



Monsoon-driven bioaccumulation of heavy metals in water and fish tissues of the Majalgaon Dam and Sindaphana Dam, Maharashtra, India

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Abstract

Evaluation of heavy metal contamination in aquatic ecosystems is crucial for understanding ecological integrity and food safety risks. The present investigation evaluated the concentration and bioaccumulation pattern of mercury (Hg), arsenic (As), lead (Pb), cadmium (Cd), and nickel (Ni) in water and selected fish tissues from the Majalgaon dam and Sindaphana River, Maharashtra, during July to September 2024. Fish organs, such as liver, gills, and muscle, were analysed using Inductively Coupled Plasma Mass Spectrometry (ICP-MS), a sensitive technique commonly used for trace-metal detection. The results show elevated concentrations of Pb and Ni in several fish tissues, exceeding the WHO/FAO permissible limits. Arsenic levels marginally exceeded the limits in some samples, whereas mercury concentrations remained within safe thresholds. Cadmium levels were generally low but crossed permissible levels in a few tissues. The order of tissue-specific accumulation was Liver > Gill > Muscle. The study indicates increased metal influx during the monsoon season, which may be due to surface runoff and anthropogenic discharge. These findings highlight potential ecological and human health risks associated with fish consumption.

Keywords: Heavy metals, bioaccumulation, ICP-MS, rainy season, fish tissues, Sindaphana River

Introduction

Freshwater ecosystems are highly polluted because of industrialisation, agriculture, and urban expansion (Burger, & Gochfeld 2005) ^[5]. Heavy metals are of particular concern because they are non-biodegradable and remain in aquatic environments for long periods (Clarkson & Magos 2006) ^[6]. Once the metals are introduced into water bodies, they accumulate in sediments and biota, entering the food chain (EFSA 2012).

Fish are widely recognised as effective bioindicators of aquatic pollution because they integrate contaminants from water and diet over time (Evans 2005) ^[8]. Metal accumulation varies in different tissues depending on physiological function and exposure route (Förstner & Wittmann 2012) ^[9]. The liver is a primary organ responsible for detoxification and often shows higher metal accumulation ^[10]. Gills of all fish species accumulate metals directly from water due to continuous contact during respiration ^[11]. Muscle tissues generally show lower metal concentrations but are vital for human exposure assessment ^[12]. Seasonal variation notably influences metal distribution in rivers ^[13]. During the rainy season, increased surface runoff transports metal contaminants from agricultural lands, roads, and industrial areas into rivers ^[14]. Hydrological changes due to the monsoon may enhance metal mobility and bioavailability ^[15].

The Sindaphana River, located in Beed district, Maharashtra, receives runoff from agricultural, rural, and urban zones. However, limited data are available about seasonal metal bioaccumulation in fish from this river. Therefore, the present study aims to evaluate heavy metal concentrations in water and fish tissues during the rainy season and compare them with international safety standards.

Materials and Methods

1. Study Area

The Sindaphana River flows through agricultural, rural and urban regions of Beed district Maharashtra. During the rainy season, the river receives increased runoff carrying sediments and dissolved contaminants of mining industry and agriculture waste.

2. Sample Collection

Fish specimens were collected from seven different selected sites along the river and dam during the July to September 2024. Water samples were collected simultaneously in acid-washed polyethylene bottles following standard sampling procedures ^[16].

3. Sample Preparation

Fish were dissected and liver, gill, and muscle tissues separated. Samples were washed with distilled water and homogenized. Acid digestion was carried out using nitric acid under controlled laboratory conditions ^[17].

4. Metal Analysis

Metal concentrations (Hg, As, Pb, Cd, Ni) were quantified using ICP-MS due to its high sensitivity and precision for trace element analysis (2). Results were expressed in mg/kg for tissues and mg/L for water.

Results

1. Heavy Metals in Water

In the present study mercury and cadmium level remained below the permissible limits. Rainy season water samples showed elevated concentrations of arsenic (0.0606 mg/L), lead (0.572 mg/L), and nickel (10.03 mg/L), exceeding WHO drinking water limits. These elevated values indicate runoff-mediated contamination during monsoon months.

2. Heavy Metals in Fish Tissues

Mercury concentrations in fish tissues ranged between 0.0005-0.02 mg/kg and remained below the FAO/WHO limit of 0.5 mg/kg (3). Arsenic concentrations (0.02-0.12 mg/kg) slightly exceeded recommended levels in selected tissues. Lead concentrations ranged from 0.27-3.2 mg/kg, consistently exceeding permissible limits (3). Nickel levels (1.0-16.0 mg/kg) were also extremely above the recommended values in several samples. Cadmium was generally within safe limits but surpassed 0.05 mg/kg in a few tissues.

3. Tissue-Specific Accumulation

Metal accumulation followed the trend: Liver > Gill > Muscle

The liver exhibited the highest concentrations due to its metabolic and detoxification role. Gills showed moderate accumulation due to direct exposure to contaminated water. Muscle tissues showed relatively lower accumulation but contained measurable metal concentrations.

Discussion

The elevated concentrations of lead and nickel during the rainy season suggest enhanced surface runoff carrying contaminants into the river. Agricultural fertilizers, vehicular emissions, and domestic effluents may contribute to these metals. Although mercury remained within safe limits, chronic exposure cannot be ignored due to its bioaccumulative nature. Arsenic exceedance in some samples raises concerns regarding long-term toxicity. The presence of elevated Pb and Ni in edible tissues poses potential health risks, particularly for local populations consuming fish regularly. Continuous monitoring is therefore necessary.

Conclusion

The study demonstrates significant seasonal bioaccumulation of heavy metals in fish from the Sindaphana River during the rainy season. Lead and nickel were the dominant contaminants exceeding safety limits. Tissue-specific accumulation followed the order Liver > Gill > Muscle. Water contamination during monsoon months suggests runoff as a major pollution source. The findings emphasize the need for pollution control strategies and routine environmental monitoring to safeguard aquatic ecosystems and public health.

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