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Original Paper

Assessment of Sediment-Associated Heavy Metals and Physico-chemical Interactions in Telaje-Cabugan Creek, Philippines

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Abstract: Heavy metal contamination in freshwater ecosystems poses a persistent threat to environmental and public health, particularly in urban regions with limited waste management infrastructure. This study assessed the concentration and spatial distribution of cadmium, lead, manganese, and zinc in the water and sediments of Telaje-Cabugan Creek, a tributary of the Tandag River in Surigao del Sur, Philippines. Water and sediment samples were collected from three designated sites and analyzed using atomic absorption spectroscopy. Physicochemical parameters including pH, salinity, temperature, turbidity, and depth were also recorded. Statistical methods, including one-way ANOVA and Pearson correlation, were used to assess spatial variations and environmental influences on metal concentrations. Results showed that only manganese was detected in water, while zinc, lead, and manganese were present in sediments, with cadmium below the detection limit in both matrices. Zinc concentrations exceeded international sediment quality thresholds, indicating moderate pollution, while other metals remained within acceptable levels. No significant spatial differences were observed in heavy metal concentrations across the sampling sites. Correlation analysis revealed that manganese in sediments was significantly influenced by salinity and pH, suggesting environmental conditions can affect its mobility. The findings provide baseline data for local water quality management and highlight the need for integrated interventions to address diffuse sources of contamination in urban freshwater systems.

1. INTRODUCTION

Heavy metal contamination in aquatic environments has become a global concern due to its persistence, toxicity, and potential to bioaccumulate across trophic levels. The increasing discharge of industrial effluents, untreated domestic sewage, agricultural runoff, and solid waste into rivers and streams contributes significantly to the elevated levels of metals such as cadmium (Cd), lead (Pb), manganese (Mn), and zinc (Zn) in water bodies (Algül and Beyhan, 2020; Hong *et al.*, 2020). Unlike organic pollutants, heavy metals do not degrade over time. Instead, they accumulate in sediments, where they pose long-term ecological risks (Wojtkowska, 2023). This persistence raises major environmental and health concerns, especially in densely populated and economically active areas where these metals may enter the human food chain through contaminated water or aquatic organisms (Orata and Sifuna, 2023; Edo *et al.*, 2024).

In the Philippines, the Tandag River traverses Tandag City, Surigao del Sur, and its tributary, the Telaje-Cabugan Creek, is particularly vulnerable to pollution due to its proximity to residential settlements, informal waste disposal areas, and agricultural activity. Visual assessment of the site reveals significant anthropogenic inputs, including untreated sewage and animal waste**,** sources that are consistent with findings from other polluted rivers, similar to the findings of Chouhan, Prajapati and Bhardwaj (2023) highlights that human activities such as urbanization and agricultural production exacerbate water pollution, leading to significant contamination from untreated sewage and waste. According to Republic Act No. 3931, the Philippine environmental law mandates the control and abatement of water pollution, highlighting the importance of local monitoring and intervention (Tendero, 2023).

Scientific studies have shown that sediments function as both sinks and secondary sources of heavy metals in aquatic systems. Due to their physicochemical properties, these metals tend to bind with particulate matter and settle in bottom layers, often reaching concentrations higher than those in the overlying water (Bhuyan *et al.*, 2017; Haynes and Zhou, 2022). Under changing environmental conditions such as pH, salinity, and redox potential, metals can be remobilized, posing risks to aquatic organisms and potentially re-entering the water column (Mckenzie *et al.*, 2024; Pellegrini *et al.*, 2024). For instance, manganese has been observed to increase in mobility and toxicity under specific pH and salinity changes, which may influence its interaction with sediments and water (Jahanirad, Nasrabadi and Karbassi, 2023; Linnik, Zhezherya and Zhezherya, 2024).

