

# Hydrogeochemical Assessment of Heavy Metal Contamination and Groundwater Quality in The Vicinity of A Landfill Site in Rumuola, Obio/Akpor, Rivers State, Nigeria

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*Abstract- Rapid urbanization and indiscriminate wastes disposal in the peri-urban environments of the Niger Delta have created a serious concern about the quality of shallow aquifer systems, which are sources of potable water for poor and marginalized communities in the area without access to treated public water supplies. In this study, a hydrogeochemical approach was employed to evaluate the quality of groundwater and surface water in Rumuola, Obio/Akpor Local Government Area, Rivers State, Nigeria, with specific focus on the potential impacts of a stagnant water body resulting from a landfill on the physicochemical and heavy metal constituents of underlying borehole aquifers in the study area. A total of eight borehole sites were surveyed, and water samples were collected from the stagnant water body, operational boreholes, and a bottled water sample as a control. Water samples were subjected to analyses for pH, electrical conductivity (EC), total dissolved solids (TDS), turbidity, total suspended solids (TSS), sulphate, nitrate, phosphate, biochemical oxygen demand (BOD), chemical oxygen demand (COD), and ten heavy metals, namely, Manganese (Mn), Zinc (Zn), Lead (Pb), Cadmium (Cd), Nickel (Ni), Chromium (Cr), Sodium (Na), Potassium (K), Calcium (Ca), and Magnesium (Mg). The direction of the groundwater flow was determined using the hydraulic head analysis of the water table using Surfer 8 software. It was observed that the groundwater flow direction lies in the south to south-east direction. It was also observed that the concentration of the analyzed heavy metals present in the groundwater samples was below the permissible limits of the World Health Organization (WHO) for water meant for human consumption. However, the stagnant water body recorded a high level of turbidity at 15.20 NTU, a high level of COD at 57.60 mg/L, and a high EC level at 186.00  $\mu\text{S}/\text{cm}$  compared to the groundwater samples. It was also observed that the groundwater quality lies within the acceptable limits using pollution indices such as the Heavy Metal Pollution Index (HPI) and the Contamination Factor (CF) for the groundwater samples, whereas the stagnant water body recorded a moderate level of heavy metal*

*concentration. These results serve as a precursor to the environmental monitoring program to be conducted in the near future in the Niger Delta area, which is undergoing rapid urbanization.*

**Keywords:** Groundwater Quality; Heavy Metal Contamination; Hydrogeochemistry; Landfill Leachate; Niger Delta; Pollution Indices; Rumuola

## I. INTRODUCTION

The issue of accessing potable water of satisfactory quality is one of the major public health concerns within the sub-Saharan Africa region, particularly within rapidly developing cities along the coastline where groundwater is identified as the main source of potable water for a large percentage of the population (Amadi et al., 2012; Egbueri & Agbasi, 2022). The combined effect of petroleum activities and uncontrolled municipal waste disposal has led to a high level of vulnerability to contamination by a wide range of chemical species, particularly heavy metals within the Niger Delta region of Nigeria (Edori & Kpee, 2017; Nwankwoala & Udom, 2011).

Groundwater is stored within the pore space of an aquifer and has traditionally been perceived as more protected from anthropogenic contamination than surface water (Nwajei et al., 2012). According to Aiyesanmi et al. (2004), groundwater is identified as the largest reservoir of potable water available to rural communities within Nigeria due to the process of natural filtration during infiltration into the saturated zone of an aquifer. However, this protection is dependent on the quality of the vadose zone above the saturated zone and the quality of land use activities within the surrounding areas (Obasi & Akudinobi,

2020). Under conditions of high leachate generation from waste disposal sites, industrial activities, and poor waste disposal practices within an aquifer where permeable geology is present within the unsaturated zone, there is an appreciable chance of groundwater contamination by heavy metals (Okonkwo & Nwankwoala, 2021).

Heavy metals comprise a group of water contaminants of special concern because they are non-biodegradable, bioaccumulative in the bodies of aquatic organisms and mammals, and possess a capacity to be toxic at concentrations that might be detectable even before the onset of symptoms of exposure to these waterborne pathogens (Yu, 2005; Tchounwou et al., 2012). Major routes of heavy metal entry into water resources comprise weathering of natural rocks, geogenic dissolution, mining activities, atmospheric precipitation, urban storm water runoff, and leachates from poorly managed waste disposal sites (Barakat, 2011; Egbueri, 2018).

