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Groundwater Quality Assessment Near A Dumpsite and Evaluation of Its Human Health Risk in Oleh, Delta State, Nigeria.

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Abstract - The negative impact of improper management of municipal solid waste (MSW) on human health, the environment, and especially groundwater has made solid waste disposal a major global concern. Open dumping remains the oldest method of solid waste disposal in most urban cities in Nigeria. The proper management of municipal solid waste for the reduction of its potential impacts on the environment is one of the most challenging issues faced by developing countries. Residents obtain water from boreholes sunk close to these dumpsites without any form of monitoring the groundwater quality, and it is consumed without treatment. This study intended to address the gap by carrying out a comprehensive characterization of leachate and groundwater samples obtained around a dump site in the Delta State University, Oleh Campus, Nigeria, to assess their potential risks to human health. The study investigated groundwater quality and the level of non-carcinogenic health hazard for residents who consume the groundwater. Five groundwater samples (S1 to S5) and one leachate sample (LS) were collected and analyzed at Thermosteel Nigeria Limited Laboratory, Warri, following the standard procedures outlined by APHA. Parameters measured included temperature, pH, turbidity, total dissolved and suspended solids, electrical conductivity, total hardness, dissolved oxygen, nitrate, chloride, sulphate, phosphate, calcium, sodium, copper, iron, lead, and total coliform. Data analysis entailed descriptive analysis and a correlation coefficient to establish relationships amongst the parameters. The WQI and LPI were computed to assess groundwater quality and the potential for leachate pollution. The residents' health risk was assessed using Hazard Quotient (HQ) and Hazard Index (HI). respectively. Results indicated that parameters such as pH, nitrate, and heavy metals exceeded the limits recommended by the World Health Organization (WHO) and the Nigerian Standard for Drinking Water Quality (NSDWQ) in four locations (S1 to S4). The leachate sample exhibited a strongly acidic pH (4.5) and elevated levels of iron (1.306 mg/L) and lead (0.013 mg/L), suggesting a contamination risk. The LPI value of 7.0031 reflected moderate pollution, while WQI values (22.366 to 41.25) placed the groundwater in the "excellent to good" quality range. Nonetheless, the presence of coliform bacteria and detectable heavy metals indicates a continuous exchange between the dumpsite leachate and the groundwater system, facilitated by the area's sandy and permeable subsurface and its shallow aquifer depth. The hydrogeological assessment revealed that the geographic direction of groundwater flow is southwest to northeast, that is, point B (S2) towards points A (S1) and C (S3), thereby heightening the risk of leachate migration. The dumpsite may have influenced groundwater quality; however, health risk assessment using the Chronic Daily Intake (CDI) and Hazard Quotient (HQ) models revealed non-carcinogenic risks below the acceptable threshold (HI < 1), indicating limited immediate health effects, although potential cumulative risks may arise from prolonged exposure. The strong and moderate correlations observed among calcium, iron, and chloride indicate that these parameters likely originate from the same source. Overall, the study concludes that the open dumpsite in Oleh contributes mild to moderate groundwater contamination. It recommends continuous groundwater monitoring, improved waste disposal systems, leachate treatment infrastructure, and the replacement of open dumps with engineered sanitary landfills to safeguard human health and ensure sustainable groundwater management in the area

Keywords: Groundwater, Leachate Pollution Index, Water Quality Index, Heavy metals, Dumpsite, Health risk assessment.

1.0 INTRODUCTION

The generation rate of solid waste is alarming globally. Solid waste generation in a locality is a function of what is produced and consumed in that locality. It has been recorded that Nigeria generates over 32 million tons of solid waste yearly, and only a fraction is collected (Bakare, 2020). Most of these wastes are generated by households and, in some cases, by local industries, artisans, and traders who litter the immediate surroundings. Improper collection and disposal of municipal waste have led to various environmental challenges, including blockages of sewers, drain networks, and the pollution of water bodies (George, 2010). The enormous economic and industrial growth is often accompanied by urbanization and population growth (Mamza et al., 2022). As a

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consequence, the quantity of municipal solid waste (MSW) produced in the last few decades has increased significantly throughout the world (Somani et al., 2019), despite the development of waste management practices including incineration, composting, and recycling (Aziz et al., 2021; Baghanam et al., 2020; Fadili et al., 2022). The complexity of growth in urban settlements in Nigeria in relation to its inhibiting factors has equally complicated the problem of prompt evacuation of solid waste within the urban settlement. Despite the obnoxious nature of solid waste dump sites, government and policymakers have paid little or no attention to solid waste management. The resultant impact of improperly managed solid waste includes, but is not limited to, rodents and flies infestation, spread of diseases such as typhoid, malaria, and fever. Furthermore, due to rapid urbanization, infrastructure provision is insufficient to serve the growing population

