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CONCENTRATION, DISTRIBUTION AND HEALTH RISK OF HEAVY METALS IN WATER AND BIOTA FROM EKPAN RIVER IN WET SEASON

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ABSTRACT

This study was aimed at determining the concentration of heavy metals in the surface water and aquatic sentinels from ekpan river and the health risk associated, due to the cumulative effects of industrial pollution, agricultural runoff, and urbanization which has degraded the water quality and disrupt the ecological integrity of this river.The Water samples were collected from upstream, midstream, and downstream sections of the Ekpan River. These samples were analyzed for both physio-chemical parameters, microbial contamination and heavy metals using the Atomic Absorption spectrophotmer (AAS) .Iron and lead levels were highest downstream (1.46 ± 0.26 mg/L and 2.84 ± 0.58 mg/L, respectively), Magnesium and sodium concentrations were elevated upstream (10.31 ± 2.60 mg/L and 49.28 ± 20.83 mg/L, respectively). The Water Quality Index (WQI) indicated severely degraded water quality across all sampling points. The WQI values show a progressive deterioration from upstream (124.56) through midstream (134.89) to downstream (138.23). This pattern is particularly concerning during wet season when dilution effects would typically be expected to improve water quality. The aquatic sentinels (crabs,periwinkles and water hyacinth) were found to contain high concentrations of heavy metals (particularly lead and iron) exceeding standard limits. Overall, among the three aquatic sentinels (crab,periwinkle,water hyacinth), the periwinkle accumulates the highest levels of heavy metals.During the wet season, periwinkle showed elevated concentrations of Iron (Fe) at 4.817 mg/L and Manganese (Mn) at 0.841 mg/L, it demonstrates the greatest capacity for heavy metal accumulation, particularly for Iron (Fe) and Manganese (Mn), making it the most affected sentinel.

Keywords: Aquatic Sentinels, Ekpan River, Health Risk, Heavy Metals, Pollution

INTRODUCTION

The Ekpan River in Delta State, Nigeria, serves as a vital water source for local communities, supporting domestic, agricultural, and industrial activities. Unfortunately, heavy metal pollution poses a significant threat to the river's health, particularly during the wet season, which spans from April to September. This period is characterized by increased rainfall, facilitating the mobilization of pollutants from urban, industrial, and agricultural lands. Consequently, the concentrations of toxic heavy metals such as iron (Fe), zinc (Zn), manganese (Mn), cadmium (Cd), lead (Pb), copper (Cu), and chromium (Cr) rise substantially in the river water (Funtua et al., 2014; Xia et al., 2018). These contaminants predominantly enter the river through industrial effluents, urban runoff, and the erosion of contaminated soils, resulting in a complex pollution landscape that varies both spatially and temporally (Abalaka et al., 2020; Zhang et al., 2014).

The concentration of heavy metals in the Ekpan River during the wet season is influenced by proximity to pollution sources, the volume of runoff, and the dynamic interaction between river water and sediments. Research has demonstrated that the order of prevalence of heavy metals in river water generally follows Fe > Zn > Mn > Cd > Pb > Cu > Cr, with iron being the most abundant due to both natural geochemical processes and anthropogenic activities (Mu et al., 2018; Ali et al., 2019). Sediments act as reservoirs for these metals, accumulating them in a distinct order: Fe > Cu > Mn > Cr > Pb > Zn > Cd, highlighting the potential for sediment-bound metals to be resuspended into the water column during peak flow events (Xia et al., 2018; Zhang et al., 2014). Moreover, spatial analysis reveals that regions adjacent to industrial discharge points and urban settlements exhibit significantly higher pollutant levels than more remote areas, underscoring the need for focused monitoring and remediation efforts in high-risk zones (Abalaka et al., 2020; Wang et al., 2021).

Public health risks associated with heavy metal exposure during the wet season are particularly profound. Increased turbidity and enhanced bioavailability of metals in river water can lead to serious health complications, as metals like Pb, Cd, and Cr are linked to neurological impairment, kidney dysfunction, carcinogenesis, and developmental disruptions—particularly among vulnerable populations such as children and pregnant women (Kumar et al., 2021; Pund & Kurhe, 2023; Corbi et al., 2010). The primary exposure pathways include ingestion of contaminated water and consumption of fish or other aquatic organisms that bioaccumulate these metals. During the wet season, reliance on river water for drinking and domestic purposes increases, leaving communities more susceptible to contamination, especially in areas where alternative water sources are scarce (Yang et al., 2022; Nema et al., 2015).

Risk assessments conducted in similar Nigerian river systems indicate that hazard indices for metals such as Cd, Cr, and Pb frequently exceed safety thresholds during the wet season, signaling a significant risk of systemic toxicity among exposed populations (Ali et al., 2019; Silva et al., 2011). The carcinogenic risks associated with certain metals, particularly those classified as human carcinogens, further necessitate comprehensive risk evaluations and timely protective interventions, including improved water safety measures for local communities (Wang et al., 2014; Malik & Maurya, 2015).

The ecological consequences of heavy metal contamination in the Ekpan River during the wet season are considerable. Aquatic organisms—including fish, crustaceans, and algae—are exposed to elevated metal concentrations, leading to bioaccumulation and subsequent biomagnification throughout the food chain (Huang & Keller, 2020; Funtua et al., 2014). This phenomenon threatens the river's ecological diversity and jeopardizes the livelihoods of communities dependent on fisheries and aquaculture (Abalaka et al., 2020; Kumari et al., 2014). Additionally, heavy metal influx can alter key water quality parameters such as pH, dissolved oxygen, and turbidity, increasing stress on aquatic ecosystems and diminishing their resilience to pollution (Zhang et al., 2014; Xia et al., 2018).

To effectively address the pervasive issue of heavy metal contamination in the Ekpan River, a holistic approach is paramount. This should include systematic monitoring of both water and sediment quality to identify pollution hotspots. Source control measures, such as strict regulation of industrial discharges and enhanced waste management practices, are vital to reducing heavy metal inputs. Remediation efforts employing technologies such as adsorbents and constructed wetlands—can help remove metals from the water and restore ecosystem functions (Huang & Keller, 2020; Liu & Liu, 2022). Furthermore, raising community awareness about the dangers of heavy metal exposure and promoting safe water usage practices are crucial components of any comprehensive risk management framework (Corbi et al., 2010; Zhao et al., 2015).

This study provides a comprehensive understanding of the concentration, distribution, and health risks associated with heavy metal contamination in Ekpan River, Delta State. The findings revealed significant levels of heavy metals in both water and biota, with notable spatial variations during the wet season, which results from complex interactions between natural processes and human activities, posing risk to both public health and environmental integrity. A broad spectrum of risk assessments, targeted interventions, and active community participation is essential to mitigate these threats and preserve the ecological integrity of the Ekpan River for future generations. This research seeks to determine the extent of ecological damage caused by these activities resulting in elevated levels of heavy metals present, and suggest strategies for sustainable management and health risk assessments.

MATERIALS AND METHODS

Study Area

Uvwie local government is one of the twenty-five local government areas (LGA) of the urhobo people in Delta State Nigeria. It comprises of different communities and towns and the Ekpan community is one of them and It is widely known for fish farming with large number of ponds. Ekpan is located within longitude 5,54°E and 5.7°W and latitude 5.3°N and 5.6°S.

The Ekpan river is a flowing river that is located in delta state Nigeria, of Uvwie local government area. The river comes from the Utagba-uno in Ndokwa LGA and flows through Effurun into the Warri river and finally go into the atlantic ocean. It is surrounded by mangroves and trees. The river is highly turbid due to various activities such as agricultural practices, industrial discharges, sand dredging, fishing, waste dumpsites. The Ekpan river is a major channel for releasing domestic and industrial waste from Warri refining company and other industries around the Warri axis.

