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Assessment of Water Quality and Heavy Metals Pollution in the Nearby Residential Zone of Cuddalore Sipcot

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ABSTRACT: The State Industries Promotion Corporation of Tamil Nadu (SIPCOT) established Phase 1 of its industrial complex in Cuddalore in 1984, spanning an area of 518.79 acres. Currently, there are 23 operational units within Phase 1, with approximately 16 villages situated either within or near the industrial estate. According to the industries own reports, out of the 20 million liters of fresh water required by the companies, 18 million liters (90%) are released back into the environment as toxic effluents. Water, a fundamental element for life, blankets 70.9% of the Earth's surface. The planet's water distribution is largely dominated by oceans, holding 96.5% of the total water volume, followed by groundwater and ice caps with 1.7% each. Other significant reservoirs include glaciers, rivers, lakes, and atmospheric water vapor, collectively accounting for a minute fraction of the Earth's water resources. Freshwater constitutes merely 2.5% of the total, with the majority locked in ice and groundwater reserves. Only a tiny portion of freshwater is readily accessible in rivers, lakes, and the atmosphere, while a minuscule fraction is contained within living organisms and human-made products. The levels of heavy metals—specifically Zn, Cd, Cu, and Pb—gathered from various locations within the study area. These samples were analyzed using an Atomic Absorption Spectrophotometer (Perkin Elmer 1983–400 HGA 900/AS 800). The obtained results were then compared against Indian standards for drinking water to ascertain their pollution levels. To assess the groundwater quality in and around the SIPCOT industrial complex in Cuddalore district, a study was conducted. The evaluation focused on various physicochemical parameters, and groundwater samples were collected from 30 locations within the study area for analysis (according to APHA, 1998 standards). These samples were analyzed using an ANOVA 1918 Roanld fisher.

KEYWORDS: SIPCOT, groundwater reserves, heavy metals, Atomic Absorption Spectrophotometer, ANOVA.

I. INTRODUCTION

Groundwater, which exists beneath the surface in voids, fractures, cracks, and soil spaces, serves as a crucial water source for both urban and rural populations across India. Not only does it predominantly supply drinking water, but it also serves as a primary source for irrigation. Groundwater has become increasingly indispensable in meeting the escalating water demands. With approximately 210 billion cubic meters, including replenishment through infiltration, seepage, and evaporation, groundwater is a natural boon. However, the intrusion of salinity and industrial pollution are significant factors contributing to the deterioration of groundwater quality. This study aims to analyze the impact of waste discharge from SIPCOT industries on groundwater quality. Water serves as a vital indicator of human resilience, being crucial for the well-being and development of communities. Access to clean, fresh water is essential for public health and prosperity. However, the risks to well-being posed by water scarcity, particularly in tropical regions with contaminated water sources, are more pronounced than in areas with abundant and clean water resources. Potable water for domestic use should meet specific criteria, including clarity, paleness, odorlessness, taste, and freedom from harmful impurities. The health and sustainability of human populations heavily rely on the availability of clean water for drinking and various household activities. Unfortunately, many people still lack access to this invaluable resource, leading to adverse impacts on health, particularly in vulnerable regions. Heavy metals, non-biodegradable and stable, pose health risks by accumulating in organisms. Industrial complexes amplify heavy metal contamination risks. Some metals like Cu, Fe, Mn, and Ni are essential, while others like Pb, Cd, and Cr are harmful beyond certain limits. These

samples were analyzed using an Atomic Absorption Spectrophotometer (Perkin Elmer 1983–400 HGA 900/AS 800). The study aims to analyze heavy metal concentrations in SIPCOT effluents water, chemically known as dihydrogen monoxide (H₂O), is essential for life, with human survival depending on its consumption. Water exists in various states - liquid, solid (ice), and gaseous (steam) - depending on environmental conditions. It also forms a liquid film near hydrophilic surfaces. Comprising 70% of the Earth's surface, water is indispensable for all known forms of life. The majority of the planet's water (86%) is contained within oceans, with smaller portions found in groundwater, polar ice caps, and other bodies of water. Only a small fraction of Earth's water (2.5%) is freshwater, predominantly locked in ice and groundwater reserves. These samples were analyzed using an ANOVA 1918 Roanld fisher. Surface water sources like rivers and lakes, as well as atmospheric water, account for a minuscule portion of freshwater resources. The hydrological cycle, involving evaporation, condensation, precipitation, and runoff, ensures the continual circulation of water through the environment, replenishing soil moisture and sustaining life.