The disposal of waste in open dumpsites is still one of the widely used methods for municipal solid waste management (Chidichimo et al., 2020; Kapelewska et al., 2019). As a result, mitigating the negative environmental impacts of open dumpsites has become one of the most challenging issues worldwide (Akoto et al., 2021). The management of municipal solid waste (MSW) has proven to be a major challenge for developing and underdeveloped countries, exacerbated by underfunding for waste management and/or treatment before disposal (Maeti et al., 2025). The absence of a sound national policy for Solid Waste Management (SWM) has caused tremendous negative environmental consequences in Nigeria (Lalitha & Fernando, 2018). Over the years, the effective management of Municipal Solid Waste (MSW) has been a major problem in most urban cities of Nigeria. Stemming from inadequate funding support and low prioritization given to solid waste management, some countries resort to open disposal of waste into dumpsites that are not engineered (Majolagbe et al., 2017). These unlined dumpsites have become the best method of solid waste disposal in Nigeria. These dumpsites are not able to trap leachate, which negatively impacts the air, soil, and water, together with human health. Borrow pits from where soil is collected for road construction are utilized as dumpsites. Population size, industrialization, urbanization, and sometimes poverty all contribute (Mohobane, 2008). The problem of poor waste management begins with a lack of segregation at the point of waste generation, the absence of waste collection structures, and indiscriminate disposal into the environment (Sharma and Ganguly, 2018). Global anthropogenic pollutant enrichment of the environment by dumpsites consequently threatens water quality (Agrawal et al., 2021).

The decomposition by-products of solid wastes and the rainwater seeping through layers of waste produce open dump leachate. It is a heterogeneous mixture of organic and inorganic compounds, and its physicochemical and microbiological composition depends on several parameters, including climate conditions and the composition of municipal waste. Landfill leachate can cause severe environmental and human health issues if it is discharged to the environment without proper treatment (Hamza et al., 2022). It has been demonstrated that leachate consists of a myriad of pollutants, including dissolved organic matter, heavy metals, and salts (Przydatek and Kanownik, 2019; Talalaj and Biedka, 2016; Tenodi et al., 2020). The leachate management has become a burning issue throughout the world because the untreated leachate could significantly affect the quality of ground and surface waters in its vicinity. In this context, the environmental concern and the possible scenarios of water pollution, migration of leachate pollution have been extensively discussed in the literature (Alam et al., 2020; Bellezoni et al., 2014; Najafi Saleh et al., 2020; Przydatek and Kanownik, 2019; Rathod et al., 2013; Singh et al., 2016; Talalaj and Biedka, 2016; Tenodi et al., 2020). Like many other countries in the world, Nigeria is not exempt from groundwater contamination by leachate because of poor solid waste management strategies, with open dumps being the most common disposal destinations.

Water is undoubtedly the most precious resource for human well-being. Unfortunately, water is extensively wasted and polluted by both natural and anthropogenic activities. An estimated 1.5 billion people rely on groundwater for drinking globally (Adimalla and Wu, 2019; Mukherjee and Singh, 2018). It is further estimated that groundwater meets at least 60% of global daily needs for the rural population (Grönwall and Danert, 2020). Climate change threatens water security globally, including in Nigeria. Furthermore, there is an intermittent supply of water from the water utility, and groundwater seems to be a promising source, which calls for its protection against various forms of pollution. Studies carried out in Aduramigba Estate, within the Southwestern part of the Osun state in Nigeria, a dumpsite contaminated water, and physicochemical properties analyzed were pH, EC, trace metals, and some ions (Oyelami et al., 2013). From these, chlorides exceed the WHO allowable value of 250 mg/L at 268.87 mg/L (WHO, 2011).

Groundwater in Oleh is the major source of drinking water that sustains some urban livelihoods, and these include domestic and agricultural activities (Lapworth et al., 2017). Due to the augmentation of domestic, industrial, and pharmaceutical waste disposal at the dumpsites, groundwater can be laden with organic pollutants and potential toxic elements (PTEs). It has been reported that, collectively, PTEs like mercury, copper, cadmium, and lead are cumulative poisons (Yargholi and Azimi, 2008) and are exceptionally toxic and carcinogenic (Hei T et al., 2004; Leonard et al., 2004; Wang et al., 2004). Even though it is specified that one of the inappropriate regions for landfill sites is those within 40 m of a permanent or intermittent water body or in an area overlying an aquifer with a drinking water quality groundwater that is vulnerable to pollution (EPA 2016). The same report further restricts landfills within 250 m of residential areas, schools, or hospitals, which are not associated with the landfill facilities.

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Depending on their source, pollutants may contain potentially toxic elements (PTEs). When in excess in the human body, these PTEs are carcinogenic. Non-carcinogenic diseases include diarrhoea, vomiting, abdominal pain, and kidney destruction (Andeobu et al., 2023; Njoku et al., 2024). PTEs are able to migrate from soil, which acts as an environmental medium for translocation to other environments, like water. Some PTEs are also carcinogenic (Fiore et al., 2019; WHO, 2022) and are considered hazardous if consumed (Aswal et al., 2023). They are persistent in the environment, bioaccumulative, and also bio-magnify (De Lima et al., 2022), thus degrading the environment and threatening human health when consumed. Another issue that is under debate is the bioavailability of PTEs, a characteristic that, when well-researched, could be used for risk assessment (Kim et al., 2015) and ultimately be included in policies in order to protect human health. When groundwater quality is affected, there could be a burden of diseases for the communities.

