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Health Risk Assessment of Selected Heavy Metals along the Ethiope River in Delta State, Nigeria

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Abstract

Human activities and processes degrade water quality. Early detection of threats from contaminated water can protect all aspects of life and habitat degradation. The concentration and health risk assessment of selected heavy metals (Cu, As, Ni, Cr, Pb, Hg, and Cd) were investigated in the surface water samples of River Ethiope. Water samples were collected along its banks at the following towns; Umuaja (SWI), Ebedie (SW2), Abraka (SW3), Sapele (SW4) and Ughara (SW5) axis during the rainy season; June to October, 2023. The heavy metal contents, heavy metal pollution index (HPI) and risk assessment were determined using standard methods of analysis. Descriptive analysis and analysis of variance were employed for data interpretation of the results. The results revealed that the mean concentration values of Cu, Pb and Cr ranged from 0.012 mg/l to 0.020 mg/l, 0.004 mg/l to 0.008 mg/l and 0.004 mg/l to 0.008 mg/l respectively. The observed highest concentrations of Cu (0.0133 mg/l), Pb (0.007mg/l) at locations SW4, SW5 and SW3 may be attributed to the anthropogenic activities including domestic and mainly industrial wastewater discharges and runoff. All metals analyzed were within the WHO permissible limits for portable water. Heavy metal pollution index (HPI) was computed for stations SW3, SW4 and SW5, however, none for SW1 and SW2 as the parameters of interest were not detected. The HPI values 5.612, 10.750 and 7.796 for stations SW3, SW4 and SW5 respectively were below 100 which showed a low level of heavy metal contamination and will not adversely affect health. Estimated human health risk from each metal contamination from adsorption and drinking the water of River Ethiope gave each of the hazard quotient (HQ) and hazard index (HI) values of < 1. It is therefore obvious from the results that the observed values were below the safe limit of one, suggesting that there was no potential adverse risk in water sampled via direct ingestion or dermal adsorption to the inhabitants.

Keywords: Assessment, water quality, concentration, health risk, heavy metals, River Ethiope.

Introduction

Water resources and quality are critical to human health, economic development, and the environment [1]. Global freshwater use, including reservoirs, municipalities, industries and agriculture, has grown rapidly over the past 100 years. However, water quality deterioration has become a problem worldwide [2].

Water quality may be assessed based on its physico-chemical and biological characteristics because of increasing industrialization, urbanization and anthropogenic activities around water bodies [3]. Heavy metals have the property of environmental persistence and bioaccumulation, and these heavy metals enter the aquatic system through various routes. These heavy metals not only impair the quality of the aquatic ecosystem but also human health [4]. However, some of these metals show high toxicity, and even at low concentrations, such as lead, cadmium and mercury [5].

Exposure to heavy metals causes retardation, neurotoxicity, kidney damage, leading to the development of different cancers, liver and lungs damage. It can also lead to chronic and acute toxicity and there are even chances of death in case of huge amount of exposure [6].

In 2013, UNICEF and WHO estimated that a staggering 768 million people do not have access to safe drinking water causing hundreds of thousands of children to fall sick and die each year. Most of the people without access to safe water are poor and live in remote rural area or urban [7].

River Ethiope rises from Umuaja and flows through Ebedei, Abraka, Eku, Okpara, Jesse, Sapele, among others for over 96.6 km into the Atlantic Ocean. The inhabitants of these settlements depend on the water from the river for domestic purposes, recreation, transportation, fishing, and industrial purposes. However, a good number of researchers have reported the contamination of River Ethiope as a result of geologic and anthropogenic activities [8, 9]. In light of these activities, the water is prone to contamination and may not be safe for drinking [10]. Hence, regular and sustained monitoring is imperative to mitigate ecological and health hazards.

Water quality monitoring has one of the highest priorities in environmental protection policy [11]. The classification, modeling and interpretation of monitoring data are the most important steps in the assessment of water quality.

Multivariate statistical methods including factor analysis have been used successfully in hydrochemistry for many years. Surface water, ground water quality assessment and environmental research employing multivariate techniques are well described in literatures. Multivariate statistical approaches allow deriving hidden information from the data set [12]. A wide variety of inorganic toxic substances may be found in water in very small or trace amounts. Even in trace amounts, they can be a danger to public health [13]. Some toxic substances occur from natural sources but many others occur due to industrial activities and/or improper management of hazardous waste. They can be divided into two groups: metallic compound and nonmetallic compound [14].

Water quality is an important step of knowing the suitability of water in relation to natural quality and health effects. To determine water quality, scientists first measure and analyze characteristics of the water such as temperature, dissolved mineral content, and number of bacteria. The selected characteristics are then compared to numeric standards and guidelines to decide if the water is suitable for a particular use.