II. RELATED WORK

Gunaselvi Shanmugam (2020) assessed the ground water quality in Cuddalore, Inbanila T and Arutchelvan (2015) studied on ground water quality around cuddalore SIPCOT industrial area, J. Ahamed sultan et, al., (2015) [1] studied about impact of heavy metals on ground water, R. Manikandan et, al., (2016) [2] assessed the ground water quality in Cuddalore. Water Pollution in Industrial Zones: Previous studies have highlighted the significant impact of industrial activities on water quality in various regions worldwide. Industries often discharge effluents containing pollutants such as heavy metals, organic compounds, and suspended solids into water bodies, leading to contamination and degradation of aquatic ecosystems (Ahmad et al., 2019) [3]. Waste of heavy metals in water: Heavy metals including lead, cadmium, mercury, arsenic, chromium and nickel are of particular concern due to their persistence, toxicity and bioaccumulation properties Thus these metals can leach into water bodies through various human activities such as mining, construction and urban runoff -Significant risks to health and environment (Mohammed et al., 2020) [4]. Health Effects of Heavy Metal Exposure: Exposure to water contaminated with heavy metals is associated with a variety of adverse health effects including arthritis, kidney damage, heart and neurological diseases and cancer Children and pregnant women are particularly vulnerable to heavy metal toxicity, which can impair growth and development (Khan et al., 2018) [5]. Water Quality Monitoring and Analysis: Monitoring and analyzing water quality metrics plays an important role in identifying pollution sources, assessing environmental risks, and implementing management strategies guidelines Physicochemical parameters such as pH, dissolved oxygen, biochemical oxygen demand, and heavy metal concentrations. Indicators of water quality and pollution levels are commonly used (Wu et al., 2019) [6]. Regulatory Framework and Regulation: Effective waste management requires the integration of legal, regulatory mechanisms and remediation technologies Federal laws and regulations governing industrial discharge standards, water quality monitoring and pollution control are essential to prevent environmental pollution and protect public health (Kumar et al., 2021) [7].

III. METHODOLOGY

In the study area around the SIPCOT region, 24 sampling points were chosen to assess groundwater quality from July 2023 to June 2024. Water samples were collected during various rainy seasons and analyzed for several physicochemical parameters including pH, dissolved oxygen (DO), electrical conductivity (EC), turbidity, total suspended solids (TSS), and total dissolved solids (TDS). The analysis followed standardized protocols developed by the American Public Health Association (APHA, 2010). Heavy metals such as zinc (Zn), cadmium (Cd), copper (Cu), and lead (Pb) were also examined using an atomic absorption spectrophotometer (Perkin Elmer 1983–400 HGA 900/AS 800). Laboratory methods included precise measurements of organic matter, metal content, organic contaminants, nutrients, and microbial parameters. For instance, pH was measured with a pH meter, DO by the Winkler method or electronic meter, conductivity with a conductometer, turbidity with a turbidity meter, TSS by filtering and weighing residue, and TDS by evaporating the sample and weighing the residue. These methods align with protocols from regulatory bodies like the EPA, WHO, and ISO, ensuring reliable and comparable water quality results for the area.

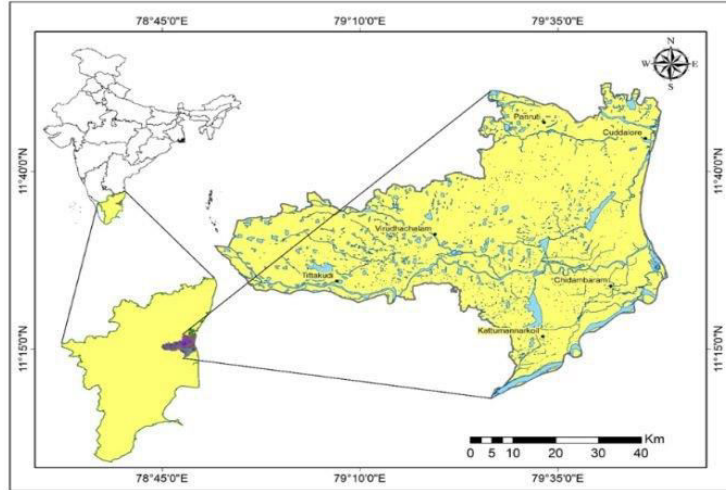


Fig. 1. Cuddalore district on the map of India



Fig. 2. Sampling Area (SA) Cuddalore SIPCOT Near Residential Area

IV. EXPERIMENTAL RESULTS

Water and sediment samples were collected from various sampling sites in and neighboring residential areas of Cuddalore SIPCOT area on the southeast coast of India. Analysis was conducted to detect heavy metals, including cadmium, copper, zinc, and lead, measured in parts per million (ppm) concentrations within both the water and sediment samples.

