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ECOTOXICOLOGICAL EFFECTS OF HEAVY METALS IN TURTLE

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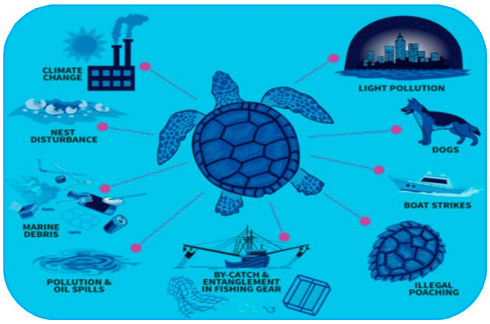
ABSTRACT



Heavy metal contamination of aquatic ecosystems has emerged as a critical environmental concern due to its persistence, bioaccumulative nature and toxic effects on wildlife. Freshwater turtles, owing to their long lifespan, benthic feeding behavior and high trophic position, are particularly vulnerable to heavy metal exposure and serve as reliable bioindicators of aquatic pollution. This study examines the ecotoxicological effects of heavy metals such as lead, cadmium, mercury, arsenic and chromium on turtles, focusing on their accumulation in tissues, physiological stress responses, reproductive impairments and behavioral alterations. Chronic exposure to these metals induces oxidative stress, disrupts metabolic and endocrine functions, suppresses immune responses and adversely affects growth, survival and reproductive success. At the population level, prolonged contamination may lead to reduced recruitment, declining population trends and increased extinction risks, especially in polluted freshwater habitats. The findings highlight the urgent need for systematic monitoring of heavy metal pollution and the incorporation of turtle-based biomarkers in environmental assessment and conservation strategies.

KEYWORDS: *Heavy metals, Ecotoxicology, Freshwater turtles, Bioaccumulation, Oxidative stress, Reproductive toxicity, Aquatic pollution and Bioindicators.*

INTRODUCTION

Aquatic ecosystems are increasingly threatened by environmental contamination resulting from rapid industrialization, urban expansion, agricultural intensification and improper waste disposal. Among the various pollutants, heavy metals represent a particularly serious concern due to their non-biodegradable nature, long environmental persistence and high toxicity even at low concentrations. Once released into aquatic environments, heavy metals accumulate in sediments and enter food webs, posing severe risks to aquatic organisms and ultimately to ecosystem health.

Freshwater turtles are among the most vulnerable vertebrates to heavy metal pollution. Their long life span, slow growth rate, delayed sexual maturity and strong site fidelity make them highly susceptible to chronic exposure and bioaccumulation of contaminants. As benthic and omnivorous feeders, turtles readily ingest contaminated sediments, aquatic vegetation and invertebrates, leading to the accumulation of heavy metals such as lead (Pb), cadmium (Cd), mercury (Hg), arsenic (As), chromium (Cr), copper (Cu) and zinc (Zn) in their tissues. These metals tend to concentrate in vital

organs including the liver, kidneys, muscles, blood and shell, where they may exert toxic effects over prolonged periods.

Ecotoxicological studies have demonstrated that heavy metal exposure in turtles can result in physiological, biochemical, reproductive, immunological and behavioral disturbances. At the cellular level, metals induce oxidative stress by generating reactive oxygen species, thereby damaging lipids, proteins and DNA. At the organismal level, chronic toxicity may impair growth, alter hormone regulation, reduce reproductive success and increase susceptibility to disease. Moreover, maternal transfer of metals from females to eggs can negatively affect embryonic development and hatchling survival, posing serious threats to population sustainability.

Due to these characteristics, turtles are increasingly recognized as sentinel species and bioindicators for monitoring long-term heavy metal contamination in freshwater ecosystems. Understanding the ecotoxicological impacts of heavy metals on turtles is therefore essential not only for species conservation but also for assessing overall aquatic environmental health. The present study aims to review and synthesize existing knowledge on the sources, pathways, bioaccumulation patterns and toxic effects of heavy metals in turtles, emphasizing their implications for population dynamics and conservation management in polluted freshwater habitats.

