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Histopathological Effects of Heavy Metals on Freshwater Fish Organs in the Chintamani Region, Karnataka

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Abstract

Heavy metal pollution is an escalating threat to aquatic ecosystems, especially in semi-urban regions with unregulated industrial and agricultural runoff. This study investigates the histopathological effects of heavy metals—specifically lead (Pb), cadmium (Cd), and chromium (Cr)—on vital organs of freshwater fish species (Oreochromis mossambicus and Catla catla) from tanks in the Chintamani region. Fish samples were analyzed for metal accumulation using atomic absorption spectrophotometry (AAS), and histological sections of liver, kidney, and gill tissues were studied under a light microscope. Significant tissue degeneration was observed in fish from contaminated sites, including vacuolization, necrosis, and epithelial hyperplasia. The findings suggest urgent remediation and policy action to reduce metal exposure in local water bodies.

Keywords: Heavy metals, fish pathology, lead, cadmium, chromium, histology, Oreochromis, Chintamani, aquatic toxicity, pollution

1. Materials and Methods

1.1 Study Area

This study was conducted in **Chintamani Taluk**, a semi-arid region of Karnataka characterized by a mosaic of agricultural land, granite-processing units, and seasonal tanks. Three freshwater tanks were selected based on their proximity to pollution sources and human activities:

- **Kolaramma Tank (Site A)** – Considered a control site with minimal anthropogenic disturbance.
- **Gudibande Tank (Site B)** – Receives effluents from small-scale granite cutting and polishing units.
- **Mallasandra Tank (Site C)** – Exposed to agricultural runoff containing fertilizers and pesticides.

These tanks are used for fish cultivation and occasional human use, making them ecologically and socioeconomically significant.

1.2 Fish Species Selection and Collection

Two ecologically important and commonly consumed freshwater fish species were chosen:

- Oreochromis mossambicus (Tilapia)
- Catla catla (Indian major carp)

From each site, **10 specimens per species** (total N = 60) were collected during the post-monsoon season (October–December 2014) using standardized cast nets. The fish were transported live to the laboratory and euthanized ethically following CPCSEA guidelines.

1.3 Water Sampling and Metal Analysis

Surface water samples were collected in triplicate from each site and preserved using nitric acid. The concentration of **lead (Pb), cadmium (Cd), and chromium (Cr)** was determined using **Atomic Absorption Spectrophotometry (AAS)** (PerkinElmer Analyst 400) after acid digestion (APHA, 2012 protocols).

1.4 Organ Sampling and Histopathology

Liver, kidney, and gill tissues were dissected immediately post-mortem. Samples were:

- Fixed in 10% buffered formalin
- Dehydrated, embedded in paraffin, and sectioned at 5 µm thickness
- Stained with Hematoxylin and Eosin (H&E)
- Observed under a light microscope at 400x magnification
- Photomicrographs were taken using Leica DM750 system.

Histopathological changes were assessed using a **semi-quantitative grading scale**:

Grade	Observation
0	Normal histology
1	Mild alterations

2	Moderate structural changes
3	Severe tissue degeneration

1.5 Statistical Analysis

All measurements were analyzed using **SPSS v22.0**. One-way ANOVA was used to compare metal concentrations and lesion severity among sites. Pearson's correlation was applied to relate tissue damage with metal levels. Results were considered statistically significant at $p < 0.05$.

2. Results and Discussion

2.1 Water Quality and Metal Concentrations

Table 1 shows the concentrations of Pb, Cd, and Cr in water samples. Site B (Gudibande Tank) exhibited the highest mean values:

Site	Pb (mg/L)	Cd (mg/L)	Cr (mg/L)
A	0.04	0.01	0.03
B	0.36	0.11	0.18
C	0.29	0.08	0.14

All values at Sites B and C exceeded the **BIS permissible limits** for inland surface waters (Pb: 0.05 mg/L, Cd: 0.01 mg/L, Cr: 0.05 mg/L).