Materials and Methods

Study Area

River Ethiope lies within the Niger Delta Basin in the Southern part of Nigeria, on the West African Coast region. It covers a distance of 96.6 km and flows into the Atlantic Ocean. The river is located between latitudes $5^0 55^1$N and $5^0 45^1$N, and longitudes $5^0 60^1$E and $6^0 10^1$E at the equatorial region. The river takes its origin from Umuaja in Ukwuani Local Government Area, Delta State. The geographical coordinates of the sampling points are shown in Table 1. The river is shared by four local government councils namely; Ukwuani, Ethiope East, Okpe and Sapele. Inhabitants of the surrounding villages rely on the river for domestic water supply, washing, fishing, sand mining and inter-village transportation. Five designated stations were surveyed along the Ethiope River watercourse [15].

Table 1 Geographical Coordinates of the Sample Points

Sample Site Descriptions	Abr.	Nort	East
Umuaja	SW1	05º56'31.52148"	6º13'57.68796"
Ebedei	SW2	5º53'13.17732"	6º11'35.16648"
Abraka	SW3	5º47'22.92612"	6º5’14.262"
Sapele	SW 4	5º52'22.16244"	5º43'11.58168"
Oghara	SW 5	5º55'18.04692"	5º41'55.78836"

Samples Collection and Preservation

Samples were collected from Ethiope River at the following towns: Umuaja, Ebedie, Abraka, Sapele and Ughara axis during the rainy season; June, August and October as shown in Figure 1. A total of 30 water samples were collected, made up of 10 samples in each month, comprising five sampling sites. The grab sampling technique was employed for the collection of all the water samples at about 1m below the surface. Water samples were collected into plastic bottles. All collected samples were transported in ice-chest to the laboratory and were preserved using HNO_3.

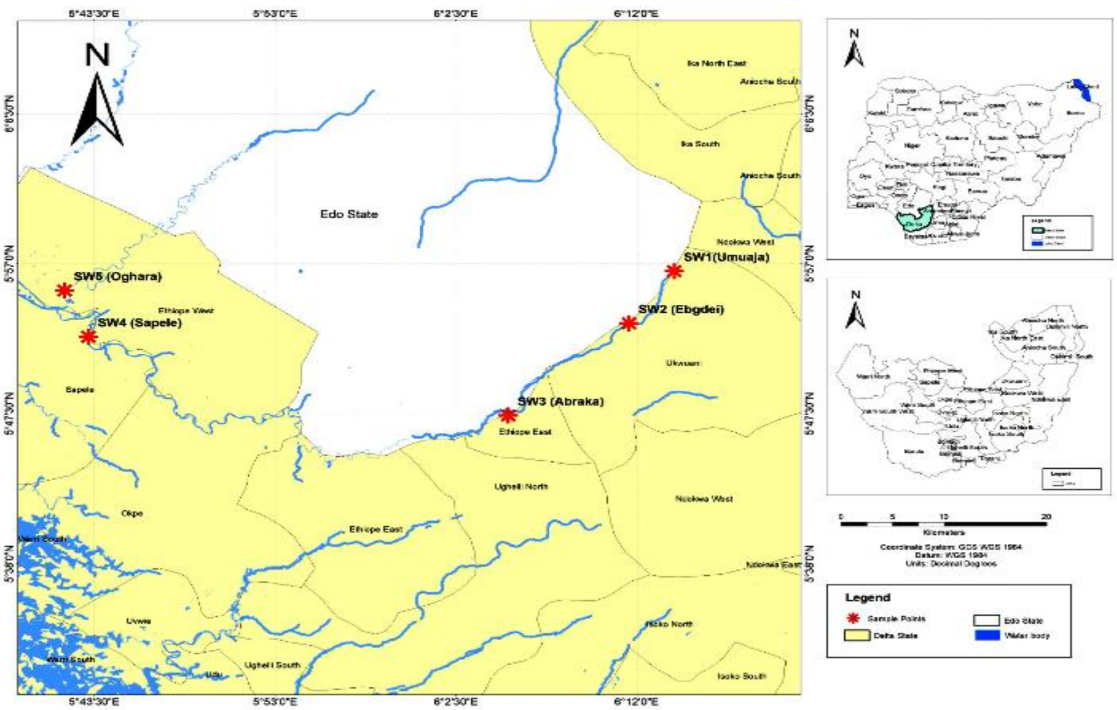

Fig. 1: Map of the Study Area

Laboratory Methods

The samples after collection were taken to Endpoint Laboratories and Equipment Limited, a government certified laboratory located in Port Harcourt for the various analyses of the surface water samples. Analysis of samples were guided by Federal Ministry of Environment guidelines and standard methods such as APHA, ASTM, EPA and API standard methods. The following are the description of the standard methods for the various analyses carried out on the surface water samples.