2.0 MATERIALS AND METHODS

2.1 Study area

Oleh is the administrative headquarters of the Isoko South Local Government Area (ISLGA) Figure 1. One of the two administrative units of the Isokos in Delta State, Nigeria. Oleh is located in the southern geographical region of Delta State, at a latitude of 5°27'42" N and longitude 6°12'22" E. According to a report by the Nigerian meteorological agency, Oleh is one of the most populated communities in the ISLGA, one of the towns in Delta state that is more vulnerable to flooding. The Nigeria Population Commission estimated that ISLGA had a population of 323,800 as of 2016, with Oleh having a population exceeding 20,000 people (NPC, 2018). ISLGA resides within the tropical rainforest axis with luxuriant vegetation. It does experience wet and dry climate, with relatively constant temperatures throughout the year (Owamah et al., 2013). The region is generally of flat topography and slopes slightly towards the sea (Akpokodje and Etu- Efeotor 1987; Atakpo and Ayolabi, 2009). The region lies in the sedimentary basin and has no outcrop. It experiences flooding during the wet season and has a mean elevation of about 10 m above sea level. Geologically, the region comprises three major subsurface lithostratigraphic units, overlain by Quaternary deposits (Atakpo and Ayolabi, 2009). The Akata formation is the base of the unit and consists mainly of marine shales. The thickness of the formation is within the range of 550 to over 6000 m. The underlying paralic sequence is the Agbada formation, comprising interbedded sands and shale with a thickness range of 300 to 4500 m, with the uppermost unit being the Benin formation. Details of the hydrogeological characteristics of the study area are documented in Atakpo and Ayolabi (2009). The hydraulic conductivity has been reported to be in the range of 3.82 × 10–3 to 9.0 × 10-2 cm/s, implying that the aquifer is productive (Offodile, 1991; Olobaniyi and Owoyemi, 2006).

Civil service work, farming, trading, and artisanship are some of the major economic activities of the residents of the study area. The study area has a mean precipitation (annual), monthly temperature average, and relative humidity range of 2800mm, 31◦C and 76–90% respectively (Owamah, 2020). The ISLGA is a prominent oil-producing part of the South-South zone of Nigeria. There is a flow station near the Faculty of Engineering, Delta State University, Oleh Campus.

The Isoko people are a group of people in Nigeria who are mainly involved in farming and fishing. The major crops grown in the area are cassava, plantain, maize, etc. Cassava is the main source of most foods consumed by the people, such as garri, starch, and fufu. The area is also known for its oil palm production. In terms of infrastructure, Oleh is relatively well–developed with a good road network linking it to nearby towns and cities. There are several markets in Oleh where people buy food, clothing, and other household items. Oleh is one of the many communities in Nigeria, but it stands out for hosting one of the major campuses of Delta State University, Abraka. Oleh has about four to five major dumpsites, one located in the Faculty of Law, which happens to be the main focus of this study, Figure 2. The dumpsite measures 35.7m in length and 15.5m in width.

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FIGURE 1: Map of Delta State showing Isoko South Local Government Area.

Fig. 2: Location of the Oleh dumpsite and water sampling sites.

2.2 Methods

2.2.1 Data collection

2.2.1.1 Reconnaissance and waste classification

The waste stream was characterized and categorized as solid waste, which was classified by source as residential waste, commercial waste, institutional waste, and others. Furthermore, it was noteworthy to assess activities that took place around the dumpsite. The sampling sites (existing private boreholes) around the dumpsite were also identified, noting their GPS coordinates and distances from the dumpsite (Table 1).

2.2.1.2 Water samples collection

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Water samples were taken from five private boreholes, S1, S2, S3, and S4 around the dumpsite and at a control point, S5, located at a distance of 600m from the dumpsite. GPS coordinates and depth to water level in each borehole are presented in Table 1. The water samples were collected with new high-density PET screw-capped containers of 1.0 litres capacity. The bottles were soaked in 10% nitric acid for a night prior to sampling. The PET containers and stoppers were thoroughly washed with distilled water three times and once with the water to be sampled before collecting the actual sample. The bottles were filled, allowed to overflow, and immediately corked, properly labeled to avoid mix-up, placed in an ice block chest, and transported to a laboratory within a prescribed period of not more than three hours after collection and preserved in refrigerators at 4 °C to keep them intact until analysis was carried out following the standard guidelines (Njoku et al., 2024).

Table 1: Details of sampling sites coordinates

Code	Easting (UTM)	Northing (UTM)	Depth to water table (m)	Location
S1	189549	602636	19	Staff quarters
S2	189607	602788	14	Brooklyn hostel
S3	189565	602829	19	IVL hostel
S4	189697	603041	17	Staff club
S5 (control point)	189111	602702	16	Administrative block (Engineering faculty)
Dumpsite	189568	602697	20	Staff quarters

2.3 Analysis of water samples

The American Public Health Association recommended standard methods of testing water and wastewater were employed in this research to obtain the concentration of the physico-chemical and bacteriological parameters (Fiore et al., 2019). To ensure quality control measures, instrument calibration was performed before each analytical assessment according to APHA (APHA 2005) standards and manufacturer specifications. The Atomic Absorption Spectrometry (AAS) was calibrated for each analysis using a blank and 5 standard solutions. Calibration verification standards were analyzed after every 5 samples to ensure stability, such that results would be within±10% of the true value (APHA 2005). Blank water samples free of the analyte were carried through the entire analytical procedure, including digestion for COD, and were analyzed with each batch of samples. All blanks were below detection limits indicating negligible contamination.

