A Study on Heavy Metal Contamination and Seasonal Distribution of Trace Metals in Mallapur Lake, Chitradurga District, Karnataka

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***Abstract*—Heavy metal contamination of freshwater ecosystems has emerged as a major environmental concern due to its persistence, toxicity, and potential ecological and human health impacts. Seasonal monitoring of heavy metals is essential for understanding their temporal distribution and supporting effective water quality management. Water samples were collected from four sampling sites in Mallapur Lake, Chitradurga District, Karnataka, between February 2022 and January 2024, covering summer, southwest monsoon, and northeast monsoon seasons. The concentrations of heavy metals viz. copper (Cu), nickel (Ni), lead (Pb), zinc (Zn), iron (Fe), aluminium (Al), chromium (Cr), manganese (Mn), and cadmium (Cd) were determined using atomic absorption spectrophotometry (AAS) following acid digestion. The data were summarized using descriptive statistics, and seasonal trends were illustrated using mean concentration plots. Heavy metal concentrations exhibited distinct seasonal variations, with comparatively higher concentrations during the summer season and lower concentrations during the monsoon periods. Cu and Fe recorded the highest concentrations during summer 2022 and summer 2023, respectively. Whereas, Ni, Pb, and Zn also showed elevated concentrations during summer 2023 before declining during subsequent monsoon seasons. Al and Cr were detected primarily during the northeast monsoon, while spatial variations among the four sampling sites were relatively minor. In conclusion, seasonal hydrological conditions had a greater influence on heavy metal distribution than site-specific differences. Regular monitoring of heavy metals is recommended to support sustainable management and conservation of the water quality of Mallapur Lake.**

***Index Terms*—Heavy metals, Mallapur lake, Monitoring, Seasonal variation, Water quality**

I. INTRODUCTION

.The deterioration of river water quality due to indiscriminate discharge of untreated sewage, industrial waste and other anthropogenic activities like urbanization, population growths and land development along river basin is one of the major concerns throughout the world [1]. River system provides historical records of metal pollution. Metal pollution analysis allows an establishment of correlation between metal partitioned into the sediment and present in dissolved state in water [2].

Freshwater lakes are vital aquatic ecosystems that provide water for domestic, agricultural, industrial, and ecological purposes. However, increasing anthropogenic activities, including urbanization, agricultural runoff, industrial discharge, and improper waste disposal, have significantly deteriorated the quality of freshwater resources worldwide [3]. Among various pollutants, heavy metals are considered one of the most persistent contaminants because of their non-biodegradable nature, long environmental residence time, and potential to bioaccumulate and biomagnify through aquatic food chains [4].

Excessive concentrations of heavy metals in surface waters may adversely affect aquatic organisms and pose serious health risks to humans through direct consumption or indirect exposure [4,5]. The distribution and concentration of heavy metals in freshwater ecosystems are influenced by several environmental factors, including seasonal rainfall, catchment characteristics, hydrological conditions,

and anthropogenic inputs [6,7]. Seasonal variations often modify metal concentrations through dilution during monsoon periods and concentration during dry seasons, making continuous monitoring essential for evaluating water quality and identifying pollution sources [8.9] Therefore, the assessment of seasonal fluctuations in heavy metal concentrations provides valuable information for sustainable lake management and environmental conservation.

Mallapur Lake, located in Chitradurga District of Karnataka, serves as an important freshwater resource supporting local domestic activities and surrounding ecosystems. Despite its ecological and socio-economic significance, information regarding the seasonal distribution of trace metals in the lake water remains limited. Furthermore, there is resurgence to provide baseline information on heavy metal contamination and seasonal distribution patterns, contributing to the scientific understanding of water quality and supporting future conservation and management strategies for Mallapur Lake.

Moreover, elevated levels of heavy metals, including cadmium, chromium, copper, mercury, lead, zinc, arsenic, boron, etc., in aquatic environments, can pose a significant toxic impact on various elements of ecosystem due to bioaccumulation through different levels of the food chain [10]. Therefore, the present study aimed to determine the concentrations of heavy metals viz. copper (Cu), nickel (Ni), lead (Pb), zinc (Zn), iron (Fe), aluminium (Al), chromium (Cr), manganese (Mn), and cadmium (Cd) in water samples collected from four sampling sites during different seasons between 2022 and 2023.

II. MATERIALS AND METHODS

A. Study Area

The present investigation was conducted at Mallapur Lake, located near Chitradurga town in Chitradurga District, Karnataka, India (14.2491° N and 76.3999° E, Figure 1). The lake serves as an important freshwater resource for irrigation, livestock activities, groundwater recharge, and domestic purposes. The region experiences three distinct seasons, namely pre-monsoon (February–May), monsoon (June–September), and post-monsoon (October–January).