This study investigates the distribution of heavy metals—specifically Cd, Pb, Mn, and Zn—in both water and sediments in Telaje-Cabugan Creek, using standard physicochemical parameters to evaluate their potential influence on metal concentration and mobility. The data were compared with permissible limits set by international benchmarks such as the United States Environmental Protection Agency **(US EPA, 2014)** and the World Health Organization (Kubra *et al.*, 2022). The findings are expected to contribute baseline data necessary for future environmental monitoring and policymaking, particularly in the formulation of local intervention measures and compliance with Sustainable Development Goal 14: “Life Below Water.”

Despite the growing body of research on heavy metal contamination in various water bodies, there is a notable gap in baseline data concerning sediment-associated heavy metal contamination in minor urban tributaries like Telaje-Cabugan Creek, particularly in relation to physicochemical interactions. To date, few studies have examined the intricate dynamics of metal concentration and mobility within the context of such minor tributaries, leaving a gap in knowledge that this study aims to address. By identifying the contamination levels and spatial variations of these metals and assessing the role of environmental parameters in their behavior, this study offers a science-based foundation for river management and ecological conservation in Tandag City. Ultimately, this research aims to bridge the gap between environmental diagnostics and policy-driven responses for sustaining the ecological health of urban waterways.

2. MATERIALS AND METHODS

2.1. Study Area and Sampling Sites

Figure 1 shows the precise locations of all 15 sampling points across the transect. A total of 30 water samples (two replicates per point) and 15 sediment samples (one per point) were collected accordingly. The 1.5-kilometer stretch of Telaje-Cabugan Creek in Tandag City, Surigao del Sur, was strategically divided into three general segments Site A (downstream), Site B (midstream), and Site C (upstream)—based on the creek's flow direction, surrounding land use patterns, and observable pollution sources such as domestic runoff, informal waste disposal, and agricultural inputs (Figure 1). Specifically, the river drains into Dawis Strait, possibly contributing to the pollution of the coastal area. Each segment represents approximately 500 meters of the transect and includes five georeferenced sampling points spaced at 100-meter intervals, labeled SAP1–SAP5 (Site A), SBP1–SBP5 (Site B), and SCP1–SCP5 (Site C).

This zonal approach is consistent with established methodologies in riverine pollution studies. For instance, Towfiqul Islam et al. (2020) segmented river systems in Bangladesh into upstream, midstream, and downstream zones to effectively assess spatial variations in heavy metal contamination, co-occurrence patterns, and ecological risks. Their study demonstrated that such segmentation allows for meaningful comparisons of pollution dynamics along the river gradient, especially in urban-influenced settings.

