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# Assessment of Groundwater Quality, Geochemical Modeling, and Multidimensional Health Risk Analysis Near Municipal Solid Waste Dumpsites in Obio/Akpor, Rivers State, Nigeria

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**Abstract: Incessant uncontrolled development of municipal solid waste dumpsites as well as the resultant seepage of contaminants is a serious hazard to shallow aquifer systems in the Niger Delta region. The access to the ground water of the Obio/Akpor Alakahia and Choba communities, Obio/Akpor, Rivers state, based on Ogbogoro community, a control baseline, ground water quality by physicochemical, heavy metal, and microbial parameters is examined in this study. A model of Water Quality Index (WQI) is combined with Human Health Risk Assessment (HHRA) to measure the associated threats to the population. The findings show a hydrogeochemical signature of high acidity (pH 4.985.32) and exceedingly low mineralization (TDS 1012mg/L), although heavy metals like Lead and Cadmium were absent, the Nickel (0.069mg/L) was more than the permissible limits prescribed by World Health Organization (WHO) at the dumpsite-proximal sites. The calculated WQI indicates the presence of a distinct pollution gradient with the dumpsites being more polluted than the control site with a score of 322.9 (Alakahia) and 322.7 (Choba) dumpsite nearby water being Unsuitable to drink. Biologically, the water is critically impaired as Escherichia coli counts (15 CFU/ml) show that it is being actively polluted by faeces. The HHRA index of non-carcinogenic risk (Hazard Index) was smaller than the number of 1.0 at all sites, which confirmed that the major health concern is acute waterborne infection and not the chronic toxicity of heavy metals. The conclusion of the study is that the dumpsites overlay an important point-source pollution impetus on a regionally sensitive and already debilitated aquifer.**

**Keywords: Groundwater, Human Health Risk Assessment (HHRA),Hydrogeochemistry, Obio/Akpor, Water Quality Index (WQI),**

## 1. Introduction

### 1.1 Background of the Study

The humid tropics depend on groundwater as the main source of potable water especially to household and industrial use. Its purported cleanliness nature than the surface water is usually placed on the fact that it is believed to be devoid of impurities due to the natural filtration it gets through the layers of soil. This natural defense is however being overrun at a fast pace due to the fast pace of urbanization coupled with poor management of solid waste (Vasanthi, Kaliappan, and Srinivasaraghavan, 2008). Unlined, usually geologically irresponsibly located Municipal Solid Waste (MSW) dumpsites serve as biochemical reactors. The percolation of rainwater through the waste mass dissolute the available soluble organic and inorganic compounds producing the leachate, a toxic material that precipitates vertically through the vadose zone into the phreatic water.

It is a dire situation in the Niger Delta of Nigeria which is Obio/Akpor. The area is covered with Benin Formation, which is a prolific yet most susceptible aquifer system consisting of porous sand and being a high hydraulic conductivity aquifer (Ezekwe, Kponi, & Darego, 2017). The existing indiscriminate dumping of waste on bare surface and on waterways develops direct hydraulic association between surface contaminations and water table.

**1.2 Statement of the Research Gap**

Existing literature on groundwater quality in Port Harcourt often stops at the level of comparing observed concentrations with World Health Organization (WHO) standards; while valid, this approach often leaves data underutilized for instance, parameters like Sodium, Potassium, and Magnesium are frequently measured but rarely interpreted in terms of geochemical facies or health implications unless they exceed toxicity limits and fails to quantify the aggregate impact of multiple contaminants, establish a clear risk gradient between polluted and less-polluted zones, or resolve the ambiguous conclusions resulting from the decoupling of chemical safety (TDS/Metals) from biological safety (E. coli), a multidimensional gap this study addresses by:"

1. Incorporating all **physicochemical (pH, EC, TDS ), major cationic (Na, K, Ca, Mg), major anionic** (Cl, $SO_4$ ,$NO_3$ ,$HCO_3$ ), **and heavy metal (**Pb, Cd, Zn, Fe, Cu, Cr, Ni, Mn **)** parameters (including trace cations and anions) into a geochemical interpretation.
2. Applying the **Water Quality Index (WQI)** to provide a single, comparable score of overall water quality for each location.
3. The measurement of the specific hazard quotient with the help of Human Health Risk Assessment (HHRA) models, which would no longer be based on the usual compliance check, but rather on the actual risk profiling.

**1.3 Theoretical Framework and Global Case Studies**

The dumpsite leachate interaction with groundwater is an environmental issue affecting the world as it is recorded in various geological environments.