Figure 1. Mallapur Lake, Chitradurga District, Karnataka, India

B. Sample Collection

Water samples were collected from four representative sampling stations (S1–S4) of Mallapur Lake during the study period. Sampling was carried out during the morning hours between 08:00 and 09:00 h following the standard procedures as prescribed by American Public Health Association Standard Methods.6 Samples were collected in clean polyethylene bottles and transported immediately to the laboratory for physico-chemical analysis.

C. Heavy Metal Analysis

The concentrations of heavy metals viz. copper (Cu), nickel (Ni), lead (Pb), zinc (Zn), iron (Fe), aluminium (Al), chromium (Cr), manganese (Mn), and cadmium (Cd) were determined from the collected water samples. Prior to analysis, the water samples were digested using a tri-acid mixture consisting of perchloric acid, nitric acid, and sulphuric acid. The digested samples were filtered through Whatman No. 42 filter paper and diluted to a final volume of 100 mL with 1 M nitric acid. Heavy metal concentrations viz. copper (Cu), nickel (Ni), lead (Pb), zinc (Zn), iron (Fe), aluminium (Al), chromium (Cr), manganese (Mn), and cadmium (Cd) were determined using an atomic absorption spectrophotometer (GB Avanta Σ, Version 1.32, Australia). Calibration curves were prepared using standard solutions for each element, and 1 M nitric acid was used as the analytical blank. Metal concentrations were expressed as mg/L.

III. STATISTICAL ANALYSIS

The heavy metal concentration data obtained from the four sampling sites (S1–S4) were summarized using descriptive statistics. The mean concentration of each heavy metal was calculated for each sampling season to evaluate seasonal variations in Mallapur Lake water. The results were presented as site-wise concentrations and seasonal mean values in tabular form, while seasonal trends in the mean concentrations of the analysed heavy metals were illustrated using a line graph. No inferential statistical tests were performed because the study primarily aimed to describe the seasonal and spatial distribution of heavy metals in the lake water.

IV. RESULTS

The concentrations of heavy metals in Mallapur Lake water during 2022 exhibited noticeable seasonal variation between the summer and northeast monsoon seasons. Copper was detected at relatively higher concentrations during the summer season, with values ranging from 0.923 to 0.927 mg/L across the four sampling sites (S1–S4), while its concentration decreased markedly during the northeast monsoon, ranging from 0.0151 to 0.0162 mg/L. Nickel concentrations remained comparatively stable between the two seasons, varying from 0.0388–0.0398 mg/L during summer and 0.0350–0.0358 mg/L during the northeast monsoon. Lead was detected only during the northeast monsoon, with concentrations ranging from 0.0405 to 0.0413 mg/L, whereas zinc was also detected exclusively during the northeast monsoon and varied between 0.0184 and 0.0194 mg/L. Iron showed higher concentrations during the summer season (0.1356–0.1374 mg/L) and lower concentrations during the northeast monsoon (0.0130–0.0135 mg/L). Aluminium was detected only during the northeast monsoon, with concentrations ranging from 0.0975 to 0.0980 mg/L. Chromium was detected in both seasons, with concentrations ranging from 0.0052 to 0.0059 mg/L during summer and increasing slightly to 0.0082–0.0088 mg/L during the northeast monsoon. The heavy metal concentrations exhibited only minor spatial variation among the four sampling sites, while more pronounced differences were observed between seasons, indicating the influence of seasonal hydrological conditions on the distribution of trace metals in the lake water (Table 1).

Table 1. Heavy metal concentrations in mallapur lake water during 2022

Heavy Metals	Season	S1 (mg/L)	S2 (mg/L)	S3 (mg/L)	S4 (mg/L)	Mean
Cu	Summer	0.927	0.925	0.923	0.927	0.925
	Northeast Monsoon	0.0158	0.0151	0.0162	0.0153	0.0156
Ni	Summer	0.0398	0.0388	0.0394	0.0390	0.0392
	Northeast Monsoon	0.0356	0.0353	0.0350	0.0358	0.0354
	Northeast Monsoon	0.0409	0.0413	0.0405	0.0410	0.0409
	Northeast Monsoon	0.0188	0.0194	0.0184	0.0190	0.0189
Fe	Summer	0.1374	0.1356	0.1366	0.1365	0.1365
	Northeast Monsoon	0.0133	0.0135	0.0130	0.0134	0.0133
	Northeast Monsoon	0.0977	0.0980	0.0975	0.0978	0.0977
Cr	Summer	0.0056	0.0059	0.0052	0.0055	0.0055
	Northeast Monsoon	0.0082	0.0086	0.0087	0.0088	0.0085