In Rumuola, within the Obio/Akpor Local Government Area of Rivers State, the construction of the New Rumuola Link Road led to the excavation and subsequent flooding of a low-lying area that over time developed into a stagnant water body. Over the years, the water body has been a receptacle for domestic wastes, organic matter, and potentially toxic substances. However, the water body has been a source of water for the local inhabitants who continue to explore the shallow aquifers within the area. Some people also harvest fish from the water body. Despite the known ecological sensitivity of the area, no study of the water quality of the area had been conducted to determine the concentration of heavy metals within the water body and the degree to which the water body might be affecting the water quality of the groundwater resources within the area.

This study was therefore designed to address this knowledge gap by: (1) characterizing the physicochemical parameters and heavy metal concentration of water samples from the landfill water body, adjacent boreholes, and a commercially sourced control sample; (2) determining the direction of groundwater flow through hydraulic head analysis; (3) comparing all measured parameters to the WHO

(2017) water standards; and (4) calculating pollution indexes to determine the level of heavy metal pollution and health implications.

## II. STUDY AREA

The study area is located along the New Rumuola Link Road in Rumuola, Obio/Akpor Local Government Area, Rivers State, Nigeria, at Latitude 4°49'59"N and Longitude 7°00'17"E, as shown in Figure 1. It falls in the coastal plain sands of the Niger Delta, a sedimentary basin characterized by Tertiary to Quaternary fluvio-deltaic deposits predominantly of unconsolidated sands, silts, and clays (Nwankwoala & Udom, 2011). Hydrogeologically, the shallow aquifer in this area is hosted in medium to coarsely grained sands of the Benin Formation, a geologic unit of the Coastal Plain sands of the Niger Delta, which is the most exploited aquifer unit in Rivers State (Amadi et al., 2012).

The study area has low-lying gently undulating topography, with a range of 21 to 33 m above the mean sea level, as measured in the field. The area has an equatorial climate characterized by a bimodal rainfall pattern, with rainfall of more than 2,400 mm annually, thereby facilitating quick groundwater recharge in the shallow aquifers, although it can lead to surface runoff and lateral migration of contaminants from waste disposal sites into the drainage channels (Okonkwo & Nwankwoala, 2021). The stagnant water body under investigation is a depression created during road construction that has since served as a repository for organic and inorganic refuse, and which has been informally exploited as a fish pond by adjacent residents.

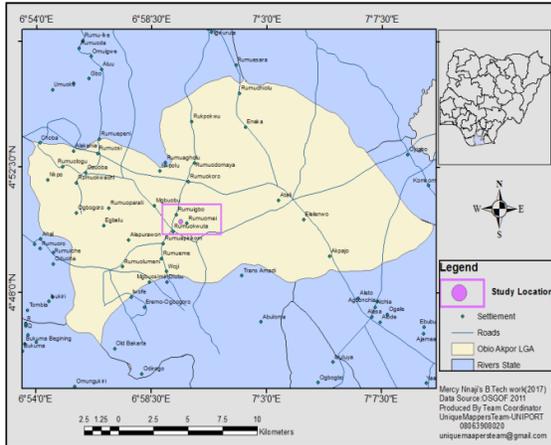


Figure 1. Study location map showing sampled boreholes and the landfill water body in Obio/Akpor Local Government Area, Rivers State, Nigeria. Base map data derived from OSGOF (2011); produced using ArcGIS 10.3.

### III. MATERIALS AND METHODS

#### 3.1 Field Sampling Design

Eight borehole locations were selected within the study area based on their spatial distribution relative to the stagnant water body and along the inferred direction of groundwater flow. An additional sample was collected from the stagnant water body itself, and a commercially sourced, sealed bottled water sample was used as a control. Sampling was conducted during the dry season (January–February) to minimize the influence of rainfall dilution and to represent worst-case hydrogeochemical conditions associated with peak anthropogenic activity. The spatial coordinates, surface elevations, and static water levels of all borehole locations were measured using a calibrated GPS unit (Garmin GPSMAP 64) and a calibrated water level meter respectively (Table 1).