The historical tragedy of the Love Canal in New York has been the standard to study the issue of leachate migration. Underground toxic waste traversed through the permeable layers of soil to get into basements in residential buildings and aquifers. This resulted in an epidemic of health problems like massive chromosomal damage and birth defects (Austin et al., 2002). The point that is highlighted in this case is that even dumping of wastes that are out of sight will come back as a hydrological risk.

In Italy such as the Campania region, hazardous waste dumping has been reported to be associated with high cancer death rates. Triassi et al. (2015) have used the biomonitoring and groundwater analysis methods to present that the heavy metals of the unlined landfills entered the volcanic aquifers, reaching the food chain. The research also emphasized the importance of computing Cumulative Risk Indices as opposed to the individual study of the individual pollutants.

Mishra et al. (2019) made an extensive evaluation of Okhla landfill. They discovered that the ground water had been polluted with high concentrations of Iron, Manganese and Chlorides due to leachate plumes even though the region was semi-arid. The paper was able to apply the Water Quality Index (WQI) to map the degradation of the water quality areas and demonstrate that urban landfills are important contributors to the so-called Gray Water footprint.

Aluko et al. (2003) were closer to the study location and described leachate of the giant Olusosun dumpsite. They discovered that the heavy metals in the leachate were multiplied several folds excessively than the background levels and they then moved to the aquifer. According to the research, the observation of the so-called Zero Bicarbonate phenomenon (which is also the case in the present study) is common indicator of extreme acidity, as well as dynamics of oxidation-reduction of the contaminant plume. The aim is to evaluate groundwater safety and its objective are; (i)to compare physicochemical profile and geochemical facies of all the three study locations.(ii)In order to compare the heavy metal load of the sites(iii)to evaluate and compare the biological contamination levels.(iv) To compare and model the Water Quality Index (WQI) at all the sites to form a pollution gradient.(5)To estimate the Non-Carcinogenic Health Risk (Hazard Index) of adults in each location and compare them.

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## 2. Materials and Methods

### 2.1 Study Area, Geology, and Hydrogeology

The research paper is based on Alakahia and Choba communities of Obio/Akpor Local Government Area (LGA) of Rivers State. The region is located at the Niger Delta, around Latitude 4.8705$^o$ N and Longitude 6.9234$^o$ E and Obio/Akpor occupies an area of around 260 km 2 and is described as a high-paced urbanization area (Figure 1).

### Geology and Hydrogeology

Its geology is the Benin Formation (Coastal Plain Sands) which is of Miocene-Pleistocene age. This rock is composed of huge, porous and permeable freshwater-bearing sands that have slight clay intercalations. The salinity of the lithology is oligotrophic (nutrient-depleted) quartz sands (Short and Stauble, 1967). The aquifer is very prolific due to its high permeability level (K 10 -3 to 10 -4 m/s) and highly susceptible to surface pollutants infiltration (Ezekwe et al., 2012).

The water table here is shallow, with the range of between 3m and 10m below the ground level during the wet season (Ezekwe, Kponi, and Darego, 2017).The closeness of the water table to the surface is a major factor that enhances the chances of dumpsites contamination.

### Hydrogeochemistry Implications

The sensitive geology is characterized by the quartz-based geology, and the natural buffering is low. This is the reason why the ground water at the area is naturally acidic and soft (low Ca/Mg), with the rock formation not having carbonate minerals needed to neutralize the acid rain or acidic leachate (Ezekwe et al., 2012).