Heavy Metal Pollution Index

Contamination status of water samples was determined using the heavy metal pollution index (HPI). Pollution index was used to determine the combined effect of each heavy metal on the overall water quality [16,17]. In order to assess the suitability for human consumption [18]. The HPI represents the total quality of water with respect to heavy metals, and it is calculated by assigning a weightage (Wi) for individual parameter which is a value between 0 and 1 reflecting the relative importance of the individual quality consideration. This study used the WHO standards permissible value for drinking water. The HPI was calculated using the following equations [19, 20, 21]. HPI is calculated using formula below;

$$\boldsymbol{HPI = \frac{\sum_{i=1}^{n} W_i Q_i}{\sum_{i=1}^{n} W_i}} \qquad (1)$$

$$\boldsymbol{Q_i = \sum_{i=1}^{n} \frac{v_i}{S_i} \times 10} \qquad (2)$$

Where Qi is the sub index of ith parameter, Wi is the unit weight of the ith parameter and n is the number of parameters considered as shown in

Table 2. In equation 2, Vi is the monitored value of metal of ith parameter and Si the standard value. HPI < 100 means there is a low level of heavy metal contamination and does not adversely affect health. If HPI = 100, the risk is at limit and may adversely affect health, while HP1> 100 indicates the water cannot be used for drinking and is not suitable for consumption [22].

Table 2: Standard values (mg/l) for the indices (HPI) computation [23]

Metals	Wi	Si
As	0.1	50
Cu	0.0005	2000
Pb	0.1	100
Cd	0.33	5
Hg	0.167	6
Ni	0.01428	70

Health Risk Assessment

Hazard Quotient and Hazard Index

In this study, the health risk assessment method by USEPA was used, while the risk of trace elements in water in terms of human health was observed. It is usually taken into account the amount ingested and absorbed through dermal. Therefore, average daily dose (ADD) obtained from direct digestion (ADDing) and dermal absorption (ADDderm), were calculated with modified equations (3) and (4) suggested by USEPA [24].

$$\mathbf{ADD_{ing}} = \frac{\mathbf{C_{water} \times IR \times ABS_g \times Ef \times ED}}{\mathbf{BW \times AT}} \quad (3)$$

$$\mathbf{ADD_{derm}} = \frac{\mathbf{C_{water} \times SA \times K_p \times ET \times EF \times ED \times CF}}{\mathbf{BW \times AT}} \quad (4)$$

Where ADD_{ing} shows average daily dose by ingestion and ADD_{derm} shows average daily dose by dermal, μg/kg/d; Cwater reveals concentration of the metals in surface water, $\frac{\mu g}{L}$; IR depicts ingestion rate (L/d), in this study 2 for adult and 0.64 for children; EF stands for exposure frequency, in this study, 365d/d; ED shows exposure duration (years), in this study 70 for adults and 6 for children; BW indicates average body weight (kg), in this study 70 for adults and 20 for children, AT shows average time (d), in this study 25,550 for adults and 2190 for children; SA reveals exposed skin area (cm^2), in this study, 18000 for adults and 6,600 for children; ABSg was the gastrointestinal absorption factor, which is dimensionless. Kp indicates dermal permeability coefficient in water (cm/h); ET is the exposure time during bathing and shower, in this study 0.6h/D; CF is the unit conversion factor, IL/1,000cm^3 [25]. The possible non-carcinogenic risks of heavy metals ingested and absorbed dermally were calculated and evaluated for children as well as adults. The non-carcinogenic risk was calculated with risk hazard quotient formula (HQ) through dividing average daily dose (ADD) by reference dose (RFD) [26]. HI represent total amount of HQs and potential non-carcinogenic formed by all heavy metals. HQ and HL were calculated with the equations below.

$$\mathbf{HQ} = \frac{\mathbf{ADD_{ing}/ADD_{dermal}}}{\mathbf{RFD_{ing}/RFD_{dermal}}} \qquad (5)$$

$$\mathbf{HI} = \sum\left(\mathbf{ADD}_{\mathbf{ing}} + \mathbf{ADD_{dermal}}\right) \qquad (6)$$

If HI, HQ>1, it is probable that there are adverse effects on human health originated from heavy metal. However, if HI, HQ<1, it means no negative effect to health [27].

Multivariate Statistical Methods

The data collected were analyzed for the significant differences (p<0.05) by one-way Analysis of Variance (ANOVA) using computer statistical package for social science (SPSS) 15.0 for windows software.