Table 1. Field records obtained from borehole locations in the study area including geographic coordinates, surface elevation, water table depth, and computed hydraulic head.

S/N	Latitude (N)	Longitude (E)	Surface Elevation (m)	Water Table Depth (m)	Hydraulic Head (m)
1	04°58'21"	006°44'69"	21	1.26	19.74
2	04°50'11"	006°59'054"	21	2.54	18.46
3	04°50'13"	007°00'001"	23	2.28	20.72
4	04°50'12"	007°00'007"	21	2.34	18.66
5	04°50'10"	007°00'010"	31	3.09	27.91
6	04°50'09"	007°00'014"	33	3.26	29.74
7	04°49'57"	007°00'017"	31	3.82	27.18
8	04°49'29"	007°00'021"	30	2.73	27.27

#### 3.2 Sample Collection and Preservation

Water samples were collected in pre-cleaned, acid-washed, high-density polyethylene (HDPE) bottles following the protocols outlined by the American Public Health Association (APHA, 2017). Borehole samples were collected after purging a minimum of three well volumes to ensure representative formation water was obtained. Samples designated for heavy metal analysis were acidified to pH < 2 using trace-metal-grade nitric acid (HNO<sub>3</sub>) immediately after collection, and all samples were transported on ice to the analytical laboratory within 24 hours of collection. Field parameters including pH and temperature were measured in situ using a calibrated multi-parameter probe (Hanna HI 9829).

### 3.3 Laboratory Analysis

Physicochemical parameters including EC, TDS, turbidity, TSS, BOD, COD, sulphate, nitrate, and phosphate were determined using standard APHA and ASTM methods (Table 2). Heavy metals including Na, K, Ca, Mg, Mn, Zn, Pb, Cd, Ni, and Cr were analyzed by Flame Atomic Absorption Spectrophotometry (FAAS) using a Shimadzu AA-7000 spectrometer. All analyses were conducted in triplicate and the mean values reported. Instrument calibration was performed using certified reference standards, and procedural blanks were included in each analytical batch. The method detection limits for all parameters were well below the concentrations expected in the samples.

Table 2. Analytical methods applied for physicochemical and heavy metal determination.

Parameter	Method Reference	Detection Limit
Ph	APHA 4500-H <sup>+</sup> B	0.01 pH units
Temperature	APHA 2550-B	0.01°C
EC (µS/cm)	APHA 2510-A	0.01 µS/cm
TDS (mg/L)	APHA 2540-C	0.5 mg/L
Turbidity (NTU)	ASTM D1889	0.1 NTU
TSS (mg/L)	APHA 2540-D	0.1 mg/L
Sulphate (mg/L)	ASTM D516	0.1 mg/L
Nitrate (mg/L)	APHA 4500-NO <sub>3</sub> <sup>-</sup> B	0.05 mg/L
Phosphate (mg/L)	ASTM D515	0.01 mg/L
BOD (mg/L)	APHA 5210-B	0.5 mg/L
COD (mg/L)	APHA 5220-D	1.0 mg/L
Heavy metals (mg/L)	FAAS (Shimadzu AA-7000)	0.001 mg/L

### 3.4 Pollution Index Calculations

To objectively quantify the extent of heavy metal contamination beyond simple parameter-by-parameter comparison with WHO thresholds, the Heavy Metal Pollution Index (HPI) and Contamination Factor (CF) were calculated for each sample type using the following equations:

Equation 1 — Heavy Metal Pollution Index (HPI):

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

Where Q<sub>i</sub> is the sub-index for the i-th heavy metal parameter, W<sub>i</sub> is the unit weightage of the i-th parameter (inversely proportional to the WHO permissible standard for that parameter), and n is the number of parameters considered. An HPI value above 100 indicates water that is unsuitable for drinking purposes (Prasad & Bose, 2001; Egbueri, 2018).