Heavy metals in water

Copper

The analysis of copper concentration in water samples collected from six sampled locations revealed variations ranging from 0.059 to 0.831 ppm within the study area (Fig. 3a).

At sampled location 1, copper concentration fluctuated between 0.126 ppm in March 2024 and 0.831 ppm in June 2024. Sampled location 2 exhibited a high concentration of 0.369 ppm in June 2024, contrasting with a low concentration of 0.063 ppm in March 2024. The mean copper concentration at sampled location 3 ranged from 0.123 to 0.391 ppm in March 2024 and April 2024. Sampled location 4 depicted copper concentrations varying from 0.059 ppm in January

2024 to 0.666 ppm in November 2023. Sampled location 5 displayed a range of 0.076 to 0.359 ppm in June 2024 and February 2024. At sampled location 6, the copper concentration fluctuated between a low of 0.071 ppm in March 2024 and a high of 0.753 ppm in May 2024.

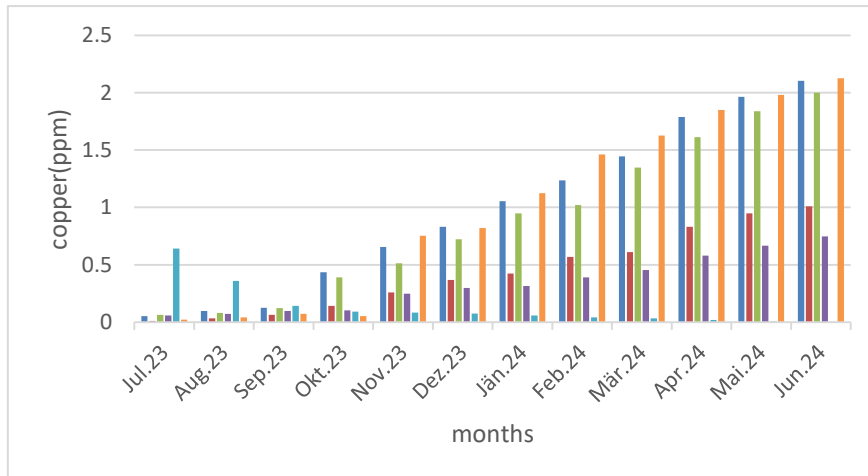


Fig 3a. Copper analyzed by various duration

Cadmium

The analysis of cadmium concentration in water samples collected from six sampled locations revealed variations ranging from 0.001 to 1.507 ppm within the study area (Fig. 2b).

At sampled location 1, cadmium concentration varied from 0.02 ppm in October 2023 to 0.91 ppm in April 2024. Sampled location 2 exhibited a high concentration of 0.004 ppm in June 2024, contrasting with a low concentration of 0.425 ppm in November 2023. The mean cadmium concentration at sampled location 3 ranged from 0.007 to 1.507 ppm in November 2023 and March 2024. Sampled location 4 depicted cadmium concentrations varying from 0.023 ppm in June 2024 to 0.089 ppm in December 2023. Sampled location 5 displayed a range of 0.003 to 0.398 ppm in May 2024 and February 2024. At sampled location 6, the cadmium concentration fluctuated between a low of 0.012 ppm in April 2024 and a high of 0.102 ppm in May 2024.