2.3.1 Field analysis

Non-conservative, sensitive parameters (temperature, pH, electrical conductivity (EC), and dissolved oxygen (DO) which change with storage time, were measured in situ using appropriate testing kits, a glass thermometer, a conductivity meter model HI 8033, and a pH meter model HI 8424, respectively, and recorded before samples were transported to the laboratory for further physical and chemical analyses. The procedure was repeated three (3) times, and the mean value was calculated for each parameter.

2.3.2 Laboratory analysis

For water parameters that could not be analyzed instantly, samples were stored in a cooler box with ice medium to arrest any reactions between sampling and analysis. The APHA standard methods of testing water and wastewater were utilized in the analysis of the water samples in the laboratory. When analysis could not be done within 24 h of refrigeration, samples were acidified with nitric acid to a pH less than 2 (APHA 2005) for iron and lead, and H_2SO_4 for COD. There was no need to preserve water for chlorides, but water was refrigerated and analyzed within one week. All samples were analyzed in triplicate for each water parameter, and the average calculated.

Microsoft Excel was then used to obtain the descriptive statistics (maximum, minimum, range, mean, and standard deviation) of each parameter and presented in Table 4. The mean water quality concentration values of each parameter were then compared to the WHO permissible standards in Table 5.

2.4 Data analysis

2.4.1 Descriptive statistics and comparison to WHO standards and NSDWQ

Microsoft Excel was utilized to compute the descriptive statistics (maximum, minimum, range, mean, and standard deviation) for each parameter, and the results are presented in Table 4. Descriptive analyses were used for distribution of water parameters within the dumpsite area, using frequencies and percentages for samples that were beyond and within the WHO standards for drinking

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water. The WHO permissible drinking water standards were compared with the observed water parameter levels. The correlation coefficient was used in order to establish the existence of relationships amongst water quality parameters in the sampling points.

2.4.2 Evaluation of Water Quality Index

The weighted arithmetic index method of evaluating WQI was adopted in this study. Six water quality parameters as recommended by the WHO, were selected from the dataset based on their importance and assigned mean weights obtained from Table 1. Equations 1 to 4 were adopted in evaluating the WQI and the status obtained based on the threshold values recommended by the Weighted Arithmetic Index method.

$$\text{Relative weight } (W_i) = \frac{w_i}{\sum_{i=1}^{n} w_i} \qquad (1)$$

$$\text{Quality rating scale } (q_i) = \frac{c_i}{s_i} \times 100 \qquad (2)$$

$$Sl_i = W_i \times q_i \qquad (3)$$

$$WQI = \sum Sl_i \qquad (4)$$

where;

w_i = weight of each parameter
n = number of parameters
c_i = concentration of each parameter in each water sample in mg/l
SI_i = sub − index of ith parameter
q_i = rating based on concentration of ith parameter
S_i = standard value

The status was based on the values of the WQI at each location. The WQI threshold values are: (0 -25) is classified as excellent; (26 - 50) is good; (51 -75) is poor; (76 - 100) is very poor and (> 100) is unsuitable for human consumption.

2.4.3 Evaluation of Leachate Pollution Index (LPI)

The Leachate Pollution Index (LPI) is a numerical tool developed to quantify the pollution potential of landfill leachate in a simple and standardized manner. It provides a single number that expresses the overall quality of leachate, considering the combined effects of several pollutants. This index is particularly useful for comparing the leachate quality of different landfill sites, assessing treatment efficiency, and monitoring pollution trends over time (Kumar & Alappat, 2003). The LPI is based on the Weighted Arithmetic Mean method, where individual pollution parameters are assigned weights according to their relative significance in causing environmental damage. Each parameter's sub-index value, which depends on its measured concentration, is multiplied by its corresponding weight. The final LPI is calculated by summing the weighted sub-index values of all the parameters considered (Kumar and Alappat, 2005). The general formula for the LPI is expressed in Equation 5

$$LPI = \frac{\sum_{i=1}^{m} w_i p_i}{\sum w_i} \qquad (5)$$

Where;

LPI = Leachate pollution index

W_i = The weight of the i^{th} pollutant variable

P_i = The sub-index value of the i^{th} leachate pollution variable

The weights (W_i) reflect the relative importance of each pollutant, while the sub-index values (P_i) are obtained using standard rating curves developed by Kumar and Alappat (2005). Six parameters selected in this study are the parameters for which data are available (Naveen et al., 2016). The steps in achieving this are enumerated below:

i. Sampling and analysis: Leachate samples were collected from the landfill and analyzed for key physicochemical parameters (Kumar and Alappat, 2003).

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ii. The measured concentration of each pollutant is converted into a sub-index score (pi) using the LPI rating curves (Kumar and Alappat, 2005) shown in Figure 3.