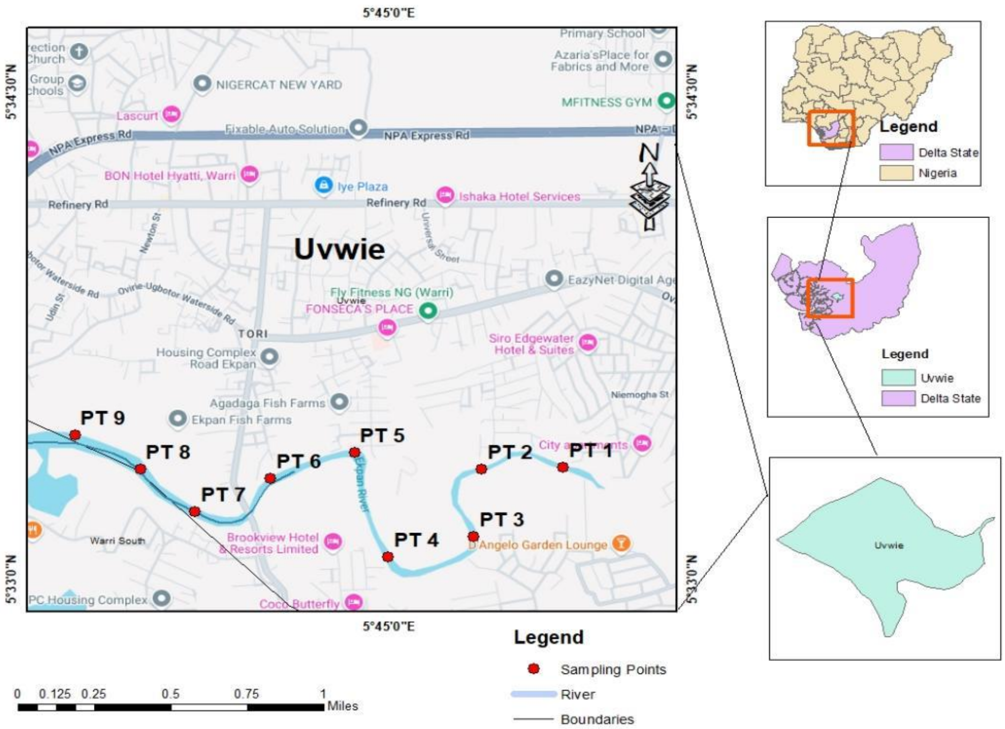

Figure 1: A Map Showing the Study Location

The Ekpan river has a semi-hot tropical humidity climate and has two main weather conditions (wet season). The wet/rainy season is classified due to regular rain fall, high humidity and low sunshine and it starts from April - October each year, while the dry season is classified due to little rainfall, high level of sunshine and it starts from November-march consequently (Ikpesu *et al.*, 2021).

As seen in fig(1) the ekpan river flows through several industrial and residential areas, making it an ideal case study for assessing the impact of anthropogenic activities.

Figure 2: The Ekpan River, Delta State Nigeria

The Sampling Stations

There were three sampling stations examined for the study area which aided this research survey which included the upstream (1,2,3), mid-stream (1,2,3) and downstream (1,2,3).

i. The water sample was collected from the 3 sampling points. (The upper portion of the river is about 5km away from the bridge which is the upstream section and this section receives effluents from the Warri refining and petrochemical company and also other industries around the Warri metropolis. The upstream sampling station was from the point of the industrial effluent discharge, fishing ponds and other ongoing activities.
ii. The middle portion of the river which is the midstream. The sampling station of the midstream is from the Run-offs of the different waste dumpsite into the river. The first point was the run off from dredging activities, the second discharge point was a runoff from the heap of waste dump, the third was a run off from a small vegetation close to the river bank.
iii. the downstream section located at about 12km away from the bridge across the NNPC housing complex at New layout Ekpan. The downstream section is predominantly characterized by mangroves and vegetations.

Control Point

The water samples used as control was gotten from Ugbomro in Uvwie local government area which has little human activities; it was taken from three points upstream, midstream and downstream.

General Overview of some activities in Ekpan River

Figure 3: Waste Dumpsites in Close Proximity to the River

Figure 4: Constructed Ponds in the River

Sampling of Water Samples

This involves sampling of water samples from the river bodies and all samples were transferred to Dukoria International Limited for all laboratory analysis. Clean sample containers for collection of water samples were rinsed with the source water at each point of collection before immersing into the surface of the water for filling and sealing before in-situ analysis was done with a multi-parameter water quality monitor (model 6000 UPG) which was already calibrated at the laboratory prior the sample collection. The in-situ analysis performed on the water samples were pH, Electrical Conductivity (EC), Total Dissolved Solids (TDS), Temperature, Dissolved oxygen (DO) and Salinity.

Preservation
Sampling for heavy metal was done in separate sampling bottles and they were preserved using 1 ml of 50% Nitric acid to ensure the integrity of the samples is preserved. Other samples were preserved in a clean cooler containing ice chest before transferred to the laboratory for further analysis.

Procedures to Ensure Sample Integrity is Maintained
A comprehensive field logbook was maintained to record any significant information related to all the sampling process, ensuring accurate documentation of location data and any other observations. Preservatives were carefully employed depending on the specific parameter being analyzed to maintain the original states of the samples until they were ready for analysis. The holding time which refers to the maximum duration before analysis was adhered to. Samples were transported in a cooler packed with ice to maintain the samples integrity. Labeling was done accurately for every sample taken accordingly.

Chemicals Used
The chemicals used in this study including the names of the suppliers, manufacturers, grades, percentage purity are as shown in table 1.

Table 1: Chemicals used for the experiment

Chemical	Suppliers	Grade	Manufacturers	Percentage (%) Purity
Hydrochloric acid	-do-	American Chemical Society (ACS)	Sigma	99
hydrogen Peroxide	-do-	GPR	BDH	99
Nitric acid	-do-	Scharlau	BDH	70
Potassium Chromate	Besgotek International limited, Warri.	Analar	BDH	99.5
Silver nitrate	-do-	ACS	Fluka	99.8
Sodium Chloride	Naafco Scientific supplies limited	Analar	BDH	99.9
Sodium Hydroxide	Besgotek International limited, Warri	Analar	BDH	99.5
Sulphuric acid	-do-	Analar	BDH	98

Equipment Used
Some equipments used in this study includes: Analytical weighing balance (Milton MA203E model), atomic absorption spectrophotometer (AA-200 model), autoclave (Equitron 74065ST model), incubator (Genlab MINI/50/VIS model), electrical conductivity meter (Jenway portable pH/ conductivity meter 430 model), water quality tester, UV Spectrophotometer (TU1810 model), COD reactor (HACH DRB 200 model).

Laboratory Analysis
Determination of Physico-Chemical Parameters on Water Samples
Water quality parameters are sectored into physical, chemical and biological. Examples of physical water quality parameters are turbidity, temperature and salinity, total dissolved solids (TDS), total suspended solids (TSS) ,while examples of chemical water quality parameters are pH and heavy metals. Examples of biological water quality parameters are total coliform and test for microbial contamination as seen in the table below.

Table 2: Determination of Physico-Chemical Parameters in Water Samples. (APHA 2017, 24th ed)

Parameters	Analytical Methods
Physico-chemicals	
pH	Electrometric method (APHA - 4500-H+)
Temperature, ^{0}C	Electrometric method (APHA-4500-H+)
Conductivity, µS/cm	Electrometric method(APHA-4500-H+)
Total dissolved solids (TDS), mg/L	Gravimetric method(APHA 2540 C)
Total Suspended Solids (TSS), mg/L	Gravimetric method (APHA-2540-D)
Turbidity, NTU	Nephelometric method (APHA – 2130-B)
Anions	
Salinity (Cl-), mg/L	Electrical conductivity method (APHA 2520-B)
Nitrate, mg/L	Ultraviolet Spectrophotometric Method (APHA 4500-NO_3^-B)
Ammonia, mg/l	Direct nesslerization method(4500-NH_3C)
Sulphate, mg/L	Turbidity method (APHA-4500 SO42-E)
Organics	
BOD, mg/L	5 day method (APHA 5210B)
DO, mg/L	Azide modification method(APHA – 4500 -O C)
COD, mg/L	Closed reflux, titrimetric method (APHA 5220 C)
Inorganics (Anions and Cations)	
Calcium, mg/L	Atomic Absorption Spectrophotometry(APHA 3400)
Magnesium, mg/L	Atomic Absorption Spectrophotometry, (APHA 3400)

Parameters	Analytical Methods
Metals	Atomic Absorption Spectrophotometry, (APHA 3400)
Microbiology	
Faecal Coliform, cfu/100mL	(APHA 9221E)
Total Heterotrophic Bacteria (THF), cfu/100mL	(APHA 9215)
Total Heterotrophic Fungi (THF), cfu/100mL	(APHA 9215)

Heavy Metal Determination

AAS is used to analyze the presence of metals. Samples are heated either in a flame or electrically in a graphite furnace, and the concentration is determined by the metal atom's adsorption of light as a particular wavelength. Prior using the AAS to ascertain the concentration of heavy metals, Digestion was carried out, a process of acid digestion which involves dissolving a sample into solution by adding acids and heating until complete decomposition of the sample to release the analyte (metals), any acid could be used but HNO3 is used because of its oxidizing nature. Two Hundred and fifty (250) mL of the water sample was transferred into 25 ml beaker and 5.0 mL conc. HNO_3 was added. The solution was evaporated or heated to about 10 mL, making sure that the sample did not heat to dryness. The mixture was then allowed to cool after which it was filtered using a filter paper. The filtrate was poured into a 25 mL calibrated volumetric flask and made up to the meniscus with appropriate volume of distilled water. The absorbance of the metal was determined by aspiration of the sample digest into an Atomic Absorption Spectrophotometer (Buck Scientific AAS model 210) while it corresponding concentration (in mg/L) was read off the linear calibration curve.

$$\text{Concentration metal (mg/kg)} = \frac{\text{CAAS} \times V_{\text{Final}} \times \text{DF}}{M_{sample}} \quad (1)$$

Analysis of Sentinels

The crabs, periwinkles and the plant were air-dried in the laboratory, digested with digestion mixture and then analyzed using the AAS machine.