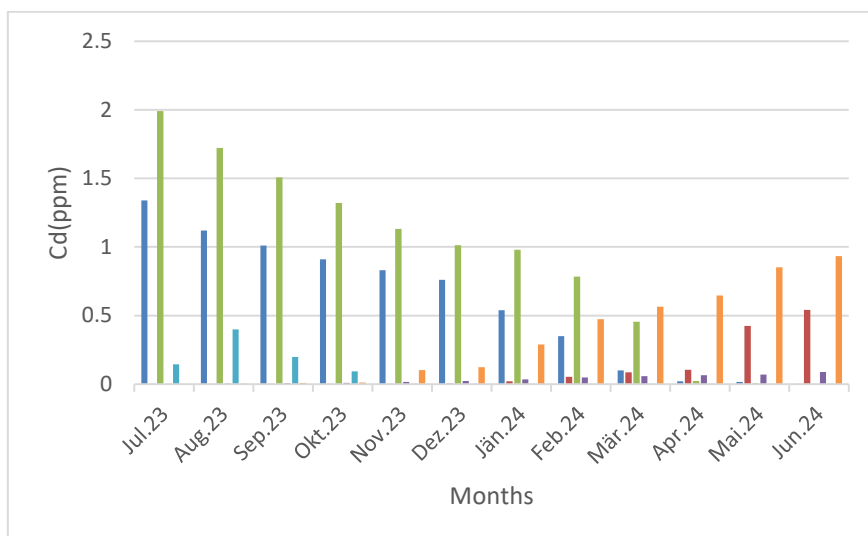


Fig 3b. Cadmium analyzed by various duration

Zinc

The analysis of zinc concentration in water samples collected from six sampled locations exhibited variations ranging from 0.254 to 0.817 ppm within the study area (Fig. 2c).

At sampled location 1, zinc concentration fluctuated from 0.254 ppm in June 2024 to 0.671 ppm in November 2023. Sampled location 2 displayed a high concentration of 0.817 ppm in December 2023, contrasting with a low concentration of 0.255 ppm in March 2024. The mean zinc concentration at sampled location 3 varied from 0.259 to 0.393 ppm in February 2024 and December 2023. Sampled location 4 depicted zinc concentrations varying from 0.284 ppm in May 2024 to 0.414 ppm in June 2024. Sampled location 5 exhibited a range of 0.271 to 0.404 ppm in April 2024 and June 2024. At sampled location 6, the zinc concentration fluctuated between a low of 0.282 ppm in March 2024 and a high of 0.465 ppm in November 2023.

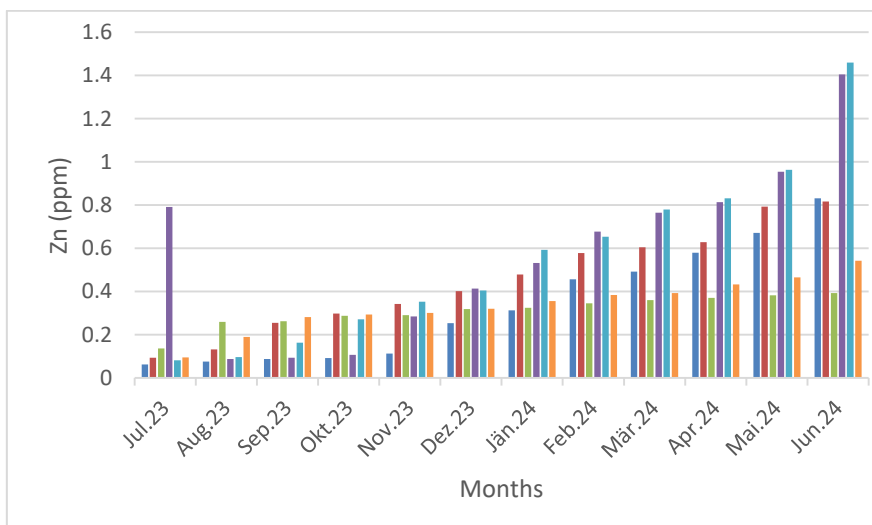


Fig 3c. Zinc analyzed by various duration

Lead

The analysis of lead concentration in water samples collected from six sampled locations revealed variations ranging from 0.001 to 1.124 ppm within the study area (Fig. 2d).

At sampled location 1, lead concentration varied from 0.001 ppm in June 2024 to 0.425 ppm in December 2023. Sampled location 2 exhibited a high concentration of 0.811 ppm in May 2024, contrasting with a low concentration of 0.001 ppm in December 2023. The mean lead concentration at sampled location 3 varied from 0.002 to 0.212 ppm in March 2024 and November 2023. In sampled location 4, lead concentration varied from 0.001 ppm in June 2024 to 0.861 ppm in May 2024. Sampled location 5 displayed a range of 0.001 to 0.003 ppm in June 2024 and January 2024. At sampled location 6, the lead concentration fluctuated between a low of 0.001 ppm in January and a high of 0.154 ppm in April 2024.