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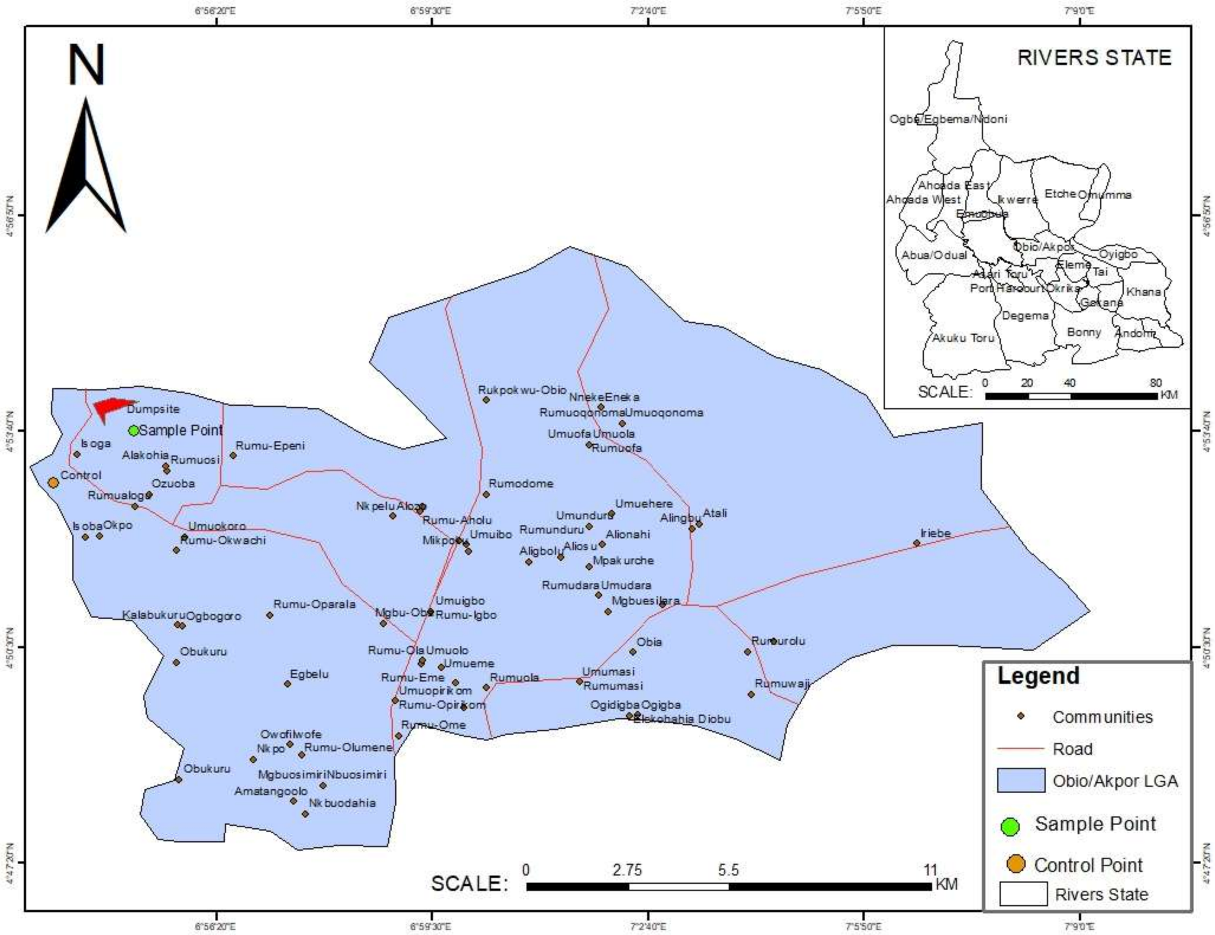


**Fig 1: Studied Area**

### 2.2 Sampling and Analysis

The purposely sampled three boreholes included Alakahia (Slaughterhouse proximity/Dumpsite), Choba (Market Dumpsite) and Ogbogoro (Control). All the laboratory analyses were done by standard APHA.

### 2.3 Mathematical Modeling

Three mathematical models were used on the data to fill the gap between the raw concentration data and usable health insights.

#### 2.3.1 Metal Pollution Index (MPI)

The Metal Pollution Index was computed in order to determine the sum of heavy metal load in each station without analyzing metals separately. This is a composite effect of all the observed metals (Ni, Fe, Zn, Mn).The geometric mean of concentrations is taken as follows:

$$MPI = (C_1 \times C_2 \times ... \times C_n)^{1/n} \quad ..........................1$$

Where:

- $C_n$ = Concentration of the nth metal in mg/L.

- $_n$ = Total number of metals analyzed.

**2.3.2 Water Quality Index (WQI) Calculation**

The 12 important physicochemical parameters were put together into one dimensionless score using the Weighted Arithmetic WQI.

$$WQI = \frac{\sum W_i Q_i}{\sum W_i} \quad \text{.......................................................2}$$

Where:

- $Q_i$ (Quality Rating) = $\frac{V_n - V_i}{S_n - V_i} \times 100$
  - V n = Observed value.
  - $V_i$ = Ideal value (7.0 for pH, 0 for others).
  - $S_n$ = Standard permissible limit (WHO).
- $W_i$ (Unit Weight) = $K/S_n$ (where K is the proportionality constant).

Rating Scale: <50 (Excellent); 50-100 (Good); 100-200 (Poor); 200-300 (Very Poor); >300 (Unsuitable for Drinking).