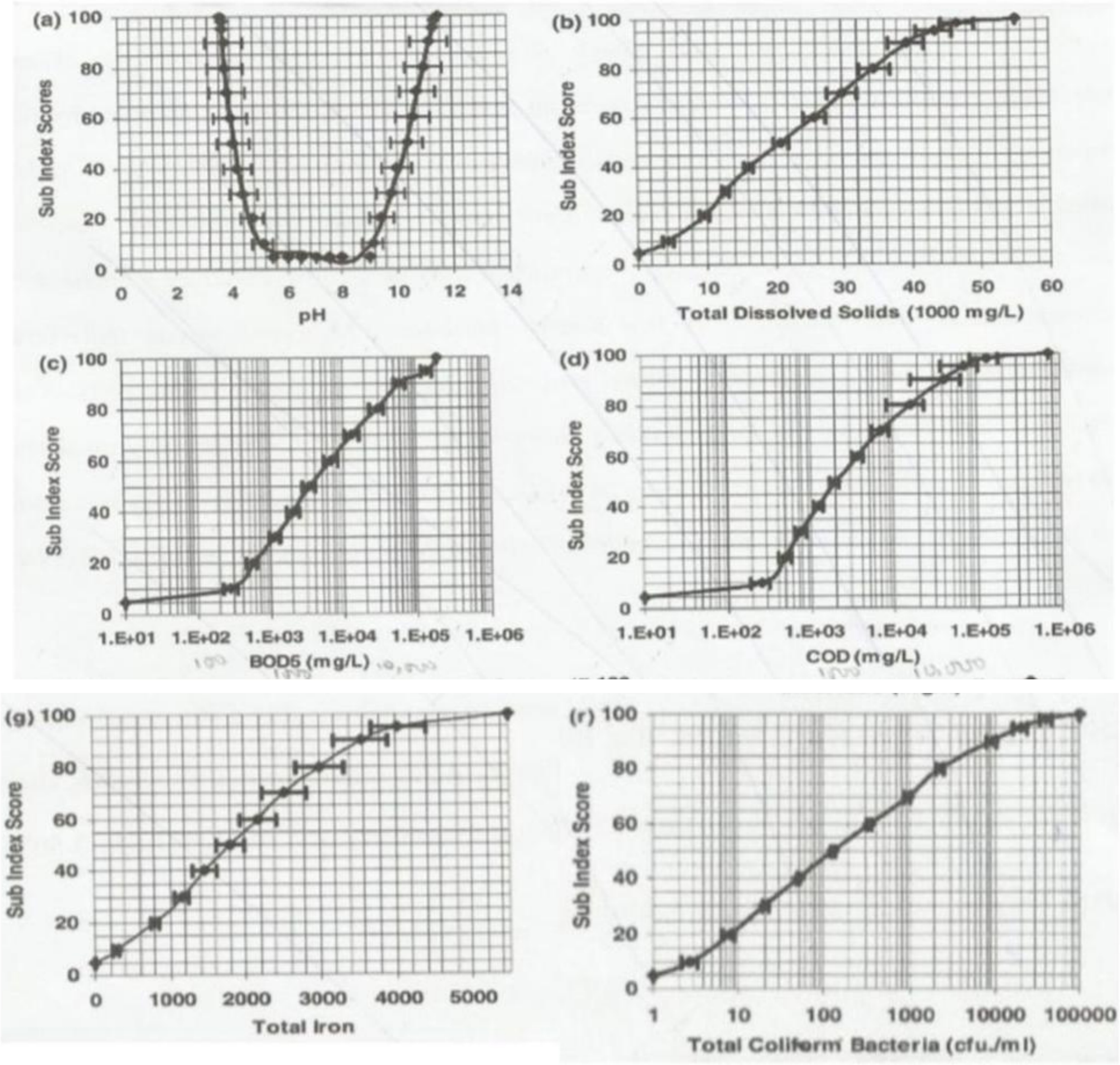

Figure 3: LPI rating curves (Kumar & Alappat, 2005).

iii. Each sub-index value is multiplied by its respective weight (Wi).

iv. The LPI value is calculated using Equation 5 (Kumar & Alappat, 2003).

v. The final LPI value was then compared with standard ranges to assess pollution potential. A higher LPI indicates greater pollution potential (Naveen et al., 2016).

2.4.4 Health risk assessment

Human health risk assessment was used for the evaluation of potential human health risk in the study area. The assessment was carried out on the basis that the pollutants primarily get absorbed into the human body through drinking the water. Reference dose (RfD) for lead was 0.004 mg/kg/day, 0.7 mg/kg/day for iron (Oyem et al., 2015). and 0.04 mg/kg/ day for copper (USEPA, 2011) as shown in Table 2. Chronic Daily Intake (CDI) and hazard quotient (HQ) were calculated, where HQ >1 implied high potential for non-cancer health risk, whereas HQ $<$ 1 reflected low potential for non-cancer health problems. More than one toxicant

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is analysed in this study, so interactions amongst them were taken into consideration, and assumed to have an additive effect if consumed. The HQs were therefore summed to obtain the hazard index (HI) for all heavy metals in the study area (Eq. 3). Health quotient (HQ) and Chronic daily intake (CDI) were calculated by Eqs. 6 (Oyem et al., 2015) and 7 (USEPA, 2011), respectively. Parameters that were used for calculations are presented in Tables 2 and 3.