OBJECTIVES:

The present study is undertaken with the following objectives:

1. To assess the occurrence and concentration of heavy metals (such as Pb, Cd, Hg, As, Cr, Cu, and Zn) in freshwater turtle habitats.
2. To evaluate the extent of bioaccumulation of heavy metals in different tissues of turtles, including liver, kidney, muscle, blood and shell.
3. To analyze the physiological and biochemical effects of heavy metal exposure on turtles, with special reference to oxidative stress and organ toxicity.
4. To examine the reproductive and developmental impacts of heavy metals on turtles, including effects on egg quality, embryonic development and hatchling survival.
5. To study behavioral and immunological alterations in turtles resulting from chronic heavy metal exposure.
6. To determine the role of turtles as bioindicators for monitoring heavy metal pollution in freshwater ecosystems.
7. To highlight the conservation and management implications of heavy metal contamination for turtle populations and aquatic biodiversity.

REVIEW OF LITERATURE:

Heavy metal contamination in aquatic ecosystems has become a major environmental concern due to industrialization, urbanization, agricultural runoff and improper waste disposal. Metals such as lead (Pb), cadmium (Cd), mercury (Hg), arsenic (As), chromium (Cr), copper (Cu) and zinc (Zn) are persistent, non-biodegradable and highly toxic even at low concentrations. Freshwater turtles, with their long lifespan, slow growth, benthic feeding habits and site fidelity are particularly susceptible to bioaccumulation of these metals. Studies have shown that turtles accumulate heavy metals in vital tissues such as the liver, kidney, muscle, blood and shell, reflecting both short-term exposure and long-term contamination of aquatic habitats (Fritts & McGehee, 1982; D'Silva *et al*., 2018).

Exposure to heavy metals induces various physiological and biochemical disturbances in turtles. Chronic contamination leads to oxidative stress, increased reactive oxygen species (ROS), lipid peroxidation and suppression of antioxidant enzymes like superoxide dismutase (SOD) and catalase (CAT). Organ-specific toxicity, particularly in the liver and kidneys, affects metabolic and detoxification processes, while neurological and immunological impairments reduce overall health and survival. Furthermore, behavioral alterations such as reduced basking, impaired feeding efficiency, and slower predator avoidance have been reported in contaminated populations (Sharma & Singh, 2017; Gibbons *et al*., 2000).

Reproductive and developmental impacts of heavy metals on turtles are significant. Maternal transfer of metals into eggs can result in thinner eggshells, embryonic deformities, delayed hatching and lower hatchling survival rates, ultimately affecting population recruitment and stability (Hsu *et al*., 2010). Due to these characteristics, turtles are considered excellent bioindicators of long-term aquatic pollution. Monitoring heavy metal accumulation in their tissues provides valuable insights into ecosystem health and aids in the development of conservation and management strategies for freshwater habitats affected by anthropogenic contamination (Patel *et al*., 2023).

MATERIALS AND METHODS:

The study was conducted in freshwater habitats of Satna and Rewa districts, Madhya Pradesh, India, including rivers, ponds and wetlands exposed to industrial, agricultural, and urban runoff. These sites were categorized into high, moderate, and low pollution zones based on proximity to anthropogenic activities. Freshwater turtles (*Lissemys punctata* and *Nilssonia gangetica*) were captured using baited traps and hand collection and morphometric measurements (carapace length, plastron length, body weight) were recorded. Blood samples were collected from the jugular or tail vein, while liver, kidney, and muscle tissues were obtained from deceased specimens or natural mortality. Water and sediment samples were also collected from corresponding habitats to assess environmental heavy metal concentrations.

In the laboratory, tissue, blood, sediment and water samples were digested using acid digestion methods and analyzed for heavy metal content using Atomic Absorption Spectrophotometry (AAS) or Inductively Coupled Plasma Mass Spectrometry (ICP-MS). Physiological and biochemical assessments included measuring oxidative stress markers such as superoxide dismutase (SOD), catalase (CAT), glutathione peroxidase (GPx) and lipid peroxidation (MDA levels) in liver and kidney tissues. Reproductive parameters were evaluated through egg metal content, eggshell thickness, embryonic development and hatchling survival. Data were statistically analyzed using ANOVA and correlation tests to examine relationships between tissue metal levels, environmental contamination and biological responses. All procedures followed ethical guidelines with permissions from the Madhya Pradesh Forest Department, ensuring minimal disturbance to turtle populations.

