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Quantitative Assessment of Hazardous Inorganic Pollutants in Wastewater Sources: Implications for Water Quality and Environmental Health

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Abstract

This study presents a quantitative assessment of hazardous inorganic pollutants in wastewater sources from four distinct locations A, B, C and D within the study area in Ikot Ekpene city in Akwa Ibom State, Nigeria. The analysis focused on evaluating both physical parameters – pH, temperature, dissolved solids (DS), suspended solids (SS) – and the concentrations of various ions, including heavy metals (Ca^{2+}, Fe^{3+}, Cu^{2+}, Co^{2+}, Pb^{2+}, Cd^{2+}) and anions (NO_3^-, Cl^-, SO_4^{2-}, CO_3^{2-}). Physical parameters revealed a pH range of 6.5 to 6.8, indicating slightly acidic to neutral conditions. DS and SS values varied across locations, with the highest recorded at 10.6 mg/L and 4.4 mg/L, respectively, at location C, reflecting potential contamination. Heavy metal analysis showed notable variations among the locations. The average concentrations of Fe^{3+} ranged from 1.373 mg/L in location A to 3.763 mg/L in location D, with the highest levels in location C (3.594 mg/L), indicating potential industrial contributions. Lead (Pb^{2+}) concentrations were highest in location D (2.231 mg/L) and lowest in location B (0.9934 mg/L), exceeding the World Health Organization's (WHO) permissible limit of 0.01 mg/L for drinking water, suggesting a health risk. Cadmium (Cd^{2+}) concentrations varied, with a peak of 0.975 mg/L in location D, also surpassing WHO's limit of 0.003 mg/L.Anion analysis revealed that nitrate (NO_3^-) levels were highest in location C (80.919 mg/L), while chloride (Cl^-) levels were most elevated in location B (15.467 mg/L). Sulfate (SO_4^{2-}) concentrations ranged from 12.779 mg/L in location C to 211.257 mg/L in location A, highlighting differences in potential sources of pollution across the study area. Statistical analysis using ANOVA showed significant differences ($p < 0.05$) in pollutant concentrations between locations, emphasizing spatial variations in contamination levels. The findings indicate that some of the sampled locations contain hazardous pollutants at concentrations above recommended limits, posing potential risks to human and environmental health. This study underscores the need for targeted wastewater management

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strategies and continuous monitoring to mitigate the impact of industrial discharges on local water quality.

Keywords: Hazardous, Inorganic Pollutants, Concentration, Wastewater

INTRODUCTION

Water pollution, particularly from hazardous inorganic pollutants, remains a significant environmental challenge worldwide. Wastewater from industrial, agricultural, and urban activities often contains elevated levels of heavy metals, nitrates, and other pollutants, which pose threats to both aquatic ecosystems and human health (Wang *et al*., 2024; Jamshidi *et al*., 2016). Heavy metals such as lead (Pb^{2+}), cadmium (Cd^{2+}), and iron (Fe^{3+}) are persistent in the environment, can bioaccumulate in aquatic organisms, and may enter human food chains, leading to severe health risks (Jiang *et al*., 2019). Elevated concentrations of nitrate (NO_3^-) in water bodies, often resulting from agricultural runoff and improper sewage management, can lead to eutrophication, which depletes dissolved oxygen levels and threatens aquatic life (Zhao *et al*., 2021).

In Nigeria, rapid industrialization and urbanization have led to increased discharges of untreated or poorly treated wastewater into rivers, lakes, and other water bodies, exacerbating water quality challenges (Ekhaise and Anyasi, 2020). Assessing the levels of hazardous inorganic pollutants in these wastewater sources is crucial for implementing effective pollution control measures and ensuring water safety (Bisht *et al*., 2021). This study aim to evaluate the concentration of key inorganic pollutants, including heavy metals, nitrates, and sulfates, in wastewater samples from various locations. Understanding the distribution of these pollutants will aid in identifying pollution hotspots and inform the development of targeted remediation strategies.