Water Quality

In this study, for the calculation of water quality index, eight important parameters were chosen namely, Temperature, pH, TSS, BOD, DO, Phosphate, Lead and Fecal coliform,. The WQI was calculated by using standards of drinking water quality recommended by the World Health Organization (WHO). The weighted Arithmetic index method (Brown *et al*., 1972; Etim *et al*., 2013) has been used for the calculation of WQI in this study. Further, quality rating was calculated using the following expression and the vales were judged using the criteria present in table (3e).

$$\text{qn} = \frac{100(\text{Vn} - \text{Videal})}{(Sn - Videal)} \quad (2)$$

(Let there be n water quality parameters and quality rating (qn) corresponding to n^{th} parameter is a number reflecting relative value of this parameter in the polluted water with respect to its standard permissible value).

qn = Quality rating for the n^{th} Water quality parameter

Vn = Estimated value of the n^{th} parameter at a given water sampling station

Sn = Standard permissible value of the n^{th} parameter

Table 3: Water Quality Classification Based on Water Quality Index (WQI) Values

Water Quality Index Value	Water Quality Status
0-25	Excellent water quality
25-50	Good water quality
51-75	Moderate
76-100	Poor
>100	Very poor

Source : (Brown, *et al.,* 1972; Etim *et al.,* 2013)

Health Risk Assessments of Heavy Metals

The health risk assessment of contaminants is based on mechanistic assumptions for humans that it may either be carcinogenic or non-carcinogenic

Humans are exposed to heavy metals through different pathways either oral,dermal absorption or inhalation (Elumalai *et al*., 2017).

The toxicity indices of each potentially toxic metal for humans can be estimated using the estimated daily intake of metals (EDI), Target hazard quotient, hazard index, and carcinogenic risk.

Target hazard quotient is the ration of chronic daily intake divided by the oral reference dose (RFD) of individual heavy metals.

$$\text{Target hazard quotient EDI} = \frac{C\,metal \times EF \times ED \times IR}{\text{AT} \times \text{LT} \times \text{BW average}} \quad (3)$$

EDI (estimated daily intake) = exposure duration in 53 years equivalent to average lifetime of a Nigerian.

IR = Is the ingestion rate (seafood consumption rate;mg/person/day)

C = is the concentration of metal in food samples in mg/kg

Rf = is the reference dose in mg /kg day

Lt = is the life time equal to exposure duration; years,

Bw = is the average body weight: for men (57kg) for women (50kg).

Atn = is he average exposure time for non-carcinogen in days (365 *ED: days)(19,345)

Total Hazard index (HI)=

$$\Sigma\, THQ\, (THQ_{Pb} + THQ_{cd} + THQ_{cr} + THQ_{n} \ldots \ldots \ldots) \quad (4)$$

Cancer Risk Assessment

Cancer risk associated with exposure to contaminants and heavy metal is estimated using ILCR.

ILCR is the increment probability of an individual developing any type of cancer over a lifetime. The total cancer risk from exposure to heavy metals can be determined by using the sum of individual ILCR.

$$\Sigma\, ILCR1 + ILCR2 + ILCR3 + \ldots .ILCR_{n} \quad (5)$$

Where n is the individual carcinogenic metals (Ni,Cr,Cd and Pb). The accepted level for cancer risk ILCR is within 1.06E-6 to 1.06E-4. thus heavy metals with risk factors less than 1.06E-4 are not considered to pose a risk (Kalagor *et al.*, 2019)

A carcinogenic risk is the estimated cumulative probability of an individual developing cancer over exposure for a long period of time to that carcinogen (Tanhan, 2022). Non carciniogenic risk is estimated using THQ

Total Hazard index (HI)= $\Sigma\ THQ\ (THQ_{Pb} + THQ_{cd} + THQ_{cr} + THQ_{n} \ldots \ldots \ldots)$ (6)

If the THQ value of the heavy metal was less than or equal to 1, then it does not pose any non-carcinogenic risk in exposure over a life time.

If the THQ value is more than 1, then the specific heavy metal can lead to non-carcinogenic risk in humans.

Statistical Analysis

The statistical analysis utilized three (3) main tools. Microsoft Excel 365 and SPSS were used for calculating descriptive statistics, performing correlation analyses and Analysis of Variance (ANOVA) on the data. For the more complex task of computing the Water Quality Index (WQI), Python programming was used for the computation. This combination allowed effectively analyzing the data and deriving meaningful insights about the water quality at different location.

RESULTS AND DISCUSSION

This section presents the wet season result through descriptive statistics of physicochemical parameters, water quality index of the collected water samples.

Physico-Chemical Parameters for Water Samples

Wet Season Result

The in situ parameters, including pH, electrical conductivity (EC), dissolved oxygen (DO), temperature, and turbidity, exhibited significant spatial variations as seen in Table 4 below. The pH values were highly alkaline upstream (11.37 ± 0.25), midstream (11.73 ± 0.23), and downstream (11.74 ± 0.21), contrasting sharply with the neutral to slightly acidic control site (5.97 ± 0.75). Electrical conductivity was highest upstream (125.67 ± 1.15 µS/cm) and decreased downstream (118.67 ± 1.53 µS/cm), while the control site showed minimal ionic content (28.33 ± 3.51 µS/cm). Dissolved oxygen levels were lowest midstream (2.37 ± 1.24 mg/L) and highest at the control site (4.83 ± 1.96 mg/L), indicating potential organic pollution in the main sampling areas. Temperature remained relatively stable across sites, with a total mean of 27.66 ± 0.66 °C. Turbidity was exceptionally high upstream (83.78 ± 5.74 NTU) but dropped significantly downstream (2.79 ± 2.14 NTU), reflecting variability in water clarity due to sedimentation and particulate matter.

Heavy metal concentrations, including iron, lead, magnesium, and sodium, showed notable spatial trends. Iron and lead levels were highest downstream (1.46 ± 0.26 mg/L and 2.84 ± 0.58 mg/L, respectively), suggesting potential contamination from industrial or natural sources. Magnesium and sodium concentrations were elevated upstream (10.31 ± 2.60 mg/L and 49.28 ± 20.83 mg/L, respectively) but minimal at the control site (2.85 ± 0.60 mg/L and 8.19 ± 0.15 mg/L, respectively). The total mean values for iron, lead, magnesium, and sodium were 1.01 ± 0.56 mg/L, 2.72 ± 0.79 mg/L, 7.45 ± 3.26 mg/L, and 37.78 ± 25.21 mg/L, respectively. These results indicate geogenic or anthropogenic contributions to heavy metal contamination, particularly in the downstream regions.

Microbiological parameters, including faecal coliforms, heterotrophic bacteria, and fungi, revealed contamination from faecal matter and microbial activity. Faecal coliform counts were highest downstream (51.33 ± 10.41 CFU/100 mL) and lowest at the control site (4.73 ± 3.10 CFU/100 mL), with a total mean of 28.54 ± 19.66 CFU/100 mL. This suggests contamination from sewage or animal waste, particularly in the downstream areas. Heterotrophic bacteria and fungi counts were low across all sites, with total mean values of 0.04 ± 0.02 CFU/mL and 0.03 ± 0.02 CFU/mL, respectively, indicating minimal microbial activity. These findings highlight the need for improved sanitation and waste management practices to reduce faecal contamination.

Other critical parameters, such as total dissolved solids (TDS), alkalinity, hardness, chemical oxygen demand (COD), biochemical oxygen demand (BOD), and nutrients (nitrate, ammonia, phosphate), further illustrate the water quality dynamics. TDS levels were highest upstream (67.33 ± 0.58 mg/L) and decreased downstream (58.00 ± 1.00 mg/L), with the control site showing minimal values (14.33 ± 1.53 mg/L). Alkalinity and hardness followed similar trends, with the highest values upstream (49.33 ± 2.31 mg/L and 30.00 ± 5.29 mg/L, respectively). COD levels were exceptionally high upstream (721.33 ± 16.17 mg/L) and midstream (749.33 ± 16.65 mg/L), indicating significant organic pollution, while BOD levels were relatively low (total mean: 1.67 ± 1.39 mg/L). Nutrient levels, particularly nitrate (8.50 ± 1.61 mg/L upstream) and phosphate (18.52 ± 4.87 mg/L upstream), suggest agricultural runoff or wastewater discharge as potential sources of contamination. These findings collectively underscore the impact of anthropogenic activities on water quality and the need for targeted mitigation measures.