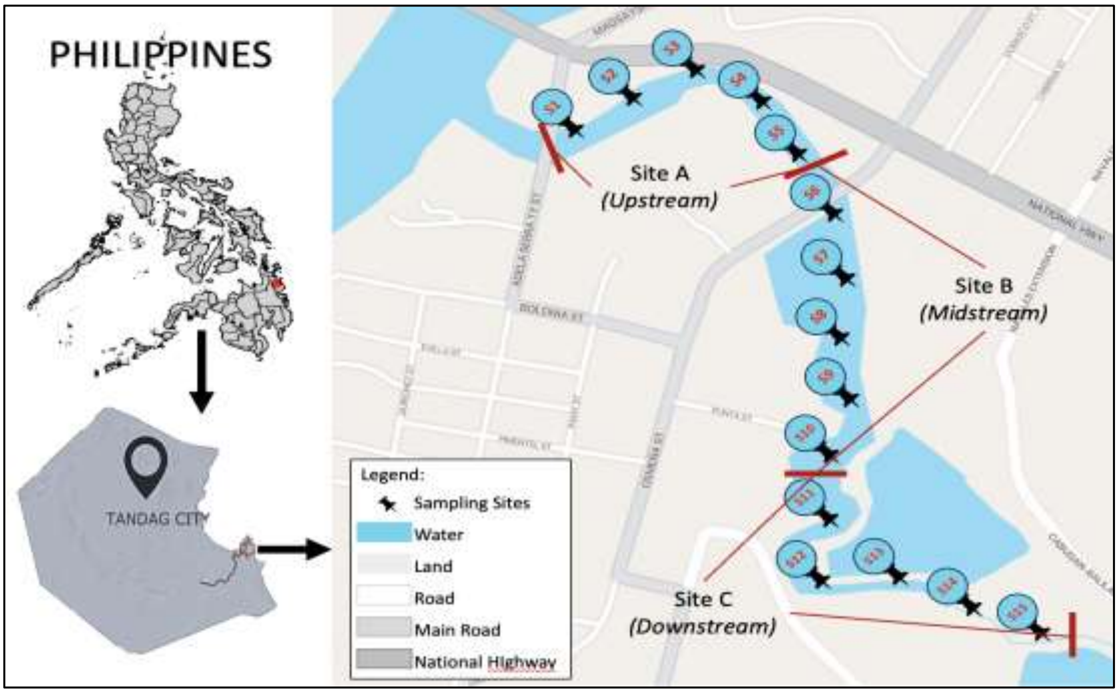

Fig. 1: Map and geographic coordinates of the study area in Tandag River.

In the present study, the grouped site design not only simplifies spatial analysis but also enables practical comparisons of pollution levels across sections most likely to experience differing anthropogenic pressures. The researchers conducted the study on December 12–13, 2021, during the wet season, when the potential for increased runoff and contamination is high. Moreover, the study area falls under the Type II climate of the Corona Climate Classification System, which is characterized by no dry period throughout the year, and a pronounced wet season from November to February (PAGASA-DOST).

2.2. Sample Collection and Preparation

Sediment samples (2 kg each) were collected using plastic zip-lock bags, while water samples (1 liter each) were stored in pre-cleaned polyethylene bottles. All sampling containers were rinsed with distilled water and the target media prior to collection to avoid cross-contamination. A total of 30 water and 15 sediment samples were collected. Samples were labeled accurately and stored in insulated containers before transport to the laboratory for analysis. Sampling was conducted during the wet season on December 12–13, 2021, following several days of moderate rainfall. According to PAGASA weather records, the area experienced intermittent rain showers and overcast skies with average daily temperatures ranging from 25°C to 28°C, relative humidity above 85%, and light to moderate wind conditions. These meteorological conditions likely influenced surface runoff and may have contributed to the observed distribution of heavy metals in water and sediment matrices.

2.3. Measurement of Physicochemical Parameters

On-site measurements were conducted for pH, temperature (°C), salinity (ppt), turbidity (cm), and depth (cm) using a calibrated portable pH meter and refractometer. These parameters were selected based on their known influence on the mobility and bioavailability of heavy metals in aquatic systems (Sazon & Migo, 2020; Zhao et al., 2013).

2.4. Laboratory Analysis

Heavy metal concentrations of cadmium (Cd), manganese (Mn), lead (Pb), and zinc (Zn) in water and sediment samples were determined by the Department of Agriculture – CARAGA Regional Soils Laboratory and the Department of Science and Technology (DOST) using atomic absorption spectroscopy (AAS), following standard digestion and detection protocols. Analytical quality was ensured through calibration with certified standards and procedural blanks. Unfortunately, due to third-party lab constraints the equipment used for the AAS model was not provided by the DOST agency who performed the analysis and the detection limit for Atomic Absorption Spectroscopy (AAS) method used in the analysis of sediment and water samples were not provided.

2.5. Statistical Analysis

Descriptive statistics were computed to summarize metal concentrations across sites. One-way Analysis of Variance (ANOVA) was used to test for significant differences in metal concentrations among sampling sites, specifically for manganese in water and zinc in sediments. Non-parametric Kruskal-Wallis tests were applied for lead and manganese concentrations in sediments. Pearson correlation analysis was employed to evaluate the influence of physicochemical parameters on metal concentrations. A significant level of $p < 0.05$ was used for all inferential tests.