Table 2: Oral reference dose (RfD) for heavy metals in the study area

Metal	RfD (mg/kg/day)
Lead (Pb)	0.004
Iron (Fe)	0.7
Copper (Cu)	0.04

Source: USEPA [34]

Table 3: Input parameters for CDI characterisation

Parameter	Symbol	Units	Adult	Children
Ingestion Rate	IR	L/day	2.0	1.0
Exposure Frequency	EF	Days/year	350	350
Exposure Duration	ED	Years	30	6
Body weight	Bw	Kg	70	15
Averaging Time	AT	(ED×365) Days	10,950	2190

Source: USEPA [34]

$$HQ = \frac{\text{chronic daily intake}}{\text{Reference dose}} \qquad (6)$$

where CDI refers to Chronic Daily Intake, being the daily dose of heavy metals in mg/L that consumers might be exposed, and calculated as shown in Eq.7.

$$CDI = \frac{C_w \times IR \times EF \times ED}{B_w \times AT} \qquad (7)$$

where C_w is the observed concentration from boreholes; IR is ingestion rate (2L/day for adults and 1L/day for children), EF is exposure frequency (350 days in one year), ED is exposure duration (30 for adults and 6 for children), Bw is body weight (70 kg for adults and 15 kg for children), and AT is averaging time (calculated as ED by 365) as shown in Table 3. HQ was considered present if it was above 1.00. Non-carcinogenic effect was
also considered negligible if HI < 1.0 and HI was calculated as shown in Eq. 8

$$HI = \sum_{i=1}^{n} (HQ)i \qquad (8)$$

where HI is the hazard index for all toxic metals analysed in the study and n is the total number of metals.

2.4.5 Correlation Coefficient between groundwater parameters

The correlation coefficients between the examined groundwater parameters were calculated using Microsoft Excel and are presented in Table 10. This analysis was carried out to determine the degree of association between the various physicochemical parameters. The correlation coefficient (r) values range from -1 to +1, where positive values indicate direct relationships, negative values show inverse relationships, and values close to zero suggest little or no relationship between parameters. The correlation matrix thus provides insight into how changes in one parameter may influence others within the groundwater system.

2.4.6 Determination of Direction of Groundwater Flow

The direction of groundwater flow was determined using the hydrologic triangle. Three boreholes spaced 60m apart were used to form the apex of an equilateral triangle shown in Figure 3. The depth of the water table at each sampling point was determined, and each side of the equilateral triangle formed was divided into equal increments; the points of equal elevation were joined to form

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equipotential lines. A perpendicular was made to the equipotential lines. Groundwater flow is on this perpendicular line, moving from a higher to a lower head, with the flow direction pointing away from the higher head equipotential lines.

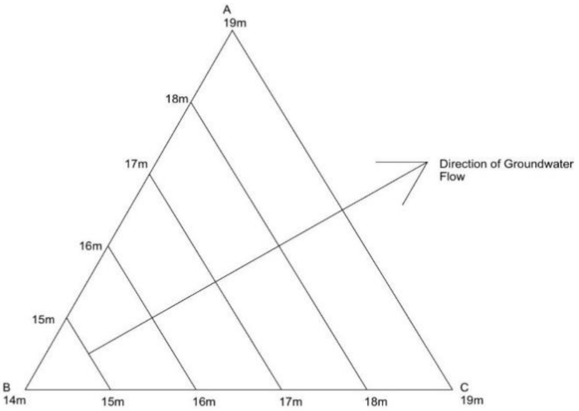

FIG. 3: Hydrogeological Triangle

3.0 RESULTS AND DISCUSSION

3.1 Groundwater physicochemical analysis in the study area.

Table 4 shows a summary of borehole physicochemical parameters, and the minimum, maximum, and mean concentrations of physicochemical parameters per sampling point (borehole) are shown in Table 5.

Table 4: Physico-chemical and bacteriological water quality parameters

Parameters	Sample Locations					Descriptive statistics				WHO Standard
	S1	S2	S3	S4	S5(CP)	Mean	S.D	Max	Min	
Temperature	29.45	28.95	30.2	26.85	30	29.09	1.202248	30.2	26.85	25
PH	4.9	3.6	3.3	3.2	4.5	3.9	0.678233	4.9	3.2	6.5 - 8.5
EC	103	105	110	140	50	101.6	29.05581	140	50	200
TSS	<1.00	<1.00	<1.00	<1.00	<1.00	0.1	0.0	0.1	0.1	500
Dissolved oxygen	6.19	5.12	4.81	5.2	4	5.064	0.705141	6.19	4	5
TDS	55.9	56.5	58	71.2	25.3	53.38	15.12262	71.2	25.3	500
Turbidity	1.5	1.5	1.6	1.4	0.52	1.304	0.397069	1.6	0.52	NS
Total Hardness	8.01	16	28	8	12	14.402	7.41717	28	8	100
Total Acidity	1.2	0.8	0.6	0.6	0.4	0.72	0.271293	1.2	0.4	NS
Total Alkalinity	4	<0.01	<0.01	<0.01	2	1.2006	1.59955	4	0.001	100
Chloride	15.95	19.15	22.33	12.76	8.51	15.74	4.8219	22.33	8.51	250
Phosphate	0.27	<0.01	<0.01	<0.01	<0.001	0.05462	0.107691	0.27	0.0001	NS
Sulphate	<0.01	6.82	<0.01	14.43	<0.01	4.2506	5.734096	14.43	0.001	200
Nitrate	4.11	3.07	3.22	5	1.48	3.376	1.17379	5	1.48	50
Sodium	11.33	15.42	16.61	9.4	7.11	11.974	3.579556	16.61	7.11	200
Calcium	7.71	9.32	11.33	6.5	7.16	8.404	1.735219	11.33	6.5	75
Copper	0.01	0.01	0.02	0.01	0.022	0.0144	0.005426	0.022	0.01	2
Lead	<0.01	<0.01	<0.01	<0.01	<0.001	0.00082	0.00036	0.001	0.0001	0.01
Iron	0.13	0.12	0.184	0.124	0.086	0.1288	0.031562	0.184	0.086	0.05 - 0.3
Coliform	4	NIL	4	NIL	7	5	1.414214	7	4	NS
COD	82.25	69	67.5	76.5	54	69.85	10.67064	82.25	54	65