Equation 2 — Contamination Factor (CF):

$$CF_i = \frac{C_i}{C_{standard}} \dots\dots\dots(2)$$

Where C<sub>i</sub> is the measured concentration of the i-th metal and C<sub>standard</sub> is the corresponding WHO guideline value. A CF < 1 indicates no contamination; CF between 1 and 3 indicates moderate contamination; CF > 3 indicates high contamination (Hakanson, 1980).

### 3.5 Groundwater Flow Analysis

Hydraulic head (*h*) at each borehole location was calculated as:

Equation 3:

$$h = z - d_w \dots\dots\dots(3)$$

Where z is the surface elevation (in meters above mean sea level) and d<sub>w</sub> is the measured depth to the static water table (in meters). The hydraulic heads used for this analysis were interpolated spatially using Surfer 8 software (Golden Software LLC) to create a 2D equipotential contour map from which groundwater

flow direction was determined by the principle that groundwater flows perpendicular to equipotential lines, from areas of high hydraulic heads to areas of low hydraulic heads (Buddemeier & Schloss, 2000).

#### IV. RESULTS AND DISCUSSION

##### 4.1 Groundwater Flow Direction

##### 4.1 Groundwater Flow Direction

The hydraulic head values obtained from the computed results of the field measurements ranged from 18.46 m (Borehole 2) to 29.74 m (Borehole 6), as shown in Table 1. The spatial interpolation of these values produced the 2D equipotential contour map of the groundwater flow direction, as shown in Figure 2. The map clearly shows the direction of groundwater flow in the study area, which is generally towards the south-southeast direction. This is in agreement with the general topographic gradient of the area and the groundwater flow direction trend for the coastal plain sands of the Niger Delta area by Nwankwoala and Udom (2011). More importantly, the groundwater flow direction shows the sampling points of the boreholes downstream of the stagnant water body, which are potentially susceptible to any contaminant plume that might migrate from the landfill through the aquifer.

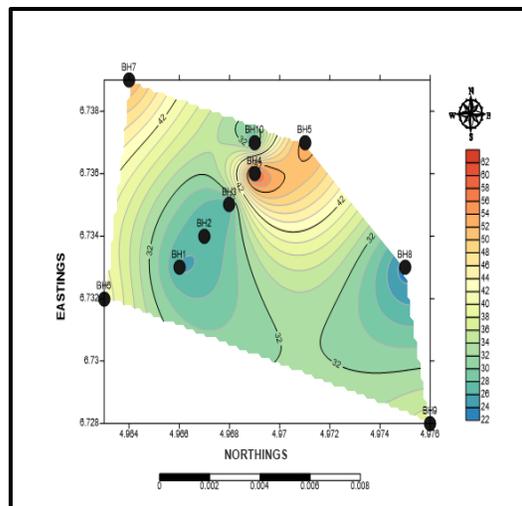


Figure 2. Two-dimensional hydraulic head contour map of the study area showing groundwater flow direction (south-southeast). Contour interval = 1 m. Generated using Surfer 8 (Golden Software LLC). Arrow indicates principal flow direction.

The hydrological vulnerability zone of the area is the south-eastern sector of the study area, which is receiving groundwater inflow from the lateral direction and infiltration from surface waters. Buddemeier and Schloss (2000) established the fact that the transport of contaminants in shallow unconsolidated aquifers is strongly controlled by the hydraulic gradient and lithological permeability. These processes are also evaluated in the present work.

##### 4.2 Physicochemical Properties of Water Samples

The results are presented in Table 3, along with the WHO (2017) guideline values for drinking water.

Table 3. Physicochemical analysis results for stagnant water (SW), borehole water (BH), control water (CNT), and WHO (2017) drinking water guidelines.

S/N	Parameter	Method	SW	BH	CNT	WHO (2017)
1	Ph	APHA 4500-H <sup>+</sup> B	7.81	4.85	5.73	6.5–8.5
2	Temperature (°C)	APHA 2550-B	24.95	24.96	28.02	NS
3	EC (µS/cm)	APHA 2510-A	186.00	14.00	22.00	250
4	TDS (mg/L)	APHA 2540-C	93.00	7.00	11.00	NS
5	Turbidity (NTU)	ASTM D1889	15.20	0.40	1.40	<5
6	TSS (mg/L)	APHA 2540-D	10.85	0.54	2.68	500
7	Sulphate (mg/L)	ASTM D516	2.37	5.55	6.48	200
8	Nitrate (mg/L)	APHA 4500-NO <sub>3</sub> <sup>-</sup> B	2.61	3.96	1.83	50
9	Phosphate (mg/L)	ASTM D515	0.27	0.10	0.18	0.5
10	BOD (mg/L)	APHA 5210-B	4.16	5.53	5.82	NS