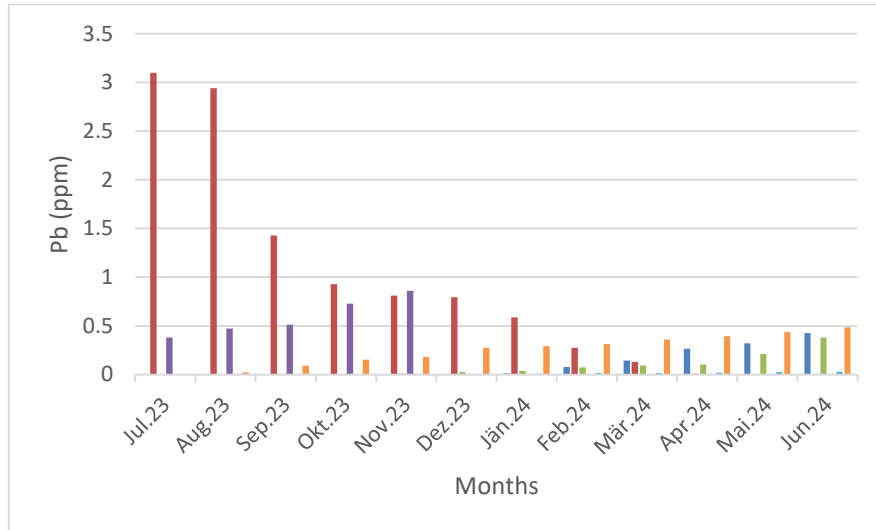


Fig 3d. Lead analyzed by various duration

Below the mentioned Fig. 3a, 3b, 3c, 3d. Concentration of Heavy Metals (Cu, Cd, Zn & Pb) in water samples collected from sampled location 1 to sampled location 6 during July 2023 to June 2024

Heavy metals in Sediment
Copper

The analysis of copper concentration in sediment samples collected from six sampled locations exhibited variations ranging from 0.45 to 30.85 ppm within the study area (Fig. 4a).

At sampled location 1, copper concentration varied from 0.45 ppm in October 2023 to 30.27 ppm in December 2023. Sampled location 2 displayed a high concentration of 18.7 ppm in July 2023, contrasting with a low concentration of 0.45 ppm in October 2023. The mean copper concentration at sampled location 3 varied from 0.525 to 24.325 ppm in September 2023 and November 2023. In sampled location 4, copper concentration varied from 0.55 ppm in September 2023 to 6.77 ppm in August 2023. Sampled location 5 exhibited a range of 0.625 to 18.375 ppm in September 2023 and July 2023. At sampled location 6, the copper concentration fluctuated between a low of 0.45 ppm in September 2023 and a high of 23.1 ppm in October 2023.

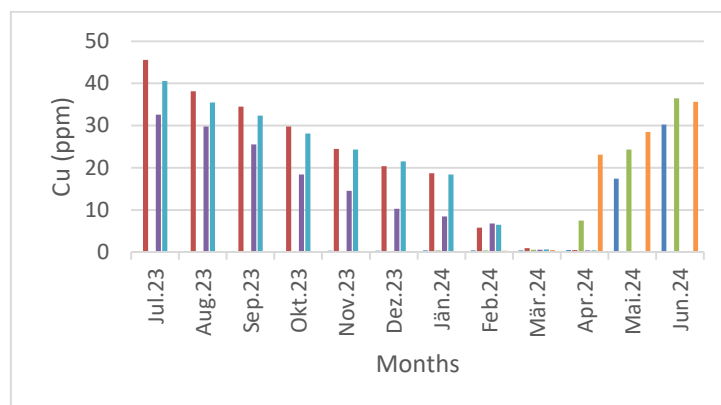


Fig. No. 4a. Copper analyzed by various duration

Cadmium

The analysis of cadmium concentration in sediment samples collected from six sampled locations revealed variations ranging from 0.025 to 4.95 ppm within the study area (Fig. 4b).

At sampled location 1, cadmium concentration varied from 0.05 ppm in April 2024 to 2.375 ppm in June 2024. Sampled location 2 exhibited a high concentration of 4.95 ppm in June 2024, contrasting with a low concentration of 0.15 ppm in August 2023. The mean cadmium concentration at sampled location 3 varied from 0.05 to 1.475 ppm in December 2023 and May 2024. In sampled location 4, cadmium concentration varied from 0.25 ppm in February 2024 to 1.3 ppm in April 2024. Sampled location 5 displayed a range of 0.375 to 3.65 ppm in November 2023 and March 2024. At sampled location 6, the cadmium concentration fluctuated between a low of 0.025 ppm in January 2024 and a high of 1.225 ppm in April 2024.