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3.2 Water Quality Index

Table 5: Parameters assigned weights and WHO permissible limits

PARAMETERS	WEIGHT (w_i)	STANDARD WHO VALUES (S_i)
pH	3.8	7.5
TDS	4.5	500
DO	4.7	5
Chloride	3.5	250
Nitrate	4.1	50
Sodium	2.4	200
	$\sum w_i = 23$	

Table 6: Water Quality Index and Status at Sampling locations

Code	Easting (UTM)	Northing (UTM)	WQI	Status
S1	189549	602636	41.25	Good
S2	189607	602788	34.08	Good
S3	189565	602829	32.53	Good
S4	189697	603041	34.1	Good
S5 (CP)	189111	602702	22.366	Excellent

3.3 Leachate Pollution Index (LPI)

Results from the laboratory analysis of the leachate sample, as indicated in Table 7 below, were used in the calculation of the Leachate pollution index (LPI).

Table 7: Leachate analysis result

Parameters	Unit	Result
pH	-	4.5
BOD	mg/l	6.1
COD	mg/l	16.46
EC	µS/cm	200
TDS	mg/l	106
Ammonia	mg/l	8.08
Lead	mg/l	0.013
Iron	mg/l	1.306
Cadmium	mg/l	0.002
Mercury	mg/l	<0.01
Coliform	cfu/ml	7

Six (6) parameters analyzed were selected because they were the available data. The P_i values or sub-index values for the six parameters were computed from the sub-index curves in Figure 2 based on the concentration of the leachate pollutions obtained during the analysis. Table 8 shows the LPI of the leachate sample.

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Table 8 Characteristics and LPI of Leachate Sample

Parameters	Laboratory Data	Individual Pollution Rating (Sub-Index Value P_i)	Parameter Weight (W_i)	Cumulative Pollution Rating ($P_i w_i$)
pH	4.5	5	0.055	0.275
TDS	106	7	0.05	0.35
BOD	6.1	3	0.061	0.183
COD	16.46	8	0.062	0.496
IRON	1.306	0.8	0.045	0.036
COLIFORM	7	18	0.052	0.936
TOTAL			$\sum W_i = 0.325$	LPI $= \frac{\sum_{i=1}^{m} w_i p_i}{\sum w_i} = 7.0031$

3.4 Health Risk Assessment

Table 9 shows the Chronic Daily Intake (CDI), Health Quotient (HQ), and the Hazard Index (HI) of groundwater in the sampled locations.

Table 9: CDI, HQ, and HI of groundwater in the sampled locations.

Sampling site	Population	Chronic Daily Intake (CDI)			Health Quotient (HQ Values			Hazard Index (HI)
		Lead	Iron	Copper	Lead	Iron	Copper	
S1	Adult	0.0000274	0.00356	0.000274	0.00685	0.00508	0.00685	0.01878
	Children	0.0000639	0.00831	0.000639	0.00159	0.0118	0.0159	0.02929
S2	Adult	0.0000274	0.00329	0.000274	0.00685	0.0047	0.00685	0.0184
	Children	0.0000639	0.00767	0.000639	0.00159	0.0109	0.0159	0.02839
S3	Adult	0.0000274	0.005	0.000548	0.00685	0.00714	0.0137	0.02769
	Children	0.0000639	0.0118	0.00128	0.00159	0.0168	0.032	0.05039
S4	Adult	0.0000274	0.00339	0.000274	0.00685	0.00484	0.00685	0.01854
	Children	0.0000639	0.00793	0.000639	0.00159	0.0113	0.0159	0.02879
S5 (CP)	Adult	0.0000274	0.00236	0.000603	0.00685	0.00337	0.015	0.02522
	Children	0.0000639	0.00549	0.00141	0.00159	0.00784	0.0352	0.04463

3.5 Correlation Coefficient between Groundwater Parameters

The correlation coefficients between the examined groundwater parameters were calculated using Microsoft Excel and are presented in Table 10.