3. RESULTS AND DISCUSSION

3.1. Heavy Metal Concentrations in Water and Sediments

The concentrations of heavy metals for Sites A (downstream), B (midstream), and C (upstream) were calculated as the mean values of five sampling points within each site (SAP1–SAP5, SBP1–SBP5, and SCP1–SCP5, respectively). Each sampling point was spaced at 100-meter intervals along a 1.5-kilometer transect of the Telaje-Cabugan Creek. To ensure accuracy and account for natural variation within each zone, the standard deviation (SD) of the five values per site was also computed and is reported alongside the mean concentrations. This approach enables comparative analysis across the three general zones while maintaining statistical rigor.

Table 1: Concentrations of Heavy Metals in Water and Sediments at each sampling points.

Sampling Sites/Points	Coordinates	Heavy Metal Concentrations Wet Season (December 12-13, 2021)							
		Water				Sediments			
		Zinc (mg/L)	Lead (mg/L)	Cadmium (mg/L)	Manganese (mg/L)	Zinc (ppm)	Lead (ppm)	Cadmium (ppm)	Manganese (ppm)

A	SAP1	09°04′33.9″ N, 126°11′36.4″ E	ND	ND	ND	0.1167	125	4.81	BDL	438
	SAP2	09°04′35.6″ N, 126°11′38.3″ E	ND	ND	ND	0.1156	80.2	4.72	BDL	241
	SAP3	09°04′36.5″ N, 126°11′41.0″ E	ND	ND	ND	0.1298	71	4.73	BDL	218
	SAP4	09°04′34.6″ N, 126°11′43.3″ E	ND	ND	ND	0.1158	57.9	4.83	BDL	130
	SAP5	09°04′32.0″ N, 126°11′45.0″ E	ND	ND	ND	0.1211	277	14.3	BDL	311
	Minimum		-	-	-	0.1156	57.9	4.72	-	130
	Maximum		-	-	-	0.1298	277	14.3	-	438
	Mean		-	-	-	0.120575	121.525	7.145	-	225
	SD		-	-	-	0.00665651	90.126034	4.26109962	-	115.131664
B	SBP6	09°04′31.2″ N, 126°11′46.1″ E	ND	ND	ND	0.1248	55.6	4.81	BDL	163
	SBP7	09°04′28.5″ N, 126°11′45.8″ E	ND	ND	ND	0.1201	108	9.80	BDL	225
	SBP8	09°04′26.3″ N, 126°11′45.7″ E	ND	ND	ND	0.1175	164	9.67	BDL	285
	SBP9	09°04′23.5″ N, 126°11′46.0″ E	ND	ND	ND	0.1102	104	4.71	BDL	250
	SBP10	09°04′20.6″ N, 126°11′45.9″ E	ND	ND	ND	0.1079	66.8	4.77	BDL	210
	Minimum		-	-	-	0.1079	55.6	4.71	-	163
	Maximum		-	-	-	0.1248	164	9.80	-	285
	Mean		-	-	-	0.1161	99.68	6.752	-	226.6
	SD		-	-	-	0.00699464	42.5707881	2.72371438	-	45.5005494
C	SCP11	09°04′18.3″ N, 126°11′45.9″ E	ND	ND	ND	0.1129	104	7.24	BDL	232
	SCP12	09°04′15.0″ N, 126°11′46.2″ E	ND	ND	ND	0.1128	69.4	2.39	BDL	158
	SCP13	09°04′15.0″ N, 126°11′49.2″ E	ND	ND	ND	0.1112	88.3	4.77	BDL	157
	SCP14	09°04′13.6″ N, 126°11′51.7″ E	ND	ND	ND	0.1226	91	4.79	BDL	153
	SCP15	09°04′12.7″ N, 126°11′54.3″ E	ND	ND	ND	0.1188	87.2	4.84	BDL	148
	Minimum		-	-	-	0.1112	69.4	2.39	-	148
	Maximum		-	-	-	0.1226	104	7.24	-	232
	Mean		-	-	-	0.11566	87.98	4.806	-	169.6
	SD		-	-	-	0.00484025	12.3661635	1.71494315	-	35.1041308

The consistently higher concentrations of heavy metals in sediments compared to water are consistent with the natural affinity of metals to bind with particulate matter and settle in benthic layers (Bhuyan et al., 2017). Among the three zones, Site A (downstream) exhibited the highest sediment concentrations of Zinc (121.53 ± 90.13 ppm), Lead (7.15 ± 4.26 ppm), and Manganese (225.00 ± 115.13 ppm), suggesting localized accumulation near probable pollution sources such as informal waste disposal zones and sewer discharges. These findings align with prior observations that urban river sediments act as reservoirs for contaminants derived from runoff and anthropogenic waste inputs (Deng et al., 2021; Tshibanda et al., 2021).