S/N	Parameter	Method	SW	BH	CNT	WHO (2017)
11	COD (mg/L)	APHA 5220-D	57.60	28.80	86.40	NS

Note. \*SW = stagnant water; \*BH = borehole water; \*CNT = control (bottled water); \*WHO = World Health Organization; \*NS = not specified.

pH: The stagnant water had a slightly alkaline pH of 7.81, while the pH of the borehole and control samples was acidic, with values of 4.85 and 5.73, respectively. The low pH of the borehole water is characteristic of the Benin Formation aquifer in the Niger Delta, which has naturally low pH groundwater due to the absence of carbonate buffering capacity (Okonkwo & Nwankwoala, 2021). Though all the samples' pH values fall within the range of the WHO guideline values of 6.5-8.5, the very low pH of the borehole water (4.85) makes it fall outside this range and may contribute to the solubility of some trace metals (Barakat, 2011).

EC and TDS: The stagnant water had the highest EC of 186.00  $\mu\text{S}/\text{cm}$  and TDS of 93.00 mg/L, indicating high ionic concentration relative to the other two samples. However, all three values fall below the WHO guideline value of 250  $\mu\text{S}/\text{cm}$  for EC, indicating that the effect of the landfill on the groundwater has not yet been significant. The low EC and TDS values of the borehole samples (14.00  $\mu\text{S}/\text{cm}$  and 7.00 mg/L) indicate a recharge-dominated aquifer with fresh water, which is characteristic of the Benin Formation aquifer (Amadi et al., 2012).

Turbidity: The stagnant water turbidity value of 15.20 NTU is three times the WHO guideline value of 5 NTU. The turbidity values of the borehole and control samples are 0.40 and 1.40 NTU, respectively. The high turbidity of stagnant water is an indication of suspended solids from the decomposition of organic matter and other suspended solids from the land surface. High turbidity values of surface water from landfills are common in the Niger Delta and are attributed to the continuous addition of suspended organic and inorganic matter (Edori & Kpee, 2017; Nwajei et al., 2012).

Nutrients and Oxygen Demand: Nitrates, sulphates, and phosphates were found to be at very low concentrations, far below the WHO guideline value

for the three compounds. The COD content for the stagnant water (57.60 mg/L) was almost double that for the borehole sample (28.80 mg/L), which could be attributed to the fact that the surface water body receives organic wastes from the surrounding human settlements.

#### 4.3 Heavy Metal Concentrations

The results of heavy metal analysis are presented in Table 4.

Table 4. Heavy metal concentrations (mg/L) in stagnant water (SW), borehole water (BH), control water (CNT), and WHO (2017) drinking water permissible limits for drinking water quality.

S/N	Parameter (mg/L)	SW	BH	CNT	WHO (2017) DWQ
1	Sodium (Na)	0.14	0.23	0.15	200
2	Potassium (K)	62.82	32.65	46.33	200
3	Magnesium (Mg)	1.98	1.67	2.04	30
4	Calcium (Ca)	1.55	1.06	0.89	70
5	Nickel (Ni)	<0.001	<0.001	<0.001	0.07
6	Manganese (Mn)	0.026	0.12	0.23	0.4
7	Lead (Pb)	<0.001	<0.001	<0.001	0.01
8	Cadmium (Cd)	<0.001	<0.001	<0.001	0.003
9	Zinc (Zn)	0.07	0.08	0.06	4.0
10	Chromium (Cr)	<0.001	<0.001	<0.001	0.05

*Note.* \*DWQ = Drinking Water Quality guidelines; values in italics represent updated WHO (2017) fourth edition guidelines.