The study focuses on four wastewater sources, analyzing their physical parameters and the concentration of ions to determine the extent of pollution and compare the findings to acceptable standards. The study areas were location A (Abiakpo Rd by Atan Rd, Sanni Ogun Rd and Market Rd Junction) with coordinates at N573175.437 and E357764.542, Location B (Control Post – Uyo Rd by Atan Rd, Old Itu Rd Junction) and Groove Memorial Rd) with coordinates at N571822.390, C (Cardinal Ekanem Avenue by Aba Rd Junction) with coordinate at N572875.913 and E355359.409 and D (Umuahia Rd by Ritman University Rd and Lutheran Rd Junction) with coordinates at N574473.533 and E356227.232 within the study area in Ikot Ekpene city, Akwa Ibom State in Nigeria. It also explores the potential sources and environmental implications of these pollutants, contributing to the growing body of research on wastewater contamination in developing regions (Chen *et al*., 2023; Wakida and Lerner, 2022).

MATERIALS AND METHODS

Study Area and Sample Collection

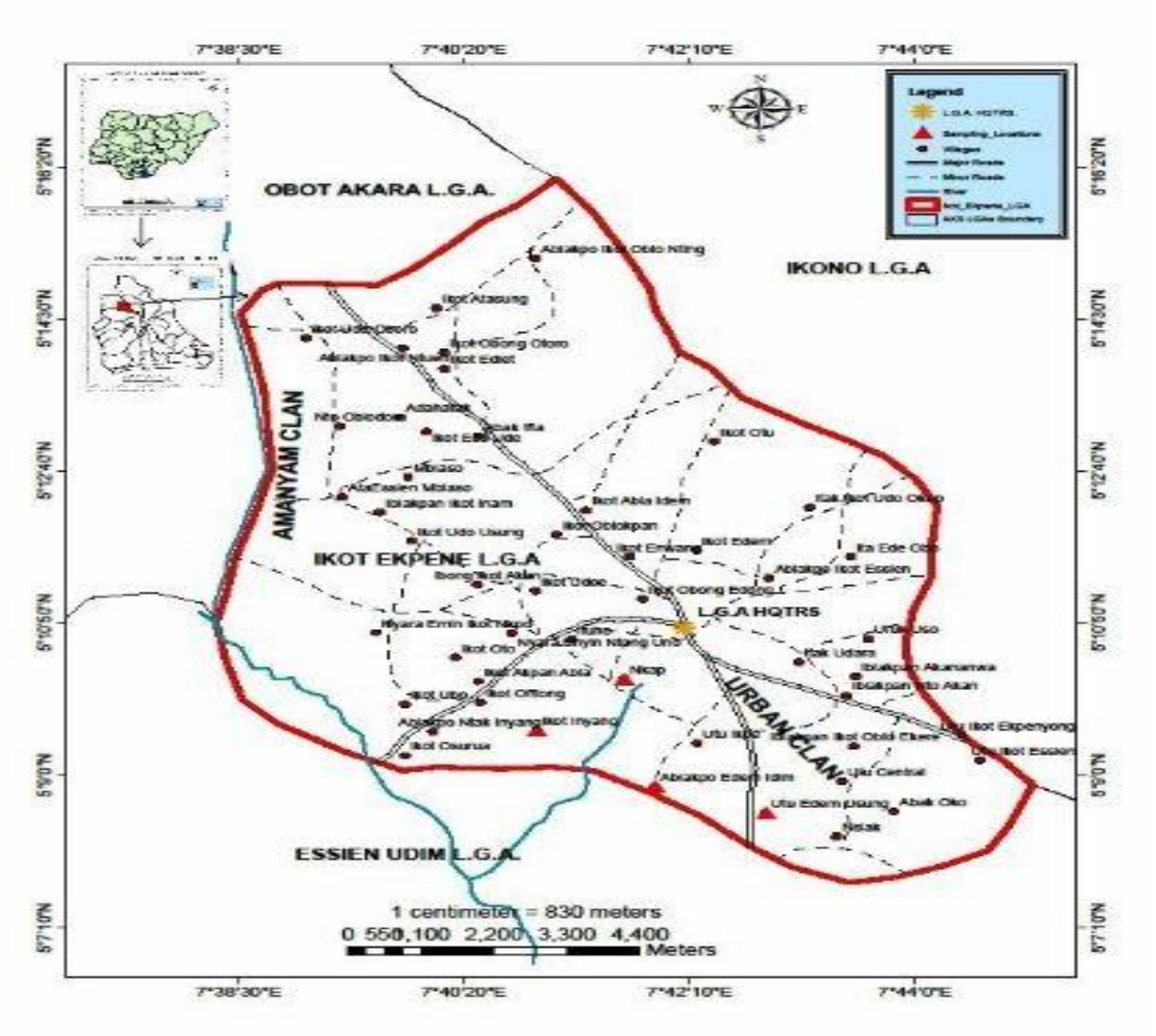

Fig 1: Map of Ikot Ekpene Municipal Area

This study was conducted in four distinct locations (A, B, C, and D) within Ikot Ekpene municipal area with some commercial activities in Akwa Ibom, State Nigeria, known for its diverse industrial, agricultural, and urban activities. These locations were selected based on their proximity to potential sources of pollution, including industrial discharges, agricultural runoff, and urban sewage systems. Each location has unique characteristics in terms of pollution sources, allowing for a comparative analysis of water quality.

Wastewater samples were collected from four spots within each location, using 1-liter polyethylene bottles that had been pre-rinsed with distilled water and the sampled wastewater. The bottles were transported to the laboratory in ice-packed coolers and analyzed within 24 hours of collection to prevent any chemical or biological changes (APHA, 2018).

Physical Parameter Analysis