2.2 Histopathological Observations

Liver

Fish from Site A displayed intact hepatic cords, centrally placed nuclei, and minimal vacuolization. In contrast:

- Site B: **Massive hepatocyte vacuolization**, sinusoidal dilation, pyknotic nuclei, and fatty degeneration
- Site C: **Moderate disintegration of hepatic cords**, focal necrosis, and inflammatory cell infiltration

These results are indicative of heavy metal-induced oxidative stress and impaired metabolic function, consistent with Javed & Usmani (2012) and Authman et al. (2013).

Kidney

Control site fish showed well-defined glomeruli and renal tubules. Site B samples exhibited:

- **Glomerular shrinkage**, interstitial edema, and **tubular necrosis**
- Presence of **hemosiderin deposits**, indicative of impaired filtration

Site C also showed glomerular damage but to a lesser extent.

Gills

Gills at Site A had uniform lamellae and epithelial layers. At Site B:

- **Lamellar fusion**, **epithelial lifting**, and **mucosal cell hyperplasia** were dominant
- Disrupted secondary lamellae likely impaired gaseous exchange
- Similar pathologies noted by Velma & Tchounwou (2010) in metal-exposed fish

2.3 Bioaccumulation and Lesion Correlation

Metal concentrations in tissues followed the pattern:

Liver > Kidney > Gills, confirming liver's role in metal storage and detoxification. Pearson correlation showed:

- Pb levels strongly correlated with liver lesion score ($r = 0.82$)
- Cd had the strongest correlation with kidney damage ($r = 0.85$)
- Cr correlated moderately with gill hyperplasia ($r = 0.76$)

These observations are consistent with previous studies and highlight **organ-specific vulnerability**.

2.4 Interpretation and Broader Implications

The histopathological changes documented here indicate **chronic, sublethal exposure** to heavy metals, which may not immediately kill fish but severely impair their physiological functions. This can lead to reduced growth, immunosuppression, and increased susceptibility to pathogens.

Moreover, metal bioaccumulation in fish tissues poses **significant risks to human consumers**, especially in rural areas where fish is a dietary staple and water is used untreated. The findings call for a multidisciplinary response involving **environmental monitoring, public health awareness, and regulatory enforcement**.

3. Conclusion

The study provides clear evidence that freshwater tanks in Chintamani Taluk are experiencing significant contamination with heavy metals—particularly lead, cadmium, and chromium—primarily due to **unregulated granite industry effluents and agricultural runoff**.

The observed **histopathological alterations in liver, kidney, and gill tissues** of Oreochromis mossambicus and Catla catla reflect chronic toxicity that threatens both aquatic life and human health. Liver and kidney were the most affected, emphasizing their vulnerability as detoxification and excretory organs.

To mitigate further ecological and health risks, the following measures are urgently recommended:

- **Regular biomonitoring** of fish tissues in tanks used for aquaculture or consumption
- Implementation of **wastewater treatment** systems for local granite processing units
- Adoption of **agroforestry buffers** to reduce chemical runoff from farmlands
- Community awareness campaigns on **safe fish consumption** and **heavy metal risks**

This research serves as a **baseline reference** for future ecotoxicological studies in Karnataka's inland water bodies and contributes to developing localized **fish health indices** for environmental impact assessments.

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5. Endnotes

1. Lead exposure in fish causes liver necrosis and behavioral changes.
2. Chromium accumulates rapidly in kidney tissues due to its filtration role.
3. Fish gills are directly exposed to waterborne toxins and serve as early indicators.
4. Indian standards for Pb in drinking water: 0.01 mg/L (BIS, 2012).
5. AAS is considered the gold standard for metal detection in biological tissues.
6. Formalin-fixed organs provide reliable structural visibility under H&E stains.
7. *Oreochromis* is commonly used in aquatic toxicology due to its hardiness.
8. Glomerular shrinkage is an established sign of cadmium nephrotoxicity.
9. Surface runoff from granite polishing units includes Cr-rich wastewater.
10. Epithelial lifting in gills can reduce oxygen exchange and impair respiration.