Table 4: Descriptive Statistics of all Physico-Chemical and Biological Parameters for all Sampling Locations During Wet Season

Parameters	Location	N	Mean	Standard Deviation	Minimum	Maximum	FMEnv. Limits
Ph	SW Upstream	3	11.37	0.25	11.08	11.52	6.5-8.5
	SW Midstream	3	11.73	0.23	11.47	11.92	
	SW Downstream	3	11.74	0.21	11.55	11.97	
	SW Control	3	5.97	0.75	5.12	6.55	
	Total	12	10.20	2.58	5.12	11.97	
Electrical Conductivity, µS/cm	SW Upstream	3	125.67	1.15	125	127	NS
	SW Midstream	3	121.00	1.00	120	122	
	SW Downstream	3	118.67	1.53	117	120	
	SW Control	3	28.33	3.51	25	32	
	Total	12	98.42	42.38	25	127	

Parameters	Location	N	Mean	Standard Deviation	Minimum	Maximum	FMEnv. Limits
Dissolved Oxygen (DO), mg/L	SW Upstream	3	3.80	0.53	3.2	4.2	
	SW Midstream	3	2.37	1.24	1.6	3.8	
	SW Downstream	3	2.93	0.38	2.5	3.2	6.0
	SW Control	3	4.83	1.96	3	6.9	
	Total	12	3.48	1.42	1.6	6.9	
Temperature (°C)	SW Upstream	3	28.27	0.06	28.2	28.3	
	SW Midstream	3	27.50	0.44	27.2	28	
	SW Downstream	3	28.00	0.26	27.7	28.2	
	SW Control	3	26.86	0.62	26.14	27.23	Ambient ±2
	SW Upstream	12	27.66	0.66	26.14	28.3	
Total Dissolved Solids, mg/L	SW Upstream	3	67.33	0.58	67	68	
	SW Midstream	3	62.67	0.58	62	63	2000
	SW Downstream	3	58.00	1.00	57	59	
	SW Control	3	14.33	1.53	13	16	
	Total	12	50.58	22.15	13	68	
Carbonate	SW Upstream	3	0.00	0.00	0	0	
	SW Midstream	3	0.00	0.00	0	0	
	SW Downstream	3	0.00	0.00	0	0	NS
	SW Control	3	0.00	0.00	0	0	
	Total	12	0.00	0.00	0	0	
Bi carbonate	SW Upstream	3	57.23	1.54	56.34	59	
	SW Midstream	3	54.01	6.47	46.7	59	
	SW Downstream	3	42.59	2.95	40.36	45.93	NS
	SW Control	3	4.90	0.40	4.62	5.36	
	Total	12	39.68	21.95	4.62	59	
Alkalinity, mg/L	SW Upstream	3	49.33	2.31	48	52	
	SW Midstream	3	46.67	6.11	40	52	
	SW Downstream	3	36.00	8.00	28	44	NS
	SW Control	3	7.00	1.00	6	8	
	Total	12	34.75	18.08	6	52	
Total Hardness, mg/L	SW Upstream	3	30.00	5.29	24	34	
	SW Midstream	3	36.67	5.03	32	42	
	SW Downstream	3	38.00	5.29	34	44	NS
	SW Control	3	5.00	1.73	4	7	
	Total	12	27.42	14.43	4	44	
Chemical Oxygen Demand, mg/L	SW Upstream	3	721.33	16.17	704	736	
	SW Midstream	3	749.33	16.65	736	768	
	SW Downstream	3	619.00	73.61	576	704	30.0
	SW Control	3	32.67	1.15	32	34	
	Total	12	530.58	306.27	32	768	
Biochemical Oxygen Demand, mg/L	SW Upstream	3	1.47	1.75	0	3.4	
	SW Midstream	3	0.77	1.33	0	2.3	
	SW Downstream	3	1.57	1.46	0	2.9	
	SW Control	3	2.87	0.49	2.3	3.2	3.0
	Total	12	1.67	1.39	0	3.4	
Salinity, Cl mg/L	SW Upstream	3	57.33	0.58	57	58	
	SW Midstream	3	52.67	0.58	52	53	
	SW Downstream	3	48.33	1.15	47	49	NS
	SW Control	3	2.00	1.00	1	3	
	Total	12	40.08	23.22	1	58	
Total Suspended Solids (TSS), mg/L	SW Upstream	3	24.89	4.31	21.15	29.6	
	SW Midstream	3	14.00	0.60	13.57	14.68	
	SW Downstream	3	10.67	0.75	9.87	11.35	NS
	SW Control	3	18.58	3.09	16.36	22.11	

Parameters	Location	N	Mean	Standard Deviation	Minimum	Maximum	FMEnv. Limits
	Total	12	17.04	6.03	9.87	29.6	
Turbidity, NTU	SW Upstream	3	83.78	5.74	77.26	88.06	
	SW Midstream	3	3.65	1.16	2.45	4.76	
	SW Downstream	3	2.79	2.14	1.22	5.23	NS
	SW Control	3	10.38	1.94	8.56	12.43	
	Total	12	25.15	35.60	1.22	88.06	
Sulphate, mg/L	SW Upstream	3	8.81	0.26	8.51	9.01	
	SW Midstream	3	8.98	0.76	8.11	9.51	
	SW Downstream	3	10.94	0.83	10.01	11.61	100
	SW Control	3	7.10	0.20	6.88	7.28	
	Total	12	8.96	1.51	6.88	11.61	
Nitrate, mg/L	SW Upstream	3	8.50	1.61	6.8	10	
	SW Midstream	3	4.33	0.91	3.3	5	9.1
	SW Downstream	3	1.66	0.71	0.89	2.3	
	SW Control	3	0.00	0.00	0	0.01	
	Total	12	3.63	3.46	0	10	
Ammonia, mg/L	SW Upstream	3	0.39	0.27	0.14	0.68	
	SW Midstream	3	0.23	0.09	0.17	0.34	
	SW Downstream	3	0.22	0.11	0.12	0.34	0.05
	SW Control	3	0.08	0.05	0.03	0.12	
	Total	12	0.23	0.18	0.03	0.68	
Phosphate, mg/L	SW Upstream	3	18.52	4.87	15.22	24.11	
	SW Midstream	3	15.92	1.47	14.33	17.22	
	SW Downstream	3	20.23	0.06	20.16	20.26	3.5
	SW Control	3	12.46	4.06	8.22	16.3	
	Total	12	16.78	4.13	8.22	24.11	
Iron, mg/L	SW Upstream	3	0.12	0.11	0.06	0.25	
	SW Midstream	3	1.24	0.06	1.17	1.29	
	SW Downstream	3	1.46	0.26	1.26	1.75	0.3
	SW Control	3	1.22	0.06	1.16	1.26	
	Total	12	1.01	0.56	0.06	1.75	
Lead, mg/L	SW Upstream	3	2.31	0.21	2.18	2.55	
	SW Midstream	3	3.68	0.81	3.16	4.61	
	SW Downstream	3	2.84	0.58	2.17	3.18	0.01
	SW Control	3	2.04	0.25	1.76	2.2	
	Total	12	2.72	0.79	1.76	4.61	
Nickel, mg/L	SW Upstream	3	0.00	0.00	0	0	
	SW Midstream	3	0.00	0.00	0	0	
	SW Downstream	3	0.00	0.00	0	0	
	SW Control	3	0.00	0.00	0	0	
	Total	12	0.00	0.00	0	0	
Zinc,mg/L	SW Upstream	3	0.00	0.00	0	0	
	SW Midstream	3	0.00	0.00	0	0	
	SW Downstream	3	0.00	0.00	0	0	
	SW Control	3	0.00	0.00	0	0	
	Total	12	0.00	0.00	0	0	
Magnesium, mg/L	SW Upstream	3	10.31	2.60	7.36	12.28	
	SW Midstream	3	9.39	0.81	8.66	10.26	
	SW Downstream	3	7.27	0.99	6.28	8.27	40
	SW Control	3	2.85	0.60	2.15	3.21	
	Total	12	7.45	3.26	2.15	12.28	
Sodium, mg/L	SW Upstream	3	49.28	20.83	32.18	72.48	
	SW Midstream	3	35.55	29.18	2.18	56.28	
	SW Downstream	3	58.10	8.53	51.34	67.69	-