The physical parameters of the wastewater samples, including pH, temperature, colour, odor, dissolved solids (DS), and suspended solids (SS), were measured using standard methods (APHA, 2018). pH and temperature were determined using a portable pH meter (Hanna Instruments, HI98107) and a digital thermometer, respectively. Colour and odour were assessed visually and organoleptically, with DS and SS measured through gravimetric methods, as described by the American Public Health Association (APHA, 2018).

Chemical Analysis of Ions
The concentrations of calcium (Ca^{2+}), iron (Fe^{3+}), copper (Cu^{2+}), cobalt (Co^{2+}), lead (Pb^{2+}), and cadmium (Cd^{2+}) were analyzed using Atomic Absorption Spectrophotometry (AAS) (Shimadzu AA-7000). The AAS technique was selected for its precision and sensitivity in detecting trace metals in environmental samples (USEPA, 2021). For each sample, 100 mL of the filtered wastewater was acidified with nitric acid (HNO_3) and digested using a hot plate before analysis.

Anions including nitrate (NO_3^-), chloride (Cl^-), sulfate (SO_4^{2-}), and carbonate (CO_3^{2-}) were measured using an ion chromatography system (Metrohm IC System, 930 Compact IC Flex). Calibration curves for each ion were prepared using certified standard solutions to ensure accuracy (USGS, 2020). The detection limits for each ion were established according to the manufacturer's guides, and triplicate analyses were performed to ensure reproducibility.

Quality Control and Data Analysis
Quality control procedures were implemented throughout the sample collection and analysis process to ensure data reliability. Blanks, duplicates, and standard reference materials were included in each batch of samples to check for potential contamination and validate the accuracy of the measurements (APHA, 2018). Data were analyzed using statistical software (SPSS Version 26.0) to compute mean values, standard deviations, and other relevant descriptive statistics.

Comparisons of ion concentrations between the sample locations were conducted using Analysis of Variance (ANOVA), followed by post-hoc tests to identify significant differences ($p < 0.05$). The results were compared with acceptable limits for water quality set by the World Health Organization (WHO, 2017) and the United States Environmental Protection Agency (USEPA, 2021) to evaluate the degree of pollution and potential risks to human and environmental health.