Meanwhile, only Manganese was consistently detected in the water samples across all sites, with concentrations ranging from 0.1157 ± 0.0048 mg/L at Site C to 0.1206 ± 0.0067 mg/L at Site A. The absence of detectable concentrations for Zn, Pb, and Cd in water may be attributed to both instrument detection limits and the natural behavior of these metals, which tend to bind to sediments. The detection of Mn in water, in contrast, may be attributed to its greater solubility and tendency to re-enter the water column under certain redox and pH conditions (Geißler et al., 2021). Additionally, the wet season during sampling likely contributed to the reduced detectability of Zn, Pb, and Cd in water due to dilution effects and vertical migration into sediments, as supported by Udoidiong et al. (2021), who observed lower levels of heavy metals including Cd, Ni, Zn, Cu, Cr, Pb, and Fe during the wet season, attributed to seasonal dilution and redistribution processes.

3.2. Physicochemical Parameters Measured at Each Sampling Point

Table 2 presents the measured physicochemical parameters—pH, temperature (°C), salinity (ppt), turbidity (cm), and depth (cm)—from 15 sampling points along Telaje-Cabugan Creek. Values are recorded separately for water (W) and sediment (S) matrices to assess environmental conditions that may influence heavy metal behavior and distribution.

Table 2: Measured Physicochemical Parameters at each Sampling Point

Sampling points	Geographic Information System (GIS)	pH (S/W)	Temperature °C (S/W)	Salinity (S/W)	Turbidity (S/W)	Depth (S/W)
A1	09°04’33.9” N, 126°11’36.4” E	6.45/6.45	27.2/22.2	1.004/1.004	61.6/61.6	67.5/67.5
A2	09°04’35.6” N, 126°11’38.3” E	6.56/6.63	27.4/27.3	1.004/1.004	70.1/70.1	54/54
A3	09°04’36.5” N, 126°11’41.0” E	6.68/6.49	27.2/27.3	1.001/1.002	50.56/46.9	99/46.9
A4	09°04’34.6” N, 126°11’43.3” E	6.75/6.79	27.4/27.4	1/1.002	110/73	135/73
A5	09°04’32.0” N, 126°11’45.0” E	6.66/6.93	27.3/27.3	1.002/1.002	89/79	139/69
B6	09°04’31.2” N, 126°11’46.1” E	6.79/6.65	27.4/27.5	1.01/1.002	100/48	126/48
B7	09°04’28.5” N, 126°11’45.8” E	6.67/6.67	27.3/27.3	1/1.002	75/75	75/75
B8	09°04’26.3” N, 126°11’45.7” E	6.76/6.76	27.2/27.2	1.01/1.001	110/110	125/125
B9	09°04’23.5” N, 126°11’46.0” E	6.66/6.66	27.5/27.5	1.001/1.001	57/57	57/57
B10	09°04’20.6” N, 126°11’45.9” E	6.83/6.83	27.5/27.5	1.001/1.002	83/83	83/83
C11	09°04’18.3” N, 126°11’45.9” E	6.81/6.73	27.4/27.5	1.001/1.002	63/42	63/42
C12	09°04’15.0” N, 126°11’46.2” E	6.65/6.83	27.3/27.2	1.001/1.001	91/75	709/75
C13	09°04’15.0” N, 126°11’49.2” E	6.89/6.75	27/27.2	1.002/1.001	113/60	110/60
C14	09°04’13.6” N, 126°11’51.7” E	6.95/6.78	27.3/27.3	1.001/1.001	87/19	97/19
C15	09°04’12.7” N, 126°11’54.3” E	6.93/6.78	27.4/27.4	1/1.001	81/75	81/75