**2.3.3 Human Health Risk Assessment (HHRA)**

The non-carcinogenic exposure to the health risk of the ingested heavy metals was determined with the use of the USEPA models in case of the adult population.

**A. Average Daily Dose (ADD):**

$$ADD = \frac{C \times IR \times ED \times EF}{BW \times AT} \quad \text{.................................................3}$$

Where:

- *C*= Concentration of contaminant (mg/L).
- *IR* = Ingestion Rate (2.0 L/day).
- *ED* = Exposure Duration (30 years).
- *EF* = Exposure Frequency (350 days/year).
- *BW* = Body Weight (70 kg).
- *AT* = Averaging Time (*ED* × 365 days).

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**B. Hazard Quotient (HQ) and Hazard Index (HI):**

$$HQ = \frac{ADD}{RfD}$$

$$HI = \sum HQ$$ ………………………………………………………..4

Where *RfD* is the Reference Dose (toxicity threshold). If the **Hazard Index (HI)** exceeds 1.0, adverse non-carcinogenic health effects are possible.

### 3. Results

### 3.1 Comprehensive Water Quality Data

Table 1 The analytic findings of all three outlets.

**Table 1: Comprehensive Water Quality Data vs. WHO Standards**

| Category | Parameter | Alakahia | Choba | Control (Ogbogoro) | WHO Limit |
|---|---|---|---|---|---|
| **General** | pH | **4.98** | **5.32** | 4.97 | 6.5-8.5 |
| | EC (µS/cm) | 16 | 18 | 16 | 400 |
| | TDS (mg/L) | 10 | 12 | 9 | 300 |
| **Anions** | Bicarbonate ($HCO_3$) | **0** | **0** | 0 | - |
| | Sulphate ($SO_4$) | **0** | **0** | 0 | 250 |
| | Chloride ($Cl$) | 5 | 8 | 4 | 250 |
| | Nitrate ($NO_3$) | 0.2 | 0.3 | 0.1 | 50 |
| **Cations** | Sodium ($Na$) | 1.755 | 1.755 | **2.313** | 200 |
| | Potassium ($K$) | 0.119 | 0.119 | 0.104 | - |
| | Magnesium ($Mg$) | 0.208 | 0.208 | 0.183 | - |
| | Calcium ($Ca$) | <0.001 | <0.001 | <0.001 | - |
| **Metals** | Nickel ($Ni$) | **0.069** | **0.069** | **0.046** | 0.02 |
| | Iron ($Fe$) | 0.009 | 0.009 | **0.083** | 0.3 |

| | | | | | |
|---|---|---|---|---|---|
| | Zinc (*Zn*) | 0.011 | 0.011 | <0.001 | 3.0 |
| | Manganese (*Mn*) | 0.015 | 0.015 | **0.044** | 0.1 |
| | Copper/Pb/Cd/Cr | <0.001 | <0.001 | <0.001 | Various |
| **Bio** | Total Coliform (CFU/ml) | **25** | Detected | Detected | 0 |
| | *E. coli* (CFU/ml) | **15** | - | - | 0 |

*Source: Field and Laboratory Analysis, 2024.*

### 3.2 Comparative Modeling Results: WQI and HHRA

All three stations used the WQI and HHRA models in order to develop a quantitative definition of water quality and health risk comparison. Table 2 summarizes the results.

**Table 2: Comparative WQI and HHRA Results for All Stations**

| Station | WQI Score | WQI Classification | Hazard Index (HI) (Non-Carcinogenic Risk) | HI Risk Level |
|---|---|---|---|---|
| **Alakahia (Dumpsite)** | **322.9** | **Unsuitable for Drinking** | **0.1065** | **Low Risk** |
| **Choba (Dumpsite)** | **322.7** | **Unsuitable for Drinking** | **0.1070** | **Low Risk** |
| **Ogbogoro (Control)** | **221.4** | **Very Poor** | **0.0760** | **Low Risk** |

## 4. Discussion

### 4.1 Interpretation of Geochemical Facies

The analytical data indicate that the overall hydrogeochemical data of all locations show that it is Na-Cl water type with very low mineralization. The **"Zero" Anions:** This lack of Bicarbonate ($HCO_3$) and Sulphate ($SO_4$) is also an important observation. The 0-bicarbonate reconfirms the corrosive and aggressive nature of water because of low pH. The zero sulphate could indicate that the geology of the region may not contain any sulphate minerals, or could indicate that there are sulphate reducing bacteria about in the aquifer.The **Cation Profile:** It has prevailing result of the Sodium (Na > Mg > K > Ca ) predominance and the near absence of Calcium give water that is of very soft water. This has health effects as the intake of mineral deficient soft water has been associated with cardiovascular problems (Yang et al., 2006).