RESULTS AND DISCUSSION
The physical parameters of the wastewater, such as pH, temperature, color, odor, dissolved solids (DS), and suspended solids (SS), are important indicators of water quality. As seen in Table 1, the pH values across all sample locations ranged between 6.5 and 6.8, which indicate a slightly acidic to neutral environment. This is within acceptable limits for most environmental standards for wastewater discharge (WHO, 2017). The temperature ranged between 29 and 30°C for all samples, reflecting a consistent condition across the locations, which could be linked to climatic conditions during sampling.

There was no detectable color or odor in most of the locations except for C1 to C4, where turbidity was observed. This suggests the presence of suspended materials in this location, potentially indicating higher particulate matter in the water column (Ekhaise and Anyasi,

2020). The values for dissolved and suspended solids (DS and SS) varied, with Location C having the highest DS and SS values, which again points to a higher pollutant load.

Table 1: Physical Parameters of the Waste-Water

Sample location	pH	Temp (°C)	Colour	Odour	DS	SS
A_1	6.5	29	None	None	8.00	3.5
A_2	6.5	30	None	None	8.1	3.0
A_3	6.5	30	None	None	8.2	3.2
A_4	6.6	30	None	None	8.1	3.4
B_1	6.5	30	None	None	9.2	4.1
B_2	6.6	30	None	None	8.9	3.2
B_3	6.6	30	None	None	8.6	3.0
B_4	6.5	30	None	None	8.9	3.1
C_1	6.5	3.2	Turbid	None	10.2	4.3
C_2	6.5	3.1	Turbid	None	10.2	4.1
C_3	6.5	3.1	Turbid	None	10.2	4.4
C_4	6.5	3.1	Turbid	None	10.6	3.9
D_1	6.7	29	None	None	7.4	3.1
D_2	6.8	29	None	None	7.4	2.8
D_3	6.7	30	None	None	7.4	2.9
D_4	6.7	29	None	None	7.8	3.2

The concentrations of hazardous ions in Location A reveal moderate pollution levels (Table 2). Calcium (Ca^{2+}) concentrations averaged 2.265 mg/L, which aligns with natural water sources but indicates possible mineral runoff (Bisht et al., 2021). Iron (Fe^{3+}) and copper (Cu^{2+}) were relatively low compared to locations C and D but were still present in potentially concerning amounts, with Fe^{3+} averaging 1.373 mg/L and Cu^{2+} at 1.068 mg/L. Lead (Pb^{2+}) and cadmium (Cd^{2+}) were detected at 1.110 mg/L and 0.251 mg/L respectively, with Pb^{2+} values nearing critical thresholds for drinking water (WHO, 2017,).

Nitrate (NO_3^-) concentrations were relatively high (26.556 mg/L), suggesting agricultural runoff or improper sewage disposal (Ukpe and Udofia, 2024; Wakida and Lerner, 2005). Sulfate (SO_4^{2-}) levels were notably high at an average of 211.257 mg/L, which can indicate industrial discharges or natural mineral dissolution.

Table 2: Concentration of Ions in Sample Spots in Location A

ION	A_1 (mg/l)	A_2 (mg/l)	A_3(mg/l)	A_4 (mg/l)	AVERAGE
Ca^{2+}	2.435	3.243	2.146	1.237	2.265
Fe^{3+}	1.449	1.887	1.167	0.989	1.373
Cu^{2+}	0.805	0.609	1.384	1.475	1.068
Co^{2+}	0.613	0.306	0.870	0.579	0.592
Pb^{2+}	0.837	1.246	1.374	0.983	1.110
Cd^{2+}	0.279	0.189	0.447	0.087	0.251
NO_3^-	30.292	25.445	26.453	24.035	26.556
Cl^-	18.147	14.268	13.465	12.003	14.471
SO_4^{2-}	210.889	200.637	215.487	218.013	211.257
CO_3^{2-}	120.058	80.453	85.874	70.325	89.178

Location B exhibited a slight increase in calcium and iron levels compared to Location A (Table 3). Calcium averaged 3.039 mg/L, while iron remained at 1.654 mg/L, showing elevated but manageable pollution levels. However, copper levels were significantly higher,

with a peculiar error likely inflating Cu^{2+} to an unusually high value (182.276 mg/L). This outlier should be rechecked, as it is beyond feasible concentrations for typical wastewater and may stem from contamination or a recording error.