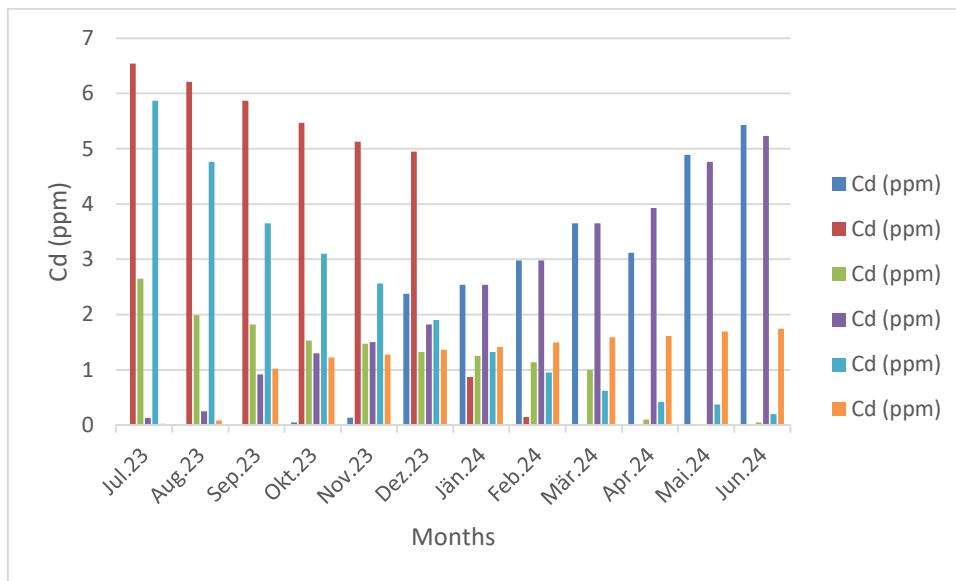


Fig. No. 4b Cadmium analyzed by various duration

Zinc

The analysis of zinc concentration in sediment samples collected from six sampled locations revealed variations ranging from 0.1 to 35.85 ppm within the study area (Fig. 4c).

At sampled location 1, zinc concentration varied from 0.325 ppm in February 2024 to 19.775 ppm in May 2024. Sampled location 2 exhibited a high concentration of 12.95 ppm in March 2024, contrasting with a low concentration of 0.1 ppm in October 2023. The mean zinc concentration at sampled location 3 varied from 0.225 to 35.85 ppm in July 2023 and November 2023. In sampled location 4, zinc concentration varied from 0.875 ppm in March 2024 to 19.3 ppm in May 2024. Sampled location 5 displayed a range of 1.15 to 4.075 ppm in April 2024 and January 2024. At sampled location 6, the zinc concentration fluctuated between a low of 0.254 ppm in September 2023 and a high of 16.55 ppm in October 2023.

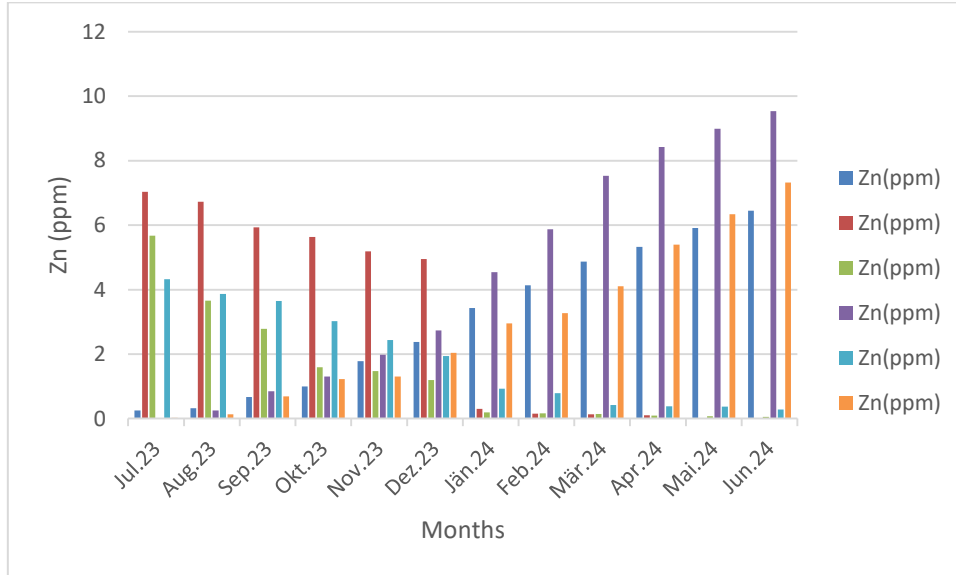


Fig. No. 4c. Zinc analyzed by various duration

Lead

The analysis of lead concentration in sediment samples collected from six sampled locations revealed variations ranging from 0.75 to 112.25 ppm within the study area (Fig. 5d).