Parameters	Location	N	Mean	Standard Deviation	Minimum	Maximum	FMEnv. Limits
	SW Control	3	8.19	0.15	8.06	8.36	
	Total	12	37.78	25.21	2.18	72.48	
Calcium,mg/L	SW Upstream	3	0.00	0.00	0	0	
	SW Midstream	3	0.00	0.00	0	0	
	SW Downstream	3	0.00	0.00	0	0	0.005
	SW Control	3	0.00	0.00	0	0	
	Total	12	0.00	0.00	0	0	
Copper, mg/L	SW Upstream	3	0.00	0.00	0	0	
	SW Midstream	3	0.00	0.00	0	0	
	SW Downstream	3	0.00	0.00	0	0	
	SW Control	3	0.00	0.00	0	0	
	Total	12	0.00	0.00	0	0	
Cadmium, mg/L	SW Upstream	3	0.00	0.00	0	0	
	SW Midstream	3	0.00	0.00	0	0	
	SW Downstream	3	0.00	0.00	0	0	
	SW Control	3	0.00	0.00	0	0	
	Total	12	0.00	0.00	0	0	
Manganese, mg/L	SW Upstream	3	0.00	0.00	0	0	
	SW Midstream	3	0.00	0.00	0	0	
	SW Downstream	3	0.00	0.00	0	0	
	SW Control	3	0.00	0.00	0	0	
	Total	12	0.00	0.00	0	0	
Faecal coliform	SW Upstream	3	24.77	14.89	9.3	39	
	SW Midstream	3	33.33	10.02	23	43	
	SW Downstream	3	51.33	10.41	43	63	
	SW Control	3	4.73	3.10	2.7	8.3	NS
	Total	12	28.54	19.66	2.7	63	
Total Heterotrophic Bacteria	SW Upstream	3	0.05	0.02	0.04	0.07	
	SW Midstream	3	0.04	0.02	0.03	0.07	
	SW Downstream	3	0.04	0.01	0.03	0.05	NS
	SW Control	3	0.03	0.01	0.01	0.04	
	SW Upstream	12	0.04	0.02	0.01	0.07	
Total Heterotrophic Fungi	SW Upstream	3	0.03	0.00	0.03	0.03	
	SW Midstream	3	0.05	0.02	0.04	0.07	
	SW Downstream	3	0.03	0.01	0.02	0.04	NS
	SW Control	3	0.01	0.00	0.01	0.02	
	Total	12	0.03	0.02	0.01	0.07	

FMEnv = Federal Ministry of Environment; NS = Not Specified

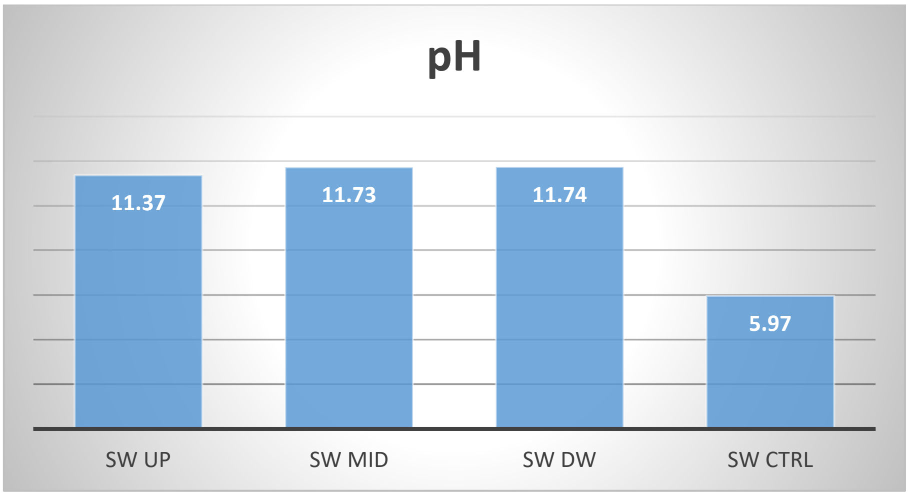

Figure 5: Ph Result for all Sampling Points During Wet Season

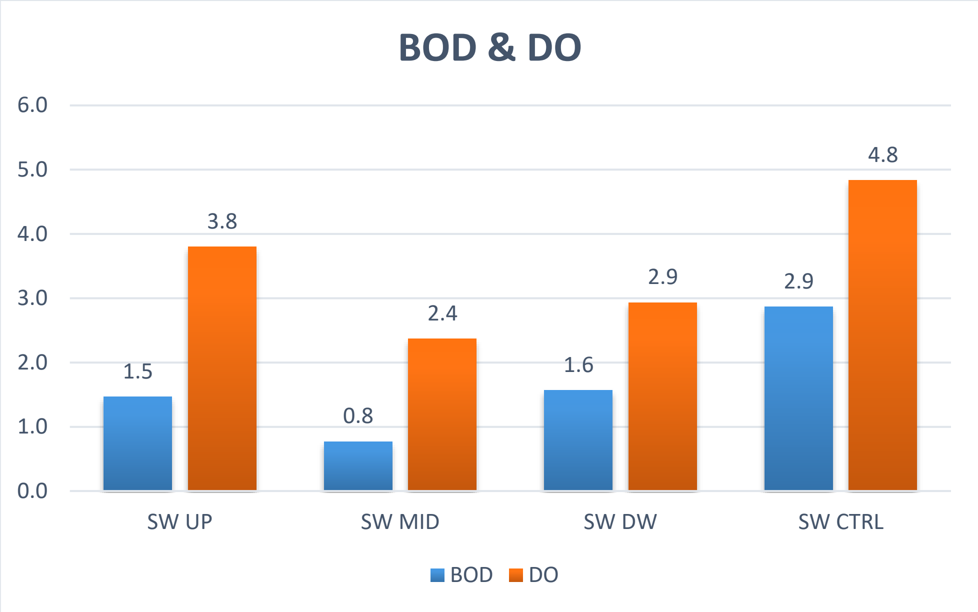

Figure 6: BOD and DO Result for all Sampling Points During Wet Season

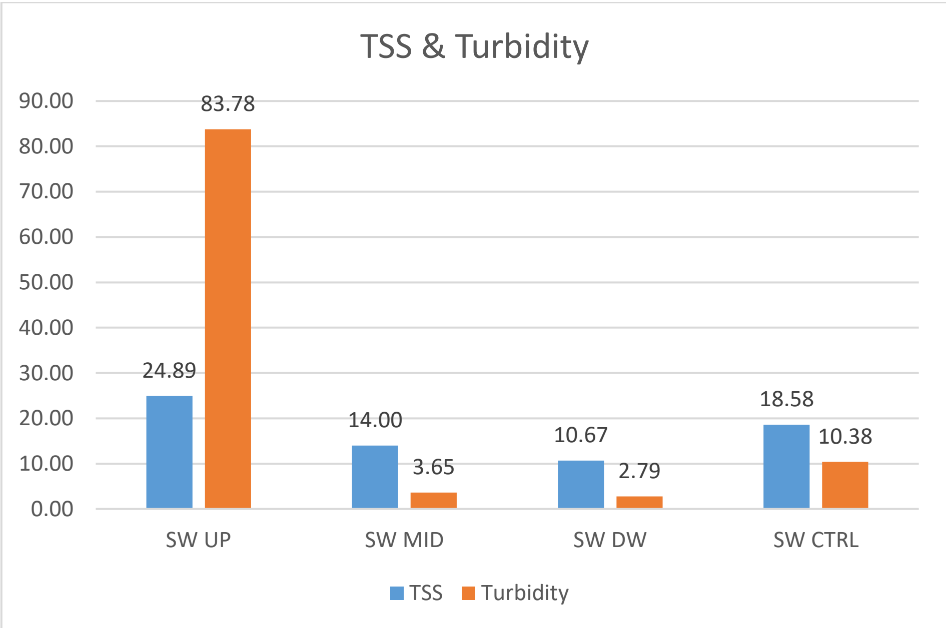

Figure 7: TSS and Turbidity Result for all Sampling Points During Wet Season

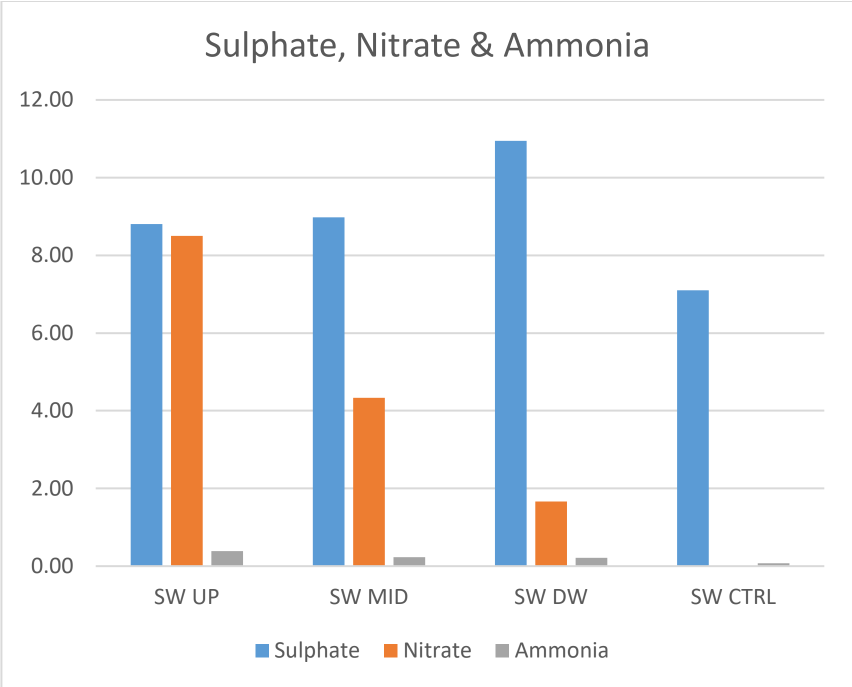

Figure 8: Sulphate, Nitrate & Ammonia Result for all Sampling Points During Wet Season