Lead (Pb^{2+}) concentrations slightly decreased to an average of 0.993 mg/L, though still above safe drinking water limits, while cadmium increased to 0.374 mg/L, indicating some heavy metal contamination. Nitrate levels increased further to 39.367 mg/L, suggesting heightened nitrate pollution, potentially from fertilizer runoff (Jiang *et al*., 2019, Ukpe 2023).

Table 3: Concentration of Ions in Sample Spots in Location B

ION	B_1 (mg/l)	B_2 (mg/l)	B_3 (mg/l)	B_4 (mg/l)	AVERAGE
Ca^{2+}	3.423	2.877	2.745	3.114	3.039
Fe^{3+}	1.665	1.597	1.476	1.876	1.654
Cu^{2+}	0727	0.667	0.594	0.843	182.276
Co^{2+}	0.889	0.457	0.593	0.774	0.678
Pb^{2+}	1.134	1.034	0.917	0.889	0.9934
Cd^{2+}	0.329	0.421	0.448	0.297	0.374
NO_3^-	40.132	39.241	38.497	39.599	39.367
Cl^-	16.256	14.823	15.493	15.295	15.467
SO_4^{2-}	180.274	192.177	159.282	190.028	180.440
CO_3^{2-}	110.167	90.234	87.136	88.167	93.926

Location C had the highest concentrations of several pollutants. Calcium (Ca^{2+}) averaged 3.383 mg/L, and iron (Fe^{3+}) was significantly higher at 3.594 mg/L. Copper (Cu^{2+}) concentrations were also elevated, averaging 1.806 mg/L, further emphasizing the impact of industrial or anthropogenic activities in this region (Kurniawan et al., 2006). Lead concentrations were at 1.364 mg/L, while cadmium was lower (0.099 mg/L) compared to other locations.

Nitrate levels in this location were alarmingly high at 80.919 mg/L, signaling potential eutrophication risk from excessive nutrient loading (Zhao *et al*., 2021). Chloride (Cl^-) concentrations were notably low at 0.081 mg/L, which contrasts sharply with other locations, possibly due to local dilution or lower salinity sources (WHO, 2017). Sulfate (SO_4^{2-}) concentrations were significantly lower at 12.779 mg/L, possibly indicating less industrial discharge or natural dilution in this location.

Table 4: Concentration of Ions in Sample Spots in Location C

ION	C_1 (mg/l)	C_2 (mg/l)	C_3 (mg/l)	C_4 (mg/l)	AVERAGE
Ca^{2+}	3.423	3.654	3.134	3.320	3.383
Fe^{3+}	3.617	3.257	3.917	3.586	3.594
Cu^{2+}	1.257	1.851	2.273	1.843	1.806
Co^{2+}	0.859	0.507	0.526	0.605	0.624
Pb^{2+}	1.243	1.379	1.238	1.597	1.364
Cd^{2+}	0.075	0.087	0.129	0.108	0.099
NO_3^-	80.257	81.105	83.051	79.263	80.919
Cl^-	0.098	0.067	0.077	0.081	0.081
SO_4^{2-}	12.104	14.304	11.901	12.805	12.779
CO_3^{2-}	4.609	6.309	5.807	5.608	5.583

Location D showed elevated levels of calcium (3.142 mg/L) and iron (3.763 mg/L), suggesting moderate to high pollution. Lead concentrations were also concerning, with an average of 2.231 mg/L, the highest recorded across all locations. This may reflect severe heavy metal contamination, particularly from industrial activities (Chen *et al*., 2019).