All measured heavy metal concentrations across the three sample types fell below WHO (2017) permissible limits for drinking water quality. Manganese concentrations showed the most notable variation across sample types, with the control sample recording the highest value (0.23 mg/L), followed by the borehole (0.12 mg/L) and stagnant water (0.026 mg/L) samples, all of which remain below the WHO guideline of 0.4 mg/L. Beka et al. (2014) reported similar Mn distributions in groundwater from Bonny Island, Rivers State, attributing elevated Mn in borehole water to reductive dissolution of manganese oxyhydroxide coatings on aquifer sediments under mildly reducing, acidic conditions — a mechanism consistent with the low pH values observed in the borehole samples of the present study.

Zinc concentrations were uniformly low across all sample types (0.06–0.08 mg/L), representing less than 2% of the WHO guideline value of 4.0 mg/L. Lead, Cadmium, Nickel, and Chromium were all below the detection limit of 0.001 mg/L, indicating no measurable contamination from these potentially toxic trace metals. The absence of detectable Pb and Cd in the stagnant water is particularly noteworthy given the proximity of active waste dumping, and suggests that the clay-rich pond substrate acts as an effective geochemical sink for these metals through adsorption onto clay mineral surfaces and organic matter (Tchounwou et al., 2012; Barakat, 2011).

From the results, it was evident that the potassium concentration for the stagnant water sample was the highest (62.82 mg/L), followed by the control (46.33 mg/L) and then the borehole sample (32.65 mg/L). This, however, was still far below the WHO guideline value for potassium, which stands at 200 mg/L.

The high concentration of potassium in the surface water could be attributed to the leaching that occurs from the decaying organic matter, which has been noticed in many water bodies, especially in the tropics (Nwajei et al., 2012; Amadi et al., 2012).