At sampled location 1, lead concentration varied from 8.225 ppm in July 2023 to 53.6 ppm in September 2023. Sampled location 2 exhibited a high concentration of 77.375 ppm in September 2023, contrasting with a low concentration of 1.225 ppm in April 2024. The mean lead concentration at sampled location 3 varied from 26.525 to 46.154 ppm in August 2023 and December 2023. In sampled location 4, lead concentration varied from 3.15 ppm in March 2024 to 46.275 ppm in November 2023. Sampled location 5 displayed a range of 0.75 to 112.25 ppm in August 2023 and September 2023. At sampled location 6, the lead concentration fluctuated between a low of 4.975 ppm in January 2024 and a high of 110.3 ppm in September 2023.

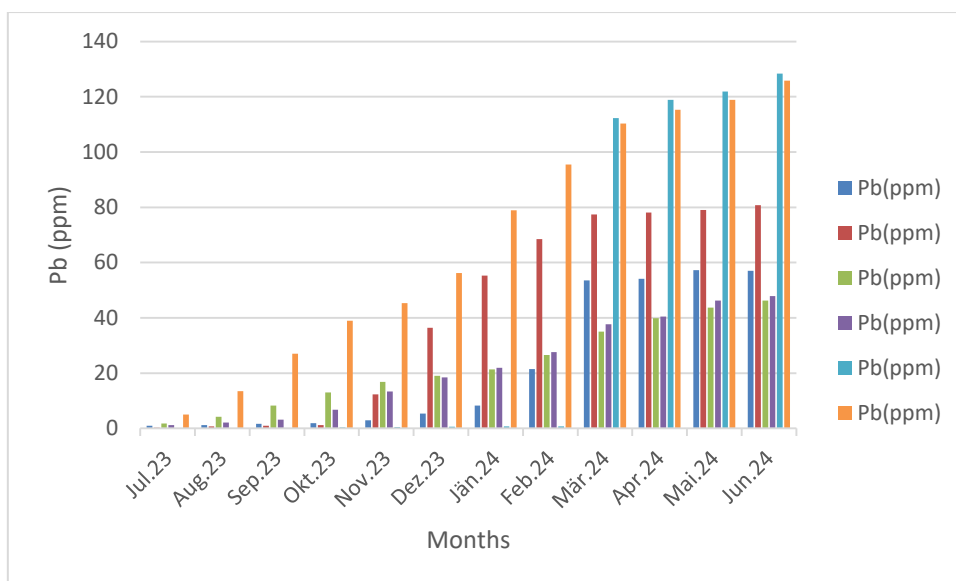


Fig. No. 4d Lead analyzed by various duration

Below the mentioned Fig. 5a, 5b, 5c, 5d. Concentration of Heavy Metals (Cu, Cd, Zn & Pb) in water samples collected from sampled location 1 to sampled location 6 during July 2023 to June 2024.

Statistical analysis

The results of two-way ANOVA tests indicated that the heavy metal concentration in water did not significantly vary over the months but rather exhibited significant differences between sampled location. Conversely, the concentration of copper in sediment samples did not show significant differences either at the sampled location level or over the months ($p > 0.005\%$).

Furthermore, the two-way ANOVA revealed significant variations at the sampled location level ($p < 0.005\%$) for zinc and cadmium in water samples, while month-wise variations were insignificant ($p > 0.005\%$). However, in sediment samples, the concentrations of cadmium and zinc did not show significant differences either at the sampled area level or over the months ($p > 0.005\%$).

Lead concentration in water samples showed significant variations over the months ($p < 0.005\%$) but not at the sampled location level, according to the two-way ANOVA analysis. Conversely, the concentration of lead in sediment samples exhibited significant variations both at the sampled location level and over the months (Table 1 & 2).

Table 1. Two-way ANOVA and seasonal variations of heavy metals in water samples of study area (mean± standard deviation)