The concentrations of heavy metals in Mallapur Lake water during 2023 exhibited marked seasonal variations among the sampling sites. Copper (Cu) concentrations ranged from 0.071 to 0.076 mg/L during the summer season, decreased to 0.0223 mg/L during the southwest monsoon, and remained between 0.0227 and 0.0230 mg/L during the northeast monsoon. Nickel (Ni) showed the highest

concentrations during summer (0.1506–0.1514 mg/L), declined to 0.0141 mg/L during the southwest monsoon, and increased slightly during the northeast monsoon (0.0306–0.0312 mg/L). Lead (Pb) exhibited relatively high concentrations during summer, varying from 0.411 to 0.417 mg/L, followed by a substantial reduction during the southwest monsoon (0.0042 mg/L) and moderate concentrations during the northeast monsoon (0.0285–0.0291 mg/L). Zinc (Zn) was detected during the summer and northeast monsoon seasons, with concentrations ranging from 0.2077 to 0.2083 mg/L and 0.004 to 0.007 mg/L, respectively. Iron (Fe) recorded the highest concentrations among the analysed metals, varying between 0.6610 and 0.6616 mg/L during summer, decreasing to 0.1091 mg/L during the southwest monsoon, and further declining to 0.0309–0.0315 mg/L during the northeast monsoon. Aluminium (Al) and chromium (Cr) were detected only during the northeast monsoon, with Al concentrations ranging from 0.026 to 0.033 mg/L and Cr concentrations ranging from 0.004 to 0.010 mg/L across the four sampling sites. In general, the concentrations of most heavy metals were highest during the summer season and decreased considerably during the monsoon periods, while spatial variations among the sampling sites (S1–S4) remained minimal, indicating that seasonal hydrological conditions exerted a greater influence on heavy metal distribution than site-specific differences (Table 2).

Table 2. Heavy metal concentrations in mallapur lake water during 2023

Heavy Metals	Season	S1 (mg/L)	S2 (mg/L)	S3 (mg/L)	S4 (mg/L)	Mean (mg/L)
Cu	Summer	0.076	0.071	0.073	0.072	0.073
	Southwest Monsoon	0.0223	-	-	-	-
	Northeast Monsoon	0.0230	0.0228	0.0227	0.0229	0.0229
Ni	Summer	0.1509	0.1514	0.1511	0.1506	0.1510
	Southwest Monsoon	0.0141	-	-	-	-
	Northeast Monsoon	0.0308	0.0310	0.0312	0.0306	0.0309
Pb	Summer	0.417	0.415	0.411	0.413	0.414
	Southwest Monsoon	0.0042	-	-	-	-
	Northeast Monsoon	0.0289	0.0285	0.0291	0.0290	0.0289
Zn	Summer	0.2080	0.2077	0.2083	0.2081	0.2080
	Northeast Monsoon	0.004	0.005	0.006	0.007	0.0055
Fe	Summer	0.6612	0.6610	0.6616	0.6614	0.6613
	Southwest Monsoon	0.1091	-	-	-	-
	Northeast Monsoon	0.0315	0.0311	0.0309	0.0313	0.0312
Al	Northeast Monsoon	0.030	0.026	0.033	0.031	0.0300
Cr	Northeast Monsoon	0.004	0.006	0.008	0.010	0.0070

Note: Data for S2–S4 during the Southwest Monsoon of 2023 were not available and therefore are not presented.

Figure 2 illustrates the seasonal variation in the mean concentrations of heavy metals in Mallapur Lake water during 2022 and 2023. Cu exhibited the highest concentration during Summer 2022 (0.925 mg/L), followed by a sharp decline during the Northeast Monsoon of 2022 and relatively lower concentrations throughout 2023. Fe showed comparatively low concentrations during 2022 but increased markedly during Summer 2023 (0.661 mg/L), before decreasing during the subsequent monsoon seasons. Ni, Pb, and Zn also exhibited elevated concentrations during Summer 2023, whereas substantially lower

concentrations were recorded during the Southwest and Northeast Monsoon seasons. Al was detected only during the Northeast Monsoon of 2022 and 2023, while Cr occurred at consistently low concentrations throughout the study period. Most heavy metals showed higher concentrations during the summer seasons and lower concentrations during the monsoon seasons, indicating the influence of seasonal hydrological conditions, particularly dilution during rainfall and concentration effects during dry periods, on the distribution of trace metals in Mallapur Lake water.