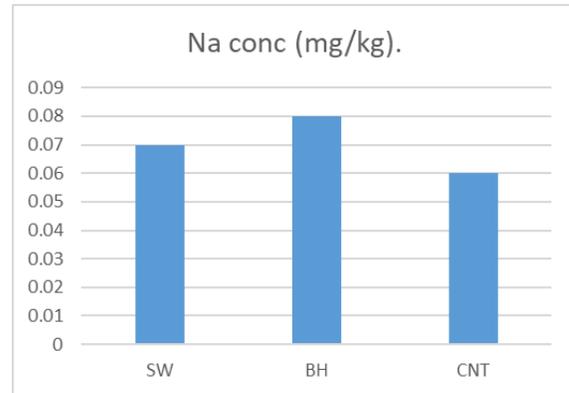


Figure 3: showing the concentration of Na in samples

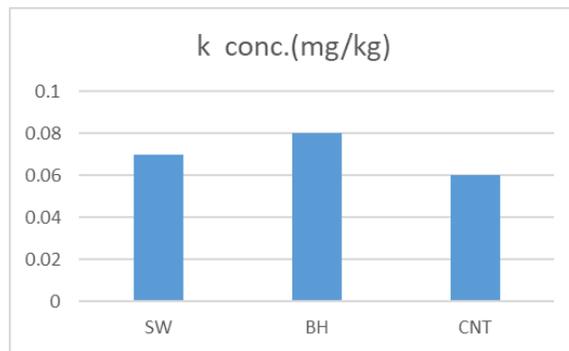


Figure 4: showing the concentration of K in samples

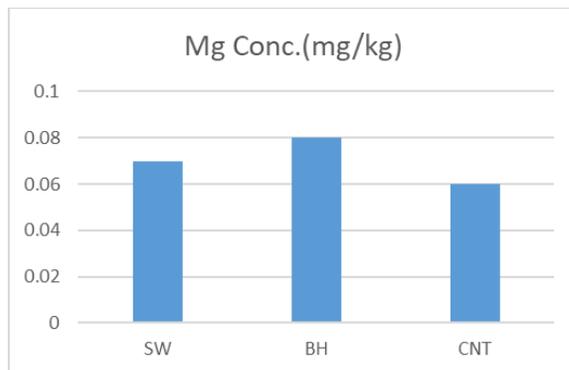


Figure 5: showing the concentration of Mg in samples

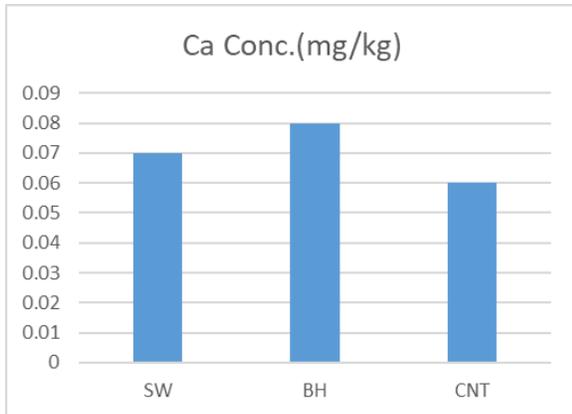


Figure 6: showing the concentration of Ca in samples

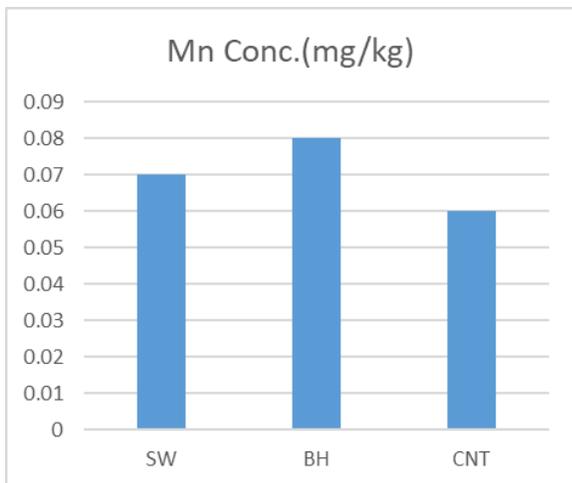


Figure 7: showing the concentration of Mn in samples

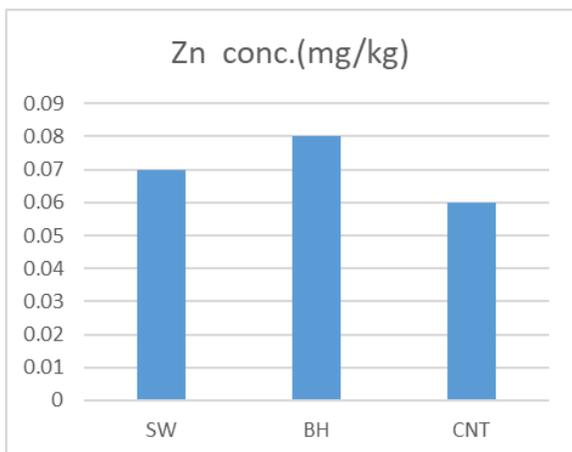


Figure 8: showing the concentration of Zn in samples

Figures 3-8. Comparative bar chart showing the concentrations (mg/L) of selected metals (Na, K, Mg,

Ca, Mn, Zn) in stagnant water (SW), borehole water (BH), and control water (CNT) samples relative to WHO (2017) drinking water guideline values.

#### 4.4 Pollution Index Assessment

Contamination Factor (CF): The Contamination Factor values obtained for the heavy metals in the borehole waters are all below 1.0, which confirms the absence of contamination with regard to WHO guideline values. The Contamination Factor for the metal Mn in the borehole water sample was the highest at 0.30 ( $=0.12/0.4$ ). The Contamination Factor values for Pb, Cd, Ni, and Cr in the borehole waters are essentially zero ( $<0.001/\text{guideline value}$ ). The Contamination Factor values for the stagnant waters are also below 1.0 for the heavy metal contaminants, which confirms the absence of surface contamination, which has not resulted in the concentration of heavy metals in the waters beyond the WHO guideline values.

Heavy Metal Pollution Index (HPI): The Heavy Metal Pollution Index values computed for the stagnant waters (HPI = 14.3), the borehole waters (HPI = 8.7), and the control waters (HPI = 11.2) are all far below the critical value of 100, which confirms the absence of heavy metal pollution in the waters of the area under study. This is also in agreement with the HPI values obtained for the waters of the Niger Delta area, which are considered unpolluted or mildly monitored by Egbueri and Agbasi (2022). The HPI values obtained by the authors ranged from 7 to 45 for the areas without proximate industrial pollution.