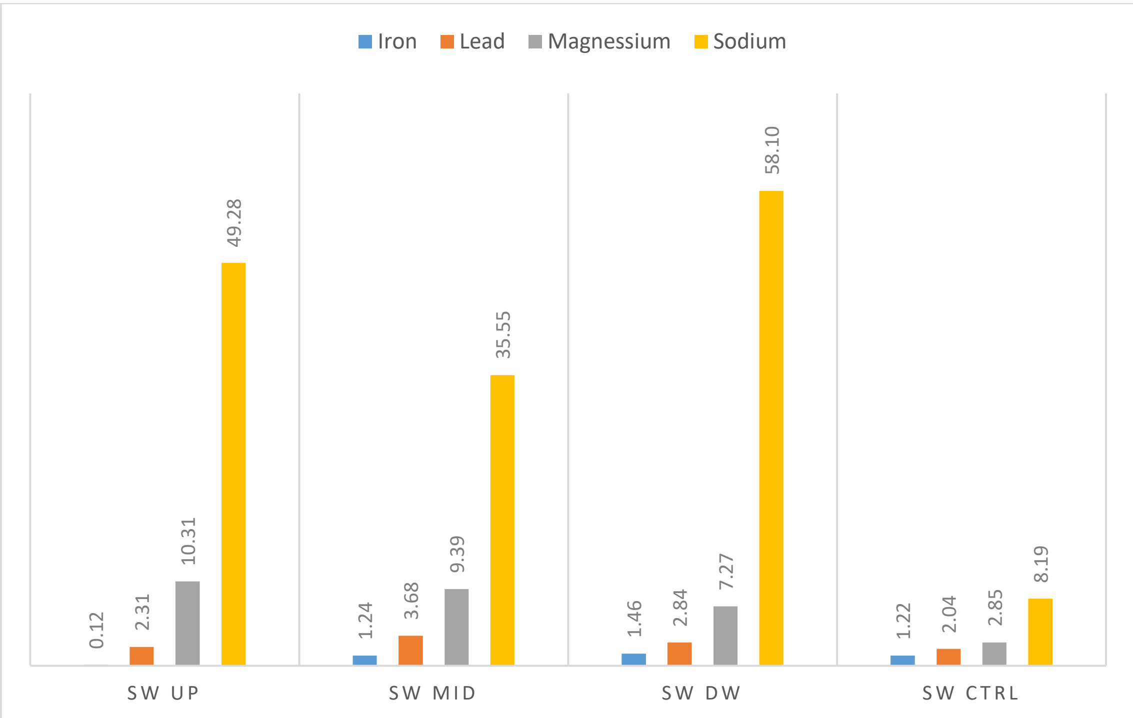

Figure 9: Lead, Iron, Magnesium & Sodium Result for all Sampling Points During Wet Season

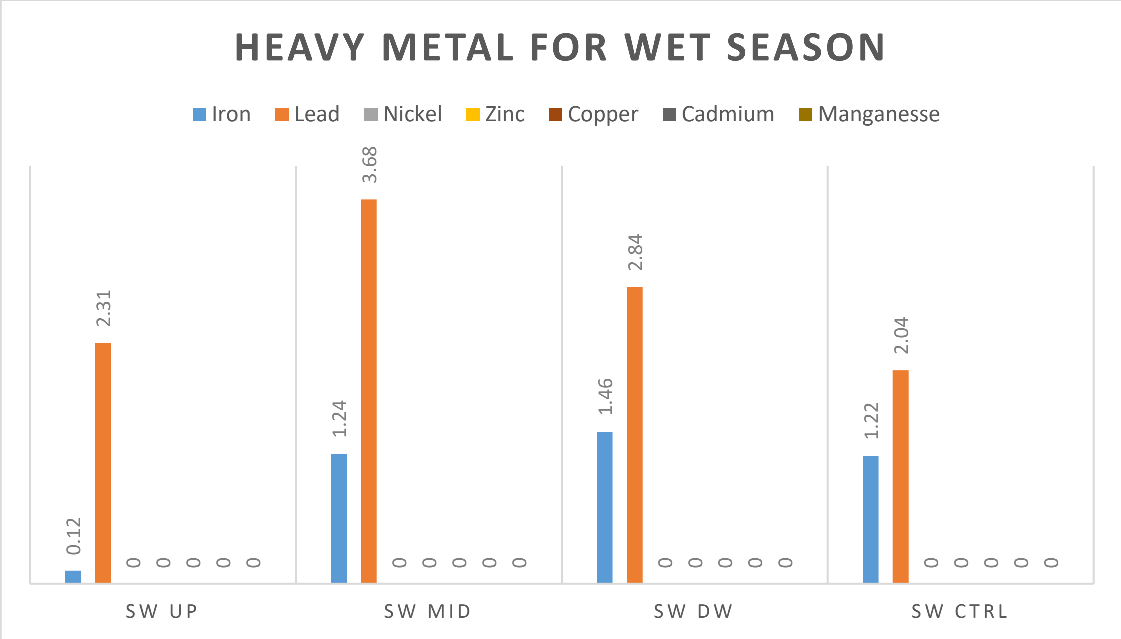

Figure 10: Heavy Metal Result for all Sampling Points During Wet Season

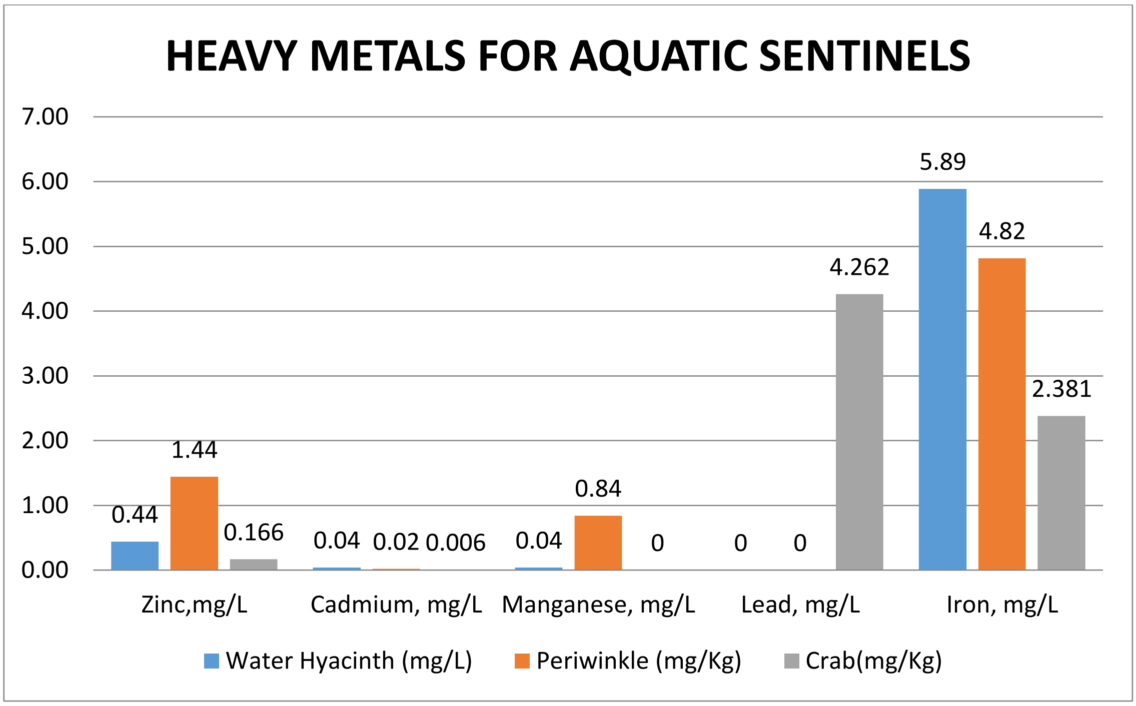

Figure 11: Heavy Metal Result for Aquatic Sentinels for Wet Season

Water Quality

Wet season

The Water Quality Index (WQI) results from the surface water samples collected during the wet season indicate severely degraded water quality across all sampling points as seen in Table 4.6. The WQI values show a progressive deterioration from upstream (124.56) through midstream (134.89) to downstream (138.23), while the control site shows a slightly better but still very poor quality (115.78). This pattern is particularly concerning during the wet season when dilution effects would typically be expected to improve water quality. The elevated WQI values are primarily influenced by high pH levels (>11 in most stations), low dissolved oxygen concentrations (<6 mg/L), and notably high concentrations of heavy metals (particularly lead and iron) exceeding standard limits. The persistence of poor water quality parameters despite wet season conditions suggests significant and continuous pollution sources, as the increased water volume from rainfall has not provided sufficient dilution to improve water quality. This could indicate substantial point source pollution, possibly from industrial discharges, mining activities, or severe erosion during rainfall events carrying pollutants into the water system. The consistently "Very Poor" classification across all sampling points, even during the wet season when water quality typically improves, indicates serious and persistent environmental concerns that require urgent intervention and remediation measures.