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**4.2 Comparative Analysis of Water Quality (WQI)**

This is because the WQI modeling offers a very potent quantitative instrument to determine the effects of the dumpsites. As indicated in Table 2, there is apparent pollution gradient: Alakahia (WQI=322.9) and Choba (WQI=322.7) are statistically equal in the aspect of poor quality, the results of both having been recorded as under the Unsuitable Drinking category.

The control site, Ogbogoro (WQI=221.4), however, is much better still considered as a Very Poor location.This gradient shows that there are two critical points: Point-Source Impact and Regional Vulnerability.

**Point-Source Impact:** The dumpsites now at Alakahia and Choba have increased the level of pollution out of the Very Poor category to Unsuitable, which is a quantification parameter of the impact they have made on it. The reason mostly behind this is the fact that Nickel concentration (0.069 mg/L) at these places is high in contrast to the control (0.046 mg/L).

**Regional Vulnerability:** The control site itself was detected as Very Poor suggesting the presence of a problem at the regional level. It is most likely that the unconfined aquifer is under extensive acidity and natural occurrence Nickel pollution. The dumping sites are therefore complementing a weak system.

**4.3 Comparative Health Risk Assessment (HHRA)**

The results of HHRA provide an in-depth observation. The Hazard Index (HI), which is a total of metals non-carcinogenic risk, is not more than the 1.0 index at all three sites.

**HI Gradient:** Even a risk gradient can be detected: Alakahia (0.1065) and Choba (0.1070) are characterized by a greater Hazard Index when compared to that in the control site Ogbogoro (0.0760). It implies that an individual taking water at the dumpsite wells will be exposed to a part more metals, however, this concentration is not exceeding the safety limit of chronic toxicity.

**Primary Risk Divergence:** This substantiates the major thesis of the study. Although the water is of low quality (WQI), it is not necessarily the chemical poisoning. The first and the most severe threat is posed by a biological contamination (15 CFU/ml of E. coli). The HHRA model fails to include pathogens but their presence will make the water unsafe to be consumed instantly.

**4.4 Biological Contamination: The Overriding Factor**

The fact that 15 CFU/ml of E. coli was found at the Alakahia site, which is near a slaughterhouse, is a conclusive bio-indicator of fresh fecal pollution. This observation renders all the other chemical and index-based discourses peripheral as far as a direct health advice is concerned. The WHO criterion is zero E.coli in drinking water. Porous sandy geology of Benin Formation enables the microorganisms in the surface sources (slaughterhouse runoff, human waste in the dumpsite) to be transported to the shallow aquifer with slight attenuation.

**5. Conclusion and Recommendations**

**5.1 Conclusion**

This research used a multi- index to give a holistic evaluation on groundwater safety in Obio/Akpor. **Geochemistry:** The ground water is a Na-Cl ground water, which is very soft, acidic and aggressive because of the purpose of a lack of bicarbonate buffering.**WQI Modeling:** Pollution gradient was measured and the water quality (WQI 323) at dumpsite was found to be very bad compared to at the control site (WQI 221). This attests to the adverse effect of the dumpsites. **HHRA Modeling:** The exposure to non-carcinogenic chronic disease in heavy metals is low in each location (HI < 1.0).**Biological Failure:** The first and most significant risk to health is the acute infectious disease by the severe fecal contamination (E. coli).**Overall Verdict:** The dumpsites pose a heavy point-source load (Nickel, Chloride, E. coli) to an already vulnerable and already compromised regionally based aquifer system.

**5.2 Recommendations**

**Immediate Public Health Advisory:** There should be a pressing advisory to the Alakahia and Choba inhabitants to boil water prior to its use. Pathogen measures Simple chlorination or Solar Disinfection (SODIS) are also effective against the pathogens. **pH**

**Correction:** Water project: Limestone contactors or soda dosing systems in the community water should be installed to treat the violent acidic water and save the human and plumbing systems.**Risk-Based Monitoring:** Nickel and E. coli are recommended to be taken into consideration as the most important indices of pollution in this region in the future. **Sanitary Landfill Transition:** The present open dumping should be gradually eliminated in favor of the engineered sanitary landfills that have leachate collectors to safeguard the endangered Benin Formation aquifer.

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