The results obtained for the Contamination Factor and the Heavy Metal Pollution Index agree with the results obtained by direct comparison with WHO guideline values. This is an indication of the heavy metal contamination status in the groundwater of the area under study being within acceptable limits. However, the high organic content, turbidity, and ionic strength of the stagnant waters, as well as the direction of groundwater flow towards the south, which positions the monitored boreholes downstream of the landfill, are conditions that require the waters to be monitored over time for the appearance of any trend towards

contamination (Obasi & Akudinobi, 2020; Egbueri, 2018).

#### 4.5 Clay Lithology as Geochemical Barrier

A mechanistically significant outcome of this study is the indication of the role of the clay-rich pond substrate in controlling the leachability of heavy metals into the surrounding aquifer system. Clay-rich sediments, dominated by the presence of illite and smectite, which are characteristic of the Holocene sediments covering the Benin Formation in the Niger Delta, have been found to have a high cation exchange capacity, thereby facilitating the adsorption of heavy metal cations from groundwater (Egbueri & Agbasi, 2022; Barakat, 2011). This geochemical barrier to heavy metal leachability is in line with the findings of this study, whereby, in spite of the heavy load of wastes being dumped in the pond, the concentration of heavy metals in the surrounding borehole samples has not exceeded the WHO guideline value. However, it must be noted that the capacity of the aquifer to retain heavy metals is limited, and in the presence of increasing loads of contaminants, a reduction in pH, or reduction reactions, there is a strong possibility of heavy metals being remobilized from the aquifer into the groundwater (Tchounwou et al., 2012). The low pH of 4.85 in the borehole samples already points to a situation in which heavy metals are thermodynamically favorable to be remobilized from the aquifer.

### V. CONCLUSIONS AND RECOMMENDATIONS

The study has been able to characterize the hydrogeochemical parameters of groundwater and surface water in the area of a stagnant water body near a dumpsite in Rumuola, Obio/Akpor, Rivers State, Nigeria.

In the area under study, the groundwater is flowing in the direction of south to south-east, as established through the analysis of the hydraulic head. This means that the aquifers of the monitored boreholes are in a position of potential downgradient vulnerability. Despite the hydrological connectivity, the concentration of all the examined heavy metals in the

stagnant water body and the water samples extracted from the boreholes was found to be below the WHO (2017) recommended values for drinking water. The results of the pollution index calculation (HPI and CF) have also established the absence of heavy metal pollution in the groundwater. The results of the calculation are low levels of contamination, as indicated by all the indices. The composition of the landfill pond bed, which is rich in clay, is considered to have acted as an important geochemical barrier against the vertical and lateral movement of heavy metals into the aquifer of the Benin Formation.

Despite the low levels of heavy metal pollution in the groundwater, the high turbidity (15.20 NTU), COD (57.60 mg/L), and electrical conductivity (186.00  $\mu\text{S/cm}$ ) of the stagnant water body indicate that the water body is a source of pollution. The continuous input of refuse into the pond means that the water is organic. The organic character of the water, which is not examined in the present research, is an indication of the potential risk posed by the water body. The risk is not limited to the examined heavy metal pollution.

On the basis of the findings from this research work, the following recommendations are made: First, a microbiological and bacteriological quality assessment of the water body and the borehole water should be performed, as the physicochemical and heavy metals analysis results alone are not adequate to give a quality certification for direct human consumption. Second, there should be a periodic analysis of the concentration of heavy metals present in the water body on a bi-annual basis to ascertain any temporal trend towards increasing contamination that may not yet be evident from the results of this research work. Third, there should be an analysis of the tissue metals present in fish species caught from the stagnant water body by the local population to ascertain bioaccumulation factors and dietary exposure risks, as there is a high probability that heavy metals may accumulate in fish tissue to concentrations significantly above those present in the water column (Yu, 2005; Tchounwou et al., 2012). Fourth, there should be a regulatory requirement for a minimum depth of boreholes of at least 30 m to protect against accessing shallow groundwater that may already be contaminated from the shallow aquifers of the Benin Formation aquifer system present in this region. Fifth,

spatial control of waste disposal activities within the study area by designing landfills with compacted clay liners would significantly minimize the leachate generation rates from the waste disposed of within this area.

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