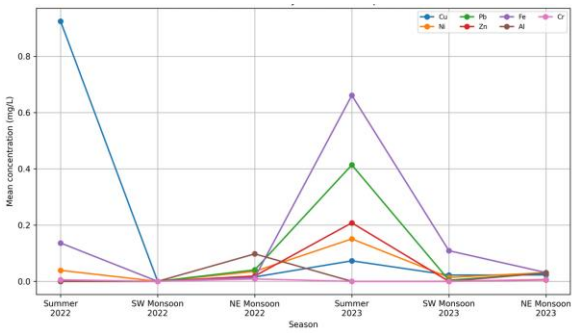

Figure 2. Seasonal variation of heavy metals in mallapur lake water

V. DISCUSSION

The present study demonstrated clear seasonal variations in the concentrations of heavy metals in Mallapur Lake water during 2022 and 2023. Most of the analysed metals exhibited comparatively higher concentrations during the summer season and lower concentrations during the monsoon seasons, suggesting that seasonal hydrological conditions strongly influenced trace metal distribution in the lake. Similar seasonal patterns have been reported in freshwater ecosystems, where evaporation during dry periods concentrates dissolved metals, while increased rainfall and surface runoff during the monsoon promote dilution and reduce metal concentrations [8,11].

Cu exhibited the highest concentration during Summer 2022 (0.925 mg/L), followed by a substantial decline during the Northeast Monsoon and comparatively lower concentrations throughout 2023. This reduction may be attributed to dilution effects associated with increased rainfall and enhanced water exchange during the monsoon season [12]. Cu in lake water generally originates from agricultural runoff, domestic wastewater, corrosion of metallic materials, and natural weathering of rocks [13]. Ni concentrations remained relatively stable during 2022 but increased considerably during Summer 2023 before decreasing during the subsequent monsoon seasons. Similar seasonal fluctuations have been reported in lakes influenced by anthropogenic inputs and changing hydrological conditions [14,15].

Pb and Zn were either absent or detected at relatively low concentrations during 2022 but exhibited elevated concentrations during Summer 2023, followed by a marked decline during the Southwest and Northeast Monsoon seasons. The observed seasonal pattern suggests that reduced water volume during summer may have increased the concentration of dissolved metals, whereas rainfall-induced dilution lowered their concentrations during the monsoon period [16]. Similar observations have been reported for tropical freshwater lakes receiving diffuse anthropogenic inputs from surrounding catchments [17,18]

Fe exhibited the greatest seasonal variation among the analysed metals, increasing from a mean concentration of 0.1365 mg/L during Summer 2022 to 0.6613 mg/L during Summer 2023 before declining substantially during the monsoon seasons. Elevated iron concentrations during summer may have resulted from increased sediment-water interactions, mineral dissolution, and concentration effects associated with reduced lake volume [19]. Seasonal changes in Fe concentrations have previously been associated with fluctuations in redox conditions and sediment resuspension in shallow lakes [20,21].

Al and Cr were detected primarily during the Northeast Monsoon, although Cr was also detected at low concentrations during Summer 2022. Their relatively low concentrations and limited spatial variation suggest that these metals were largely influenced by natural geological weathering rather than localized point sources [22]. The minimal variation observed among the four sampling sites further indicates that heavy metal distribution within the lake was relatively homogeneous, whereas

seasonal climatic conditions exerted a stronger influence on metal concentrations than spatial differences. Similar findings have been reported for freshwater lakes in semi-arid regions where seasonal hydrology governs metal transport and distribution [23,24].

The seasonal trend confirmed that heavy metal concentrations generally peaked during the summer season and declined during the monsoon periods. Continuous surveillance of Mallapur Lake is therefore recommended to identify future changes in metal loading and to support effective water quality management and conservation measures. The study provided comprehensive seasonal monitoring of trace metals at four sampling sites over two consecutive years using standard APHA sampling procedures and Atomic Absorption Spectrophotometry, generating baseline information on the temporal distribution of heavy metals in Mallapur Lake. The study was limited by incomplete heavy metal data for some sampling sites during the Southwest Monsoon of 2023, which restricted a complete site-wise comparison for that season.

VI. CONCLUSION

The present study demonstrated that the concentrations of heavy metals in Mallapur Lake water exhibited distinct seasonal variations, with relatively higher concentrations during the summer season and lower concentrations during the monsoon periods. Among the analysed metals, Cu, nickel, Pb, Zn, and Fe showed considerable temporal fluctuations, whereas Al and Cr occurred at comparatively lower concentrations with limited spatial variation. The findings indicated that seasonal hydrological conditions played a more significant role in influencing heavy metal distribution than differences among the sampling sites. Continuous monitoring of heavy metal concentrations is therefore recommended to support sustainable management and conservation of the water quality of Mallapur Lake.

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