Table 5: Water Quality Result for Wet Season

Location	WQI	Water Quality Status
Surface water Upstream	124.56	Very Poor
Surface water midstream	134.89	Very Poor
Surface water downstream	138.23	Very Poor
Surface water control	115.78	Very Poor

Health Risk Assessment

Wet season

The health risk assessment of heavy metals in surface water samples from the Ekpan River during the wet season revealed that Lead (Pb) is the primary metal of concern, with concentrations ranging from 2.04 mg/L at the control point to 3.68 mg/L at the midstream point. However, the Hazard Quotient (HQ) values for Lead (Pb) across all sampling points are below the threshold of 1, indicating no significant non-carcinogenic health risks. For other metals such as Iron (Fe), Nickel (Ni), Zinc (Zn), Copper (Cu), Cadmium (Cd), and Manganese (Mn), the concentrations are below the detection limit of 0.001 mg/L, resulting in negligible exposure doses and HQ values well below 1. This suggests that these metals do not pose significant non-carcinogenic risks.

Regarding carcinogenic risks, Cadmium (Cd) and Nickel (Ni), which are known carcinogens, were also found at concentrations below the detection limit. Consequently, the Incremental Lifetime Cancer Risk (ILCR) values for these metals are below the acceptable limit of 1×10^{-6}, indicating no significant carcinogenic risks.

In summary, while Lead (Pb) is present at relatively high concentrations in the surface water of the Ekpan River during the wet season, it does not currently pose a significant health risk based on the calculated HQ values. The concentrations of other heavy metals are below detectable levels, suggesting minimal risk. However, regular monitoring of the river, particularly for Lead (Pb), is recommended to ensure that contamination levels remain within safe limits and to protect public health.

Table 6: Health Risk Assessment Result for Water Samples During Wet Season

Sampling Point	Metal	Concentration (mg/L)	ED (mg/kg/day)	HQ (Non-Carcinogenic)	ILCR (Carcinogenic)
SW Upstream	Iron (Fe)	0.12	0.000096	0.00014	-
	Lead (Pb)	2.31	0.00185	0.53	-
	Nickel (Ni)	<0.001	<0.000008	<0.0004	<0.000014
	Zinc (Zn)	<0.001	<0.000008	<0.000027	-
	Copper (Cu)	<0.001	<0.000008	<0.0002	-
	Cadmium (Cd)	<0.001	<0.000008	<0.016	<0.000049
	Manganese (Mn)	<0.001	<0.000008	<0.000057	-
SW Midstream	Iron (Fe)	1.24	0.00099	0.0014	-
	Lead (Pb)	3.68	0.00294	0.84	-
	Nickel (Ni)	<0.001	<0.000008	<0.0004	<0.000014
	Zinc (Zn)	<0.001	<0.000008	<0.000027	-
	Copper (Cu)	<0.001	<0.000008	<0.0002	-
	Cadmium (Cd)	<0.001	<0.000008	<0.016	<0.000049
	Manganese (Mn)	<0.001	<0.000008	<0.000057	-
SW Downstream	Iron (Fe)	1.46	0.00117	0.0017	-
	Lead (Pb)	2.84	0.00227	0.65	-
	Nickel (Ni)	<0.001	<0.000008	<0.0004	<0.000014
	Zinc (Zn)	<0.001	<0.000008	<0.000027	-
	Copper (Cu)	<0.001	<0.000008	<0.0002	-
	Cadmium (Cd)	<0.001	<0.000008	<0.016	<0.000049
	Manganese (Mn)	<0.001	<0.000008	<0.000057	-
SW Control	Iron (Fe)	1.22	0.00098	0.0014	-
	Lead (Pb)	2.04	0.00163	0.47	-
	Nickel (Ni)	<0.001	<0.000008	<0.0004	<0.000014
	Zinc (Zn)	<0.001	<0.000008	<0.000027	-
	Copper (Cu)	<0.001	<0.000008	<0.0002	-
	Cadmium (Cd)	<0.001	<0.000008	<0.016	<0.000049
	Manganese (Mn)	<0.001	<0.000008	<0.000057	-

Where HQ means Hazard Quotient; ILCR means Incremental Lifetime Cancer Risk; ED means Exposure Dose

Table 7: Health Risk Assessment Result for Water Hyacinth Samples

Metal	Season	Concentration (mg/L)	ED (mg/kg/day)	HQ (Non-Carcinogenic)	ILCR (Carcinogenic)
Zinc (Zn)	Wet	0.439	0.00035	0.0012	-
Copper (Cu)	Wet	<0.001	<0.000008	<0.0002	-
Cadmium (Cd)	Wet	0.041	0.000033	0.066	0.00020
Nickel (Ni)	Wet	<0.001	<0.000008	<0.0004	<0.000014
Manganese (Mn)	Wet	0.039	0.000031	0.00022	-
Lead (Pb)	Wet	<0.001	<0.000008	<0.0023	-
Iron (Fe)	Wet	5.887	0.0047	0.0067	-

Where HQ means Hazard Quotient; ILCR means Incremental Lifetime Cancer Risk; ED means Exposure Dose

Table 8: Health Risk Assessment Result for Periwinkle Samples

Metal	Season	Concentration (mg/L)	ED (mg/kg/day)	HQ (Non-Carcinogenic)	ILCR (Carcinogenic)
Zinc (Zn)	Wet	1.44	0.00115	0.0038	-
Copper (Cu)	Wet	<0.001	<0.000008	<0.0002	-
Cadmium (Cd)	Wet	0.019	0.000015	0.030	0.000092
Nickel (Ni)	Wet	<0.001	<0.000008	<0.0004	<0.000014
Manganese (Mn)	Wet	0.841	0.00067	0.0048	-
Lead (Pb)	Wet	<0.001	<0.000008	<0.0023	-
Iron (Fe)	Wet	4.817	0.0039	0.0056	-

Where HQ means Hazard Quotient; ILCR means Incremental Lifetime Cancer Risk; ED means Exposure Dose

Table 9: Health Risk Assessment Result for Crab Samples

Metal	Season	Concentration (mg/L)	ED (mg/kg/day)	HQ (Non-Carcinogenic)	ILCR (Carcinogenic)
Zinc (Zn)	Wet	0.166	0.000133	0.00044	-
Cadmium (Cd)	Wet	0.006	0.0000048	0.0096	0.000029
Manganese (Mn)	Wet	<0.002	<0.0000016	<0.000011	-
Lead (Pb)	Wet	4.262	0.00341	0.974	-
Iron (Fe)	Wet	2.381	0.00190	0.0027	-
Nickel (Ni)	Wet	<0.001	<0.0000008	<0.00004	<0.0000014
Copper (Cu)	Wet	<0.003	<0.0000024	<0.00006	-

Where HQ means Hazard Quotient; ILCR means Incremental Lifetime Cancer Risk; ED means Exposure Dose

The health risk assessment of heavy metals in surface water samples from the Ekpan River during the wet seasons reveals notable contamination levels and associated health risks. During the wet season, Lead (Pb) concentrations ranged from 2.04 mg/L at the control point to 3.68 mg/L at the midstream point. Despite these elevated levels, the Hazard Quotient (HQ) values for Lead (Pb) in wet season remained below the threshold of 1, indicating no significant non-carcinogenic health risks. For other metals such as Iron (Fe), Nickel (Ni), Zinc (Zn), Copper (Cu), Cadmium (Cd), and Manganese (Mn), concentrations were consistently below the detection limit of 0.001 mg/L. This resulted in negligible exposure doses and HQ values well below 1, indicating no significant non-carcinogenic risks. Similarly, the Incremental Lifetime Cancer Risk (ILCR) values for Cadmium (Cd) and Nickel (Ni) were below the acceptable limit of 1×10^{-6}in both seasons, suggesting no significant carcinogenic risks. In summary, Lead (Pb) is present at relatively high concentrations in wet season.