Cadmium was similarly elevated (0.975 mg/L), exceeding safe limits for aquatic ecosystems. Nitrate concentrations were lower compared to Location C, averaging 69.021 mg/L, but still a potential risk for environmental eutrophication (Zhao et al., 2021). Sulfate and chloride levels remained low, pointing to minimal industrial discharge in this region.

Table 5: Concentration of Ions in Sample Spots in Location D

ION	D_1 (mg/l)	D_2 (mg/l)	D_3 (mg/l)	D_4(mg/l)	AVERAGE
Ca^{2+}	2.823	3.434	3.352	2.957	3.142
Fe^{3+}	2.154	4.554	4.367	3.975	3.763
Cu^{2+}	0.921	1.867	1.397	1.331	1.379
Co^{2+}	0.876	1.287	1.531	1.497	1.298
Pb^{2+}	2.327	2.457	2.145	1.993	2.231
Cd^{2+}	0.825	1.209	1.027	0.836	0.975
NO_3^-	80.213	60.135	75.198	60.536	69.021
Cl^-	0.834	0.732	0.521	0.698	0.696
SO_4^{2-}	10.479	10.823	14.657	12.923	12.221
CO_3^{2-}	6.321	5.497	8.621	5.947	6.597

The average concentrations (Table 6) show clear trends in pollution levels. Locations C and D exhibited higher levels of heavy metals and nitrates, which can be attributed to anthropogenic activities. Notably, the average nitrate concentration (53.966 mg/L) across all locations surpasses recommended levels for drinking water, posing health risks (WHO, 2017). Similarly, elevated lead and cadmium concentrations could lead to long-term ecological and human health issues (Mojiri *et al.,* 2016).

The average concentrations of ions across all locations revealed significant spatial variation. calcium (Ca^{2+}) levels were highest in Location C (3.383 mg/L) and lowest in Location A (2.265 mg/L), which might be attributed to geological differences (El-Amier *et al.,* 2022).Iron (Fe^{3+}) and Lead (Pb^{2+}) concentrations were significantly higher in Locations C and D, suggesting anthropogenic activities such as industrial discharge.Sulfate (SO_4^{2-}) levels were most pronounced in Location A (211.257 mg/L) due to possible industrial effluent discharge, whereas Location C had the lowest (12.779 mg/L).Nitrate (NO_3^-) was highest in Location C (80.919 mg/L), indicating potential risks of eutrophication if released into natural water bodies (Shariati et al, 2019)

Table 6: Average Concentrations of Ions Across Locations

ION	A (mg/l)	B (mg/l)	C (mg/l)	D (mg/l)	AVERAGE
Ca^{2+}	2.265	3.039	3.383	3.142	2.957
Fe^{3+}	1.373	1.654	3.594	3.763	2.596
Cu^{2+}	1.068	182.276	1.806	1.379	46.632
Co^{2+}	0.592	0.678	0.624	1.298	0.798
Pb^{2+}	1.110	0.9934	1.364	2.231	1.425
Cd^{2+}	0.251	0.374	0.099	0.975	0.425
NO_3^-	26.556	39.367	80.919	69.021	53.966
Cl^-	14.471	15.467	0.081	0.696	7.679
SO_4^{2-}	211.257	180.440	12.779	12.221	104.174
CO_3^{2-}	89.178	93.926	5.583	6.597	48.821

CONCLUSION

The analysis indicates that Locations B, C, and D have elevated levels of hazardous ions, particularly Pb^{2+} and Cd^{2+}, which exceed permissible limits and pose significant environmental and health risks. This necessitates targeted wastewater treatment and

pollution mitigation strategies. Elevated nitrate levels in some locations also call for careful monitoring to prevent eutrophication. Effective regulation and monitoring are essential to ensure the safety of wastewater discharge into the environment.

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