) were consistently the highest, followed by cadmium, while chromium was generally the lowest (or below the limit of quantification) in all organs of both species. This trend was seen for both *Oncorhynchus mykiss* (Rainbow trout) and *Schizothorax richardsonii* (Common snowtrout) and is representative of the fact that essential trace metals like copper are actively controlled and maintained in the fish tissue, and are therefore present at higher concentrations than non-essential metals such as cadmium, whereas chromium is not readily dissolved in water and is therefore not so readily taken up by fish tissue (Saidon *et al.*, 2024).

The liver of both species showed higher concentrations of copper than did the muscle (7.82 mg/L in *O. mykiss*, and up to 1.16–1.14 mg/L in *S. richardsonii*, which is in line with the general trend of liver tissue having a higher heavy-metal content than muscle tissue (Jeong *et al.*, 2023), and agrees with the liver's known function as an important site of metal metabolism, detoxification, and storage in fish. The levels of copper and cadmium in both species were comparatively high in Gill tissues, which is also known as a major metal uptake surface in the aquatic environment (Praveena *et al.*, 2013).

The concentration of chromium found in the muscle and intestine of the majority of the samples was not detected, or was present at levels of less than one part per million. The highest levels of chromium were seen in the gills, particularly in S. richardsonii 2 (0.225 mg/L). This is in line with the fact that chromium does not easily enter soft fish tissue, it is more likely to become attached to particulate matter and sediment and therefore is not readily absorbed unless it has direct contact with the water at the gill surface (Saidon *et al.*, 2024).

However, all the cadmium, chromium and copper concentration levels measured in both species were found to be below the recommended limits set by the FAO/WHO and the U.S. Recommended Dietary Allowance (U.S. RDA, 1989) for fish muscle consumption. This finding aligns with the reports of other rivers in the region where heavy metal pollution was detected but not reported to be severely affecting the health of consumers who eat fish (Ahmad *et al.*, 2020; Biswas *et al.*, 2023). Heavy metals are bioaccumulated in fish and are likely to gradually rise with prolonged exposure to low levels in the environment, and in view of the Swat River being subjected to industrial effluents, agricultural runoff, untreated sewage, and solid

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ISSN: (e) 3007-1607 (p) 3007-1593

waste discharge (Yousafzai & Hussain, 2018), continued monitoring is therefore justified.

CONCLUSION

This study estimated accumulation of three heavy metals (cadmium, chromium, and copper) in the intestine, muscle, liver and gills of two fish species, *Schizothorax richardsonii* (Common snowtrout) and *Oncorhynchus mykiss* (Rainbow trout) from the River Swat of Khyber Pakhtunkhwa Province, Pakistan. The pattern of accumulation of the metals was always Cu > Cd > Cr, irrespective of the species, and all four organs examined. The highest levels of copper were found in the liver and gills, cadmium was found in all tissues in moderate amounts, and chromium was found at low levels in most tissues, but was often negligible in the liver. All of the measured concentrations were below FAO, WHO and U.S. Recommended Dietary Allowance (RDA, 1989) limits, suggesting that fish from this part of the River Swat are not presently a threat to human health due to cadmium, chromium, or copper exposure, and are safe for human consumption.

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