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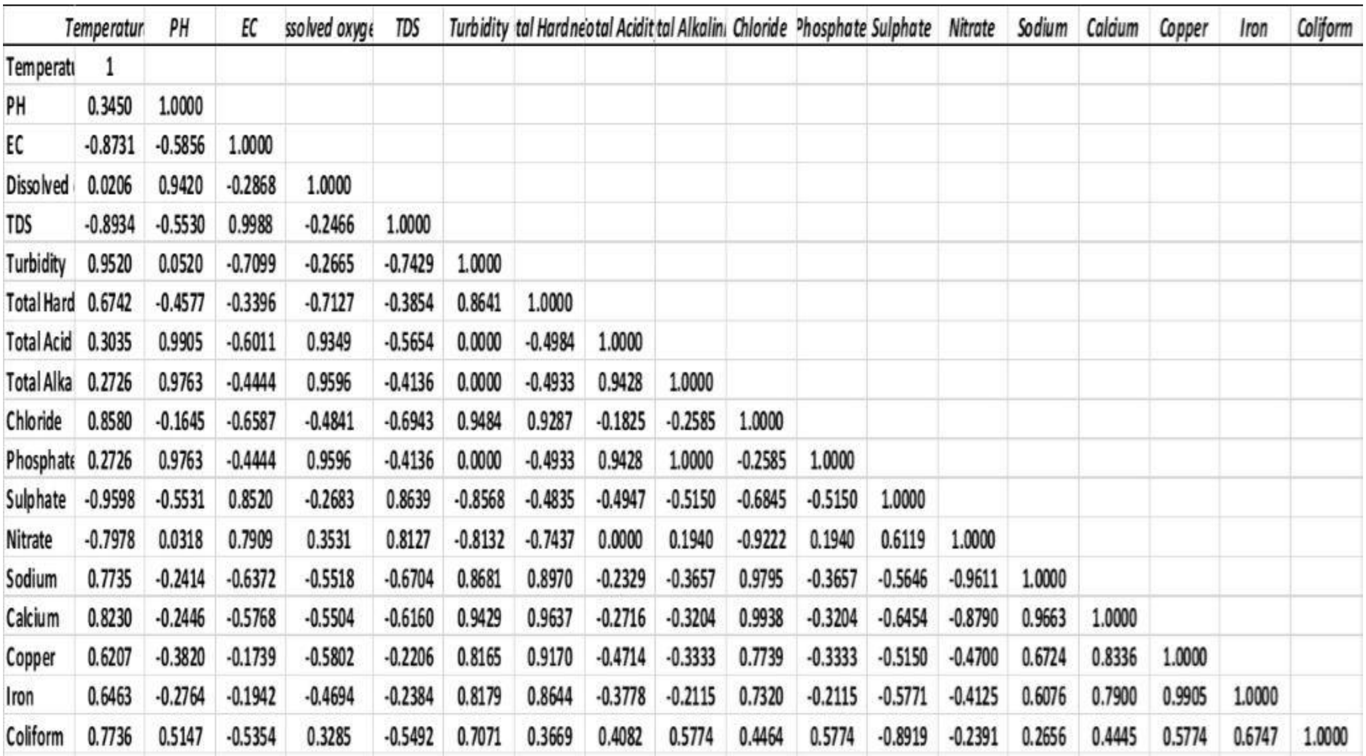
Table 10: Correlation Coefficient between the examined Groundwater Parameters



	Temperatur	PH	EC	ssolved oxyg	TDS	Turbidity	tal Hardne	otal Acidit	tal Alkalin	Chloride	hosphate	Sulphate	Nitrate	Sodium	Calcium	Copper	Iron	Coliform
Temperat	1																	
PH	0.3450	1.0000																
EC	-0.8731	-0.5856	1.0000															
Dissolved	0.0206	0.9420	-0.2868	1.0000														
TDS	-0.8934	-0.5530	0.9988	-0.2466	1.0000													
Turbidity	0.9520	0.0520	-0.7099	-0.2665	-0.7429	1.0000												
Total Hard	0.6742	-0.4577	-0.3396	-0.7127	-0.3854	0.8641	1.0000											
Total Acid	0.3035	0.9905	-0.6011	0.9349	-0.5654	0.0000	-0.4984	1.0000										
Total Alka	0.2726	0.9763	-0.4444	0.9596	-0.4136	0.0000	-0.4933	0.9428	1.0000									
Chloride	0.8580	-0.1645	-0.6587	-0.4841	-0.6943	0.9484	0.9287	-0.1825	-0.2585	1.0000								
Phosphat	0.2726	0.9763	-0.4444	0.9596	-0.4136	0.0000	-0.4933	0.9428	1.0000	-0.2585	1.0000							
Sulphate	-0.9598	-0.5531	0.8520	-0.2683	0.8639	-0.8568	-0.4835	-0.4947	-0.5150	-0.6845	-0.5150	1.0000						
Nitrate	-0.7978	0.0318	0.7909	0.3531	0.8127	-0.8132	-0.7437	0.0000	0.1940	-0.9222	0.1940	0.6119	1.0000					
Sodium	0.7735	-0.2414	-0.6372	-0.5518	-0.6704	0.8681	0.8970	-0.2329	-0.3657	0.9795	-0.3657	-0.5646	-0.9611	1.0000				
Calcium	0.8230	-0.2446	-0.5768	-0.5504	-0.6160	0.9429	0.9637	-0.2716	-0.3204	0.9938	-0.3204	-0.6454	-0.8790	0.9663	1.0000			
Copper	0.6207	-0.3820	-0.1739	-0.5802	-0.2206	0.8165	0.9170	-0.4714	-0.3333	0.7739	-0.3333	-0.5150	-0.4700	0.6724	0.8336	1.0000		
Iron	0.6463	-0.2764	-0.1942	-0.4694	-0.2384	0.8179	0.8644	-0.3778	-0.2115	0.7320	-0.2115	-0.5771	-0.4125	0.6076	0.7900	0.9905	1.0000	
Coliform	0.7736	0.5147	-0.5354	0.3285	-0.5492	0.7071	0.3669	0.4082	0.5774	0.4464	0.5774	-0.8919	-0.2391	0.2656	0.4445	0.5774	0.6747	1.0000

3.6 DISCUSSION OF RESULTS

3.6.1 Descriptive Statistics and Comparison with WHO and NSDWQ

The physicochemical and bacteriological water quality parameters, the descriptive statistics, and comparisons with WHO standards are presented in Tables 4