Table 2 presents the physicochemical conditions across the 15 sampling points in Telaje-Cabugan Creek. pH levels ranged from 6.45 to 6.95, indicating slightly acidic to neutral conditions typical of tropical freshwater systems. These levels are known to affect metal solubility and mobility; in this study, lower pH significantly correlated with higher manganese (Mn) concentrations in sediments, consistent with findings by Pellegrini et al. (2024), who noted that acidic conditions increase Mn desorption from sediment particles. Temperature remained stable (27.0–27.5 °C) and did not significantly influence metal behavior, while salinity values, though low (1.000–1.010 ppt), showed a positive correlation with sediment-bound Mn. This aligns with studies by Gantayat & Elumalai (2024), who emphasized that even slight salinity changes can enhance Mn mobility due to ionic competition and changes in sediment chemistry.

Turbidity and depth varied more widely but showed no significant correlations with heavy metal concentrations. However, areas with high turbidity may still facilitate particle-bound metal transport, as noted by Sazon & Migo (2020). Overall, the findings suggest that pH and salinity are key drivers of Mn behavior in the creek, reinforcing the importance of monitoring these parameters in pollution assessments.

3.3. Pollution Status Based on EPA Guidelines

To evaluate the level of contamination, the detected concentrations in sediment samples were compared against benchmark thresholds provided by the United States Environmental Protection Agency (US EPA, 2014). These thresholds classify sediment contamination into three categories: not polluted, moderately polluted, and heavily polluted. Table 2 provides the corresponding criteria for lead (Pb), manganese (Mn), and zinc (Zn), as well as the average concentrations observed in the present study.

Table 3: EPA heavy metal Guidelines for Sediments (mg/kg).

Metals	Not Polluted	Moderately Polluted	Heavily Polluted	Present study
Pb	<40	40-60	>60	6.07866
Mn	<300	300-500	>500	221.2667
Zn	<90	90-200	>200	103.2933

[2]United States Environmental Protection Agency (1999) and World Health Organization (2004) (Ogbeibu et al.,2014).

Among the three metals detected in sediment samples, only zinc (Zn) exceeded the lower threshold for pollution, with a mean concentration of 103.29 ppm, thereby classifying it as moderately polluted. Lead (Pb) and manganese (Mn) remained below the defined pollution limits, with average concentrations of 6.08 ppm and 221.27 ppm, respectively, suggesting that their current levels are not ecologically alarming. The elevated Zn levels point to localized anthropogenic inputs likely from municipal waste, vehicle emissions, and urban runoff contributing to its accumulation in sediments, as previously reported by Nargis *et al.*(2022) and Ortega-Camacho *et al.* (2023).

Understanding sediment contamination status is critical for risk assessment and environmental planning. As emphasized by Konstantinova *et al.* (2024) and Sim *et al.* (2024), the alignment or deviation from global standards provides an empirical basis for identifying priority pollutants and guiding remediation strategies in freshwater ecosystems.

3.4. Comparison of Heavy Metal Concentrations Among Sampling Sites

This subsection interprets the results of the ANOVA and Kruskal-Wallis tests, which determine whether there are statistically significant differences in metal concentrations among the three sampling sites. Statistical analysis was conducted to examine whether the concentrations of detected heavy metals in water and sediments significantly differed among Sites A, B, and C. Table 3 presents the p-values derived from one-way ANOVA and Kruskal-Wallis tests for manganese in water and zinc, lead, and manganese in sediments.

Table 4: Significant difference in heavy metal concentrations between sampling sites.