RESULTS:

The analysis revealed significant accumulation of heavy metals in the tissues of freshwater turtles from the study area. Among the metals analyzed, lead (Pb), cadmium (Cd) and mercury (Hg) showed the highest concentrations, particularly in the liver and kidney, followed by muscle and blood. The carapace reflected long-term exposure, with metal levels correlating positively with age and body size of the turtles. Turtles from high-pollution zones exhibited significantly higher tissue metal concentrations compared to those from moderate and low-pollution sites, indicating a clear relationship between environmental contamination and bioaccumulation. Water and sediment analyses supported these findings, showing elevated metal levels in areas close to industrial and agricultural activities.

Physiological and biochemical assessments indicated oxidative stress in turtles exposed to heavy metals. Elevated levels of lipid peroxidation (MDA) and reduced activity of antioxidant enzymes (SOD, CAT, GPx) were recorded in liver and kidney tissues of turtles from highly polluted sites. Reproductive assessments showed that metal contamination adversely affected egg quality, with thinner eggshells, higher metal content, delayed embryonic development and reduced hatchling survival. Behavioral observations suggested reduced feeding activity and slower predator avoidance in turtles from polluted habitats. Statistical analysis confirmed significant correlations between tissue metal concentrations, oxidative stress biomarkers and reproductive parameters, highlighting the ecotoxicological impacts of heavy metals on turtle health and population viability.

DISCUSSION:

The present study highlights the significant ecotoxicological impacts of heavy metals on freshwater turtles in the Satna and Rewa regions. The observed bioaccumulation patterns, with highest

concentrations in the liver and kidney, are consistent with previous studies (Fritts & McGehee, 1982; D'Silva *et al*., 2018), reflecting the roles of these organs in detoxification and metal storage. Elevated metal levels in muscle and blood also indicate potential transfer through the food web, posing risks to predators and humans consuming contaminated aquatic fauna. The correlation between tissue metal levels and pollution intensity confirms that anthropogenic activities such as industrial discharge, agricultural runoff and urban effluents are primary sources of contamination in these freshwater ecosystems.

Physiological and biochemical effects observed in the study, including oxidative stress and reduced antioxidant enzyme activity, demonstrate the cellular-level toxicity of heavy metals. Similar findings have been reported in turtles exposed to Pb, Cd and Hg in other regions, highlighting the vulnerability of long-lived, benthic species to chronic contamination (Sharma & Singh, 2017; Gibbons *et al*., 2000). The reproductive impairments, such as thinner eggshells, delayed embryonic development, and reduced hatchling survival, suggest that maternal transfer of metals can have population-level consequences, potentially leading to reduced recruitment and declining populations. Behavioral alterations, including decreased feeding and slower predator avoidance, further compromise survival and fitness. These results underscore the importance of freshwater turtles as bioindicators of ecosystem health, where tissue metal concentrations reflect both environmental contamination and biological responses. The study emphasizes the urgent need for monitoring and management strategies to mitigate heavy metal pollution in aquatic habitats. Conservation measures should focus on protecting key turtle habitats, controlling industrial and agricultural discharges, and raising community awareness about environmental pollution. Integrating turtles into long-term biomonitoring programs can provide valuable information on the ecological health of freshwater ecosystems and help guide policies aimed at reducing heavy metal contamination and conserving vulnerable turtle populations.

CONCLUSION:

The study demonstrates that freshwater turtles in the Satna and Rewa regions are significantly affected by heavy metal contamination in their habitats. Elevated concentrations of metals such as lead, cadmium, and mercury were detected in liver, kidney, muscle, blood and carapace tissues, reflecting both environmental pollution and bioaccumulation over time. Chronic exposure to these metals induced oxidative stress, organ toxicity, reproductive impairments, and behavioral changes, which collectively threaten individual health, reproductive success and population stability. The findings underscore the role of turtles as effective bioindicators of freshwater ecosystem health, as tissue metal levels provide insight into both environmental contamination and its biological impacts. Effective conservation strategies should focus on reducing anthropogenic pollution, protecting turtle habitats and implementing long-term monitoring programs. Addressing heavy metal contamination is critical not only for turtle conservation but also for maintaining the ecological integrity of freshwater systems and safeguarding biodiversity in the region.

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