Results and Discussion

Heavy Metals

The values of Cu, Pb, Cr and Ni in the study area were below limit compared to the WHO standard, this also corresponds with report of many researchers that investigated Warri Rivers [28,29,30]. In Table 3, the mean concentrations of As, Cu, Pb, Cd, Hg, Cr, Ni at each sampling locations are shown. It was observed that some of the metals were only detectable in SW3, SW4 and SW5. The observed highest average concentrations of Cu (0.0133 mg/l), Pb (0.007mg/l) at locations SW4, SW5 and SW3 may be attributed to the anthropogenic activities including domestic and mainly industrial wastewater discharges and runoff. All metals analyzed were within the WHO permissible limits for portable water.

Table 3: Heavy Metals in Water Samples

Parameters	SW1	SW2	SW3	SW4	SW5	WHO 2011 Limit
Arsenic (mg/l)	ND	ND	ND	ND	ND	0.01
Copper (mg/l)	ND	ND	0.012±0.001	0.020±0.002	0.015±0.005	2
Lead (mg/l)	ND	ND	0.004±0.001	0.008±0.001	0.006±0.002	0.01
Cadmium (mg/l)	ND	ND	ND	ND	ND	0.003
Mercury (mg/l)	ND	ND	ND	ND	ND	0.001
Chromium (mg/l)	ND	ND	0.004±0.001	0.008±0.000	0.005±0.001	0.05
Nickel (mg/l)	ND	ND	ND	ND	0.005±0.000	0.02

Tips: Values are represented as mean ± SD. Values in the same row with the same letter are not statistically different from each other at a significance level of $p>0.05$

Heavy Metal Pollution Index

The results from the calculations of Heavy Metal Pollution Index (HPI) are given in Table 4. The HPI values 5.612, 10.750 and 7.796 for stations SW3, SW4 and SW5 respectively were below 100 which showed a low level of heavy metal contamination and do not adversely affect health. Heavy metal pollution index calculations were computed for stations SW3, SW4 and SW5 as the parameters were none detectable in stations SW1 and SW2. This result agreed with that reported by Nguyen [31].

Table 4: The results and the classification of HPI for stations SW3, SW4 and SW5

Location	Qi*W	HPI	Classification
SW3	4.1068667	5.61216	Low level of contamination
SW4	7.8669917	10.75049	Low level of contamination
SW5	5.7049083	7.795934	Low level of contamination

Health Risk Assessment

In Table 5, the results indicate that the hazard quotient through ingestion (HQ_{ing}) of water from stations SW3, SW4 and SW5 for all the metals were less than one (<1) for both adults and children. The health risk assessment calculations were computed for stations SW3, SW4 and SW5 as the parameters were none detectable in stations SW1 and SW2. The HI_{ing} values for adult were SW3 (0.0147), SW4 (0.0271) and SW5 (0.0193), while SW3 (0.00049), SW4 (0.00091) and SW5 (0.00062) values for adult HI_{derm}. The H_{Iing} values for children were SW3 (0.0131), SW4 (0.0242) and SW5 (0.0173), while SW3 (0.00049), SW4 (0.00091) and SW5 (0.00062) values for children HI_{derm}. This indicates that these metals may have no health threat. The hazard quotient through dermal adsorption (HQderm) values were also found to be less than one (<1) which mean that dermal adsorption of the metals may have no health threat. The health hazard indices (HI) on exposure to water from river Ethiope through ingestion and dermal contact for adults and children are less than one (<1). It is therefore obvious from the results that the observed values are below the safe limit of one, which means that there was no potential adverse risk in water sampled via direct ingestion or dermal adsorption to the inhabitants. These results were in close agreement to those reported by Uwah for adults and children from Uruan River [32]. The HI_{ing} and HI_{derm} of each sample was < 1, implying that noncarcinogenic adverse effect due to each of the exposure pathway is negligible.

Table 4: The Health Hazard Indices (Hling and Hlderm) of the Stations (SW3, SW4 and SW5) for Adults and Children

	Hazard Index Ingestion (HIing)		Hazard Index Dermal (HIderm)	
Station	Adults	Children	Adults	Children
SW3	0.014714921	0.01313832	0.000486367	0.0006242
SW4	0.02712419	0.02421803	9.06E-04	0.0011628
SW5	0.019346413	0.01727358	0.00061549	0.0007899

Conclusion

The outcome of this research revealed that some of the analyzed parameters (Cu, Pb and Cr) in the surface water were higher at the downstream samples (SW3, SW4 and SW5) than the upstream samples (SW1 and SW2). The HPI for all the stations were below 100 which showed a low level of heavy metal contamination and may not adversely affect health. The hazard quotient through ingestion (HQing) of water from the five stations for all the metals were less than one (<1) for both adults and children. This indicated that these metals may have no health threat. The health hazard indices (HI) on exposure to water from river Ethiope through ingestion and dermal contact for adults and children were less than one (<1).

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