	Heavy Metals		p-value	Conclusion
Sampling Sites (A, B, C)	Water	Manganese	0.509	There is no significant difference
	Sediments	Zinc	0.648	There is no significant difference
		Lead	0.898	There is no significant difference
		Manganese	0.145	There is no significant difference

The results indicate that no statistically significant differences were observed in metal concentrations across the three sites ($p > 0.05$ for all variables). This suggests a relatively uniform distribution of heavy metals within the sampled stretch of Telaje-Cabugan Creek. Such even distribution may be attributed to continuous water flow, runoff dispersion, and widespread anthropogenic activity, including household discharge and animal waste that affect all sites similarly (Ahmad et al., 2022; Javaid et al., 2020). While spatial differences are often expected in river systems, the absence of significant variation here may reflect consistent upstream-to-downstream contamination sources and limited industrial point discharges. These findings further underscore the role of diffuse pollution and suggest the need for area-wide intervention strategies rather than site-specific remediation.

3.5. Influence of Physico-Chemical Parameters on Heavy Metal Concentrations in Water and Sediments

To investigate potential environmental factors influencing metal mobility and concentration, Pearson correlation analysis was applied to assess the relationship between selected physicochemical parameters (pH, temperature, salinity, turbidity, and depth) and the concentrations of Zn, Pb, and Mn in both water and sediments. The results of this analysis are summarized in Table 4.

Table 4: Influence of Physico-Chemical Parameters on Heavy Metal Concentrations

Physicochemical Parameter	Mn (Water)	Zn (Sediment)	Pb (Sediment)	Mn (Sediment)
pH	-0.328	-0.217	0.202	-0.633*
Temperature (°C)	0.008	-0.401	-0.145	-0.151
Salinity (ppt)	0.072	0.191	-0.054	0.542*

Turbidity (cm)	-0.307	-0.197	0.217	-0.433
Depth (cm)	-0.282	-0.241	0.138	-0.336

***Note**: Correlation values marked with an asterisk (*) are statistically significant at the 0.05 level (2-tailed). Values without an asterisk indicate no statistically significant influence.*

The findings revealed that salinity and pH had statistically significant correlations with manganese (Mn) concentrations in sediments, as shown in Table 4. Specifically, Mn exhibited a positive correlation with salinity ($r = 0.542$, $p < 0.05$) and a negative correlation with pH ($r = -0.633$, $p < 0.05$), indicating that these parameters directly influence the retention or release of Mn in benthic layers. These results align with earlier studies suggesting that salinity enhances metal mobility through ionic competition, while pH regulates the solubility and adsorption of metal ions (Gantayat & Elumalai, 2024; Jahanirad et al., 2023).

In contrast, all other correlation values in Table 4 were statistically non-significant ($p > 0.05$), meaning that no measurable influence was observed between the remaining physicochemical parameters and the concentrations of zinc (Zn) or lead (Pb) in either water or sediments. This suggests that Zn and Pb may be relatively stable under the prevailing environmental conditions, or that their behavior is influenced by unmeasured factors such as organic matter, sediment texture, or hydrodynamics. Recognizing which parameters significantly affect metal behavior is essential for interpreting contamination dynamics in fluvial systems. The identified influence of salinity and pH on Mn mobility underscores the need for regular environmental monitoring, especially during wet and dry seasonal transitions that may shift redox conditions and trigger metal remobilization from sediments (Rumuri et al., 2023; Sazon & Migo, 2020).

This study provides an integrated assessment of heavy metal contamination in Telaje-Cabugan Creek, offering empirical insights into the spatial distribution, pollution status, and environmental behavior of cadmium (Cd), lead (Pb), manganese (Mn), and zinc (Zn) in both water and sediment matrices. Results confirm that sediments serve as the dominant sinks for heavy metals, with Zn, Pb, and Mn consistently detected across all sites, while Cd remained below detection limits. Notably, Zn concentrations exceeded the (US EPA, 2014) guideline for unpolluted sediments, classifying the creek as moderately polluted with respect to this metal. This reflects the cumulative impacts of household waste, vehicular emissions, and potential agricultural runoff (Nargis et al., 2022), consistent with observations in other tropical urban river systems (Capangpangan et al., 2016; Pleto et al., 2020).