Physico-Chemical Parameters

The analysis of physico-chemical, heavy metal, and microbiological parameters of water samples from the Ekpan River in Delta State, Nigeria, during the wet season reveals significant spatial and seasonal variations in water quality, revealing the profound impact of anthropogenic activities and natural processes on the river's ecosystem. The highly alkaline pH values observed upstream, midstream, and downstream during the wet season (ranging from 11.37 to 11.74) contrast sharply with the neutral to slightly acidic control site (5.97), suggesting potential contamination from industrial discharges or natural geogenic processes. Alkaline conditions in aquatic systems are often associated with the discharge of industrial effluents (Lemessa *et al.*, 2023), particularly from industries such as petrochemicals, which are prevalent in the Niger Delta region. This alkaline nature was earlier reported in the findings of Lemessa *et al.*, (2023). Electrical conductivity (EC) and total dissolved solids (TDS) were also elevated upstream, decreasing downstream, indicating higher ionic content and dissolved solids in the upper reaches of the river. This pattern can attributed similar trends in the Niger Delta to industrial and agricultural runoff. Dissolved oxygen (DO) levels were lowest midstream (2.37 mg/L) during the wet season, indicating potential organic pollution, possibly from sewage or industrial effluents, while the control site maintained higher DO levels (4.83 mg/L), reflecting better water quality. According to USEPA (2024), low DO levels are often indicative of organic pollution, as microbial decomposition of organic matter consumes oxygen.

Microbiological parameters revealed significant faecal contamination, particularly during the wet season, with faecal coliform counts highest downstream (51.33 CFU/100 mL), indicating contamination from sewage or animal waste. This is consistent with findings by Adekunle and Eniola (2008), who reported high faecal coliform levels in Nigerian rivers due to inadequate sanitation and waste management practices. The presence of faecal coliforms in aquatic systems is a well-documented indicator of faecal pollution, posing significant risks to human health through waterborne diseases (WHO, 2017). Heterotrophic bacteria and fungi counts were low across all sites during both seasons, indicating minimal microbial activity, but the presence of faecal coliforms underscores the need for improved sanitation and waste management practices to mitigate health risks associated with waterborne pathogens.

Other critical parameters, such as chemical oxygen demand (COD) and biochemical oxygen demand (BOD), further illustrate the extent of organic pollution in the river. During the wet season, COD levels were exceptionally high upstream and midstream (721.33 mg/L and 749.33 mg/L, respectively), indicating significant organic pollution, likely from industrial or domestic wastewater. High COD levels are often associated with the discharge of organic pollutants from industrial and municipal sources. Although BOD levels were relatively low (1.67 mg/L), the high COD values suggest the presence of non-biodegradable organic compounds, which are resistant to microbial degradation and can persist in aquatic environments. Nutrient levels, particularly nitrate and phosphate, were elevated upstream during both seasons, pointing to agricultural runoff or wastewater discharge as potential sources of contamination. Elevated nutrient levels in aquatic systems are often linked to agricultural activities, as fertilizers and manure contribute to nutrient loading, leading to eutrophication and degraded water quality.

Concentration and Distribution of Heavy Metals

The study identified elevated concentrations of heavy metals, particularly lead (Pb) and iron (Fe), in both water and Aquatic sentinels from Ekpan River. The concentrations of these metals far exceeded the WHO permissible limits for surface water, which are 0.01 mg/L for lead and 0.3 mg/L for iron (WHO, 2017). This however different from the findings of Ikpesu *et al.,* (2021) whose level of heavy metals detected in the water sample were lower than that of the maximum acceptable limit. Howbeit, these alarming levels suggest significant contamination from both geogenic and anthropogenic sources, such as agricultural runoff, and urban wastewater, run-of from rusted metallic pipes at the refinery scrap metal dump sites and the refinery sludge lagoon (Emoyan *et al.,* 2006).

The spatial distribution of heavy metals revealed higher concentrations downstream, particularly for lead and iron. This pattern is consistent with studies in other river systems, where downstream areas often act as sinks for pollutants due to sedimentation and reduced flow velocity (Abbas *et al.,* 2023). The high turbidity and total dissolved solids (TDS) observed downstream further support this finding, as particulate matter can adsorb heavy metals and transport them over long distances (Liu *et al.,* 2024).

Health Risks Associated with Heavy Metal Contamination

The health risk assessment revealed that lead (Pb) and cadmium (Cd) are the primary metals of concern in Ekpan River. Although the hazard quotient (HQ) values for lead in water samples were below the threshold of 1. however, the concentrations in biota, particularly periwinkle, exceeded safe limits. This suggests that consuming contaminated periwinkle could pose significant non-carcinogenic health risks, particularly for local communities that rely on the river for food and livelihood.

Cadmium, a known carcinogen, also showed concerning levels in water hyacinth, The wet season, characterized by higher rainfall and increased water flow, typically dilutes pollutants and reduces their concentration (Makuwa, 2022). However, the study found that during the wet season, heavy metal concentrations in Ekpan River remained alarmingly high in some parameters, suggesting continuous and significant pollution inputs. This is consistent with findings in other river systems, where industrial discharges and agricultural runoff contribute to persistent contamination regardless of seasonal variations (Pakoksung *et al.,* 2025).The incremental lifetime cancer risk (ILCR) for cadmium exceeded the acceptable limit of 1×10^{-6}, indicating a potential carcinogenic risk for individuals exposed to contaminated water or biota over prolonged periods (USEPA, 2011). These findings are consistent with studies in other regions, where cadmium contamination has been linked to kidney damage, bone fractures, and cancer (Yan & Allen 2021).

Public Health Impact of the Findings

Health Risks from Heavy Metal Exposure

The study revealed that the concentrations of lead (Pb) and iron (Fe) in Ekpan River far exceeded the WHO permissible limits for surface water, which are 0.01 mg/L for lead and 0.3 mg/L for iron (WHO, 2017). Lead, in particular, is a toxic metal with no known safe level of exposure, and its presence in the river poses significant risks to human health due to the consumption of the aquatic species from the river. Chronic exposure to lead(pb) can lead to neurological damage, developmental delays in children, cardiovascular diseases, and kidney dysfunction (Heidari, 2022).

Vulnerable Populations

The public health impact of heavy metal contamination is particularly severe for vulnerable populations, such as children, pregnant women, and the elderly. Children are especially susceptible to the toxic effects of lead, as their developing nervous systems are more sensitive to its damaging effects (CDC, 2024). Chronic exposure to lead in children can result in reduced IQ, learning disabilities, and behavioral problems (Heidari, 2022). Pregnant women exposed to heavy metals may experience complications during pregnancy, including low birth weight and premature birth(Howe *et al.,* 2020), while the elderly are at higher risk of cardiovascular diseases and kidney dysfunction due to prolonged exposure (Dare *et al.,* 2019).

Socioeconomic Implications

The contamination of Ekpan River also has significant socioeconomic implications for local communities. Many residents rely on the river for fishing, agriculture, and domestic use, and the presence of heavy metals in the water and biota threatens their livelihoods. Consuming contaminated fish and periwinkle can lead to food insecurity and economic losses (Abera, & Adimas, 2020), as local markets may reject contaminated products. Additionally, the cost of treating waterborne diseases and heavy metal poisoning can place a significant financial burden on already resource-constrained households ((Dare *et al.,* 2019).

CONCLUSION

This study has delivered a comprehensive understanding of the concentration, distribution, and health risks posed by heavy metal contamination in the Ekpan River, Delta State. The findings reveal substantial levels of heavy metals in the water and aquatic sentinel from the river, underscoring the pronounced influence of anthropogenic activities on the river's ecosystem. Through health risk assessment, specific heavy metals were identified as primary concerns, with both non-carcinogenic and carcinogenic risks highlighted particularly for vulnerable groups such as children and pregnant women. These results underscore the urgent necessity for targeted interventions to mitigate the health risks associated with heavy metal exposure.

Furthermore, the study illuminates the limitations of current environmental regulations in addressing pollution in the Ekpan River, pointing to persistent gaps in enforcement and implementation. By analyzing water quality, this research offers a holistic perspective on the scope of contamination and its implications for public health and local livelihoods. The findings advocate for stricter enforcement of environmental policies, improved waste management practices, and enhanced public awareness to minimize exposure to heavy metals. Additionally, the study emphasizes the importance of seasonal monitoring and adaptive management strategies to effectively address the dynamic nature of contamination in river systems.

In conclusion, this research makes a valuable contribution to the fields of environmental science and public health by providing a foundation for evidence-based interventions aimed at safeguarding the ecological integrity of the Ekpan River and protecting the health of surrounding communities. The study serves as a critical reminder of the interconnectedness of environmental health and human well-being, highlighting the need for sustainable practices to mitigate the impacts of heavy metal pollution and ensure a safer, healthier future for all.

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