Metals	Sampled area	Min	Max	Avg.	STD V	Factors	df	F-Value	P-Value	MS
Copper	1	0.126	0.83	0.35	0.23	sampled area Months				
	2	0.063	0.37	0.21	0.11					
	3	0.123	0.73	0.30	0.19		11	1.397	0.195	0.050
	4	0.059	1.10	0.39	0.35		7	1.240	0.291	0.044
	5	0.076	0.36	0.19	0.07					
	6	0.076	0.75	0.34	0.16					
Cadmium	1	0.004	0.91	0.28	0.32	Sampled area Months				
	2	0.004	0.43	0.11	0.14					
	3	0.002	1.51	0.27	0.42		11	3.59	0.0004	0.034
	4	0.004	0.10	0.06	0.03		7	0.77	0.6112	0.007
	5	0.003	1.99	0.47	0.68					
	6	0.004	0.10	0.05	0.03					
Zinc	1	0.254	0.67	0.36	0.11	sampled area Months				
	2	0.255	0.82	0.41	0.16					
	3	0.259	0.79	0.36	0.14		11	3.590	0.0004	0.034
	4	0.284	0.70	0.41	0.12		7	0.773	0.6112	0.007
	5	0.271	0.40	0.33	0.04					
	6	0.282	0.47	0.35	0.06					
Lead	1	0.001	0.55	0.21	0.19	sampled area Months				
	2	0.001	0.81	0.22	0.25					
	3	0.002	0.25	0.11	0.09		11	1.234	0.274	0.074
	4	0.000	0.86	0.21	0.25		7	3.521	0.002	0.210
	5	0.001	0.00	0.00	0.00					
	6	0.001	0.15	0.05	0.06					

Table. Two-way ANOVA and seasonal variations of heavy metals in sediment samples of study area (mean± standard deviation)

Metals	Sampled area	Min	Max	Avg.	STDV	Factors	df	F-Value	P-Value	MS
Copper	1	0.45	30.28	6.22	7.97	Sampled area Months				
	2	0.45	18.70	5.01	4.76					
	3	0.53	24.33	7.04	7.86		11	1.930	0.048	70.23
	4	0.55	6.78	3.30	1.98		7	1.350	0.238	49.12
	5	0.63	18.38	5.63	4.74					
	6	0.45	23.10	5.99	5.90					
Cadmium	1	0.05	2.38	0.97	0.79	Sampled area Months				
	2	0.15	4.95	1.21	1.47					
	3	0.05	1.48	0.53	0.40		11	2.434	0.011	1.255
	4	0.25	1.30	0.63	0.28		7	1.186	0.320	0.611
	5	0.38	3.65	1.19	0.92					
	6	0.03	1.23	0.63	0.45					
Zinc	1	0.33	19.78	6.10	5.16	Sampled area Months				
	2	0.10	12.95	6.12	4.83					
	3	0.23	35.85	7.62	9.63		11	1.264	0.261	45.98
	4	0.88	19.30	10.29	6.06		7	1.507	0.177	54.81
	5	1.15	4.08	2.68	0.96					
	6	0.25	16.55	5.08	4.81					
Lead	1	8.23	53.60	18.86	12.55	Sampled area Months				
	2	1.23	77.38	25.83	25.45					
	3	26.53	46.15	37.05	5.53		11	7.524	0.0001	2173
	4	3.15	46.28	13.62	13.45		7	3.817	0.0013	1102
	5	0.75	112.25	26.79	31.86					
	6	4.98	110.30	35.14	29.00					

V. DISUCSSION

In the modern era, heavy metal waste sources contributing to residential area environments stem from various activities such as anthropogenic actions, industrial discharges, agricultural practices, and aquaculture runoff, among others. These sources persistently release heavy metals into the environment, creating challenges that cannot be entirely mitigated through natural or mechanical means. The impact of heavy metals on aquatic organisms is contingent upon their concentration levels, which consequently affect the overall residential area environment.

In this study, variations in heavy metal concentrations were observed due to the presence of different sources and seasonal fluctuations in both water and sediment samples. Notably, sediments exhibited higher concentrations of metals compared to water at all sampling sites, as they were less settled.

Based on industrial waste disposal, human activities and other contributory factors, six sampling points were selected in Cuddalore Sipkot residential area Heavy metals like cadmium, copper, zinc and copper were analyzed in collected samples in the 1990s. Agricultural and industrial activities emerged as major contributors to the concentration of these elements in river water.

The mean values of elements at different sampling sites showed that lead was the most abundant element in all the sampling sites, followed by zinc, cadmium, and copper. Notably, 2 sampling sites and 3 consistently showed higher levels of total metals. Correlation between concentrations of heavy metals in urine and concentrations of organic matter determined.

Seasonal variation was observed, with iron concentrations generally higher in summer and lower in winter. These changes can be attributed to changes in agricultural drainage, sewage flows and disposal of industrial wastes into the river

In particular, lead concentrations increased at sites where water and sediment samples 1 and 6 were taken in June 2024 and July 2023, respectively.

Additionally, the study reported high levels of cadmium and zinc in the sample

We have implemented an automatic text detection technique from an image for inpainting. Our algorithm successfully detects the text region from the image which consists of mixed text-picture-graphic regions. We have applied our algorithm on many images and found that it successfully detects the text region.

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