4. IMPLICATIONS

Despite observable differences in absolute concentrations, statistical analysis revealed no significant variation in metal levels among the three sampling locations, suggesting a relatively even dispersal of pollutants throughout the creek. This homogeneity may result from the interplay of flow regimes, sediment mixing, and sustained input of contaminants along the urban corridor. Similar spatial uniformity has been reported in other studies where non-point sources dominate pollution input (Gerenfes & Teju, 2019; Yang et al., 2022).

Importantly, the correlation analysis identified pH and salinity as significant factors affecting Mn concentrations in sediments. This supports previous research showing that low pH enhances metal solubility, while elevated salinity increases the desorption of metals from sediment particles, thereby increasing their bioavailability and ecological risk (Zhao et al., 2024). These environmental parameters are known to fluctuate seasonally and under human influence, which may increase the likelihood of remobilization and subsequent uptake by aquatic organisms (Rzymski et al., 2014; Sazon & Migo, 2020).

The ecological and human health implications of these findings are significant. Heavy metals in sediments may enter aquatic food chains, accumulate in benthic organisms, and eventually reach humans through fish consumption or dermal exposure (Cabuga et al., 2020). Furthermore, sediment-bound metals, particularly Zn and Mn, pose long-term risks due to their persistence and potential for resuspension during high-flow events or dredging activities (Haynes & Zhou, 2022b; Pérez-Ruzafa et al., 2023). If left unmonitored, this contamination may lead to chronic exposure among local populations, especially those dependent on the river for subsistence fishing or agriculture. Therefore, the study underscores the urgent need for preventive and remedial strategies. Monthly clean-up drives, strict enforcement of the Solid Waste Management Act, sediment dredging in high-risk zones, and the establishment of riparian buffer strips are all viable short-term interventions. Long-term solutions should focus on community education, wastewater treatment infrastructure, and local ordinance development to reduce pollution at its source. As stated in the Republic Act No. 9003, known as the Ecological Solid Waste Management Act of 2000, it provides a comprehensive policy framework for solid waste management in the Philippines. It mandates LGUs to establish integrated solid waste management plans based on the 3Rs (reduce, reuse, and recycle) and encourages the participation of various stakeholders in waste management efforts (Premakumara et al., 2014). Regular monitoring of both water quality and sediment contamination, especially in relation to pH and salinity changes, will also be critical to preempt further environmental degradation. In summary, this study not only contributes baseline data for Telaje-Cabugan Creek but also adds to the growing body of regional literature that advocates for integrated, science-driven management of urban water resources. It aligns with global environmental goals aimed at ensuring the sustainability of freshwater systems under increasing anthropogenic pressure (Kubra *et al.*, 2022).

5. CONCLUSIONS

This study examined the levels and spatial distribution of Cd, Pb, Mn, and Zn in the water and sediments of Telaje-Cabugan Creek, a tributary of the Tandag River in Surigao del Sur, Philippines. Among the four metals investigated, manganese was the only one detected in water samples, while zinc, lead, and manganese were consistently found in sediment samples. Cadmium was below the detection limit in both matrices. The analysis revealed that sediment samples, particularly from Site A, exhibited the highest concentrations of all detected metals. Zinc concentrations in sediments exceeded the standard threshold, classifying the site as moderately polluted, while lead and manganese levels remained within acceptable ranges. The distribution of heavy metal concentrations across Sites A, B, and C showed no statistically significant differences, suggesting uniform pollution likely driven by non-point sources such as domestic runoff and animal waste. Pearson correlation analysis revealed that only manganese in sediments was significantly influenced by salinity and pH. No other physicochemical parameter showed a meaningful correlation with the remaining metals. This indicates that under changing environmental conditions, particularly in salinity and acidity, manganese may become more mobile or concentrated in sediments. Overall, the findings provide evidence of localized contamination in sediments, especially with zinc, and emphasize the creek's role as a sink for heavy metal accumulation. These results serve as baseline data for environmental monitoring and offer insights for implementing mitigation strategies, such as sediment management and pollution source reduction. Future research should focus on investigating the biological uptake of these metals, seasonal variations in contamination levels, and expanded pollutant profiling to provide a more comprehensive understanding of the creek's ecological health and to inform long-term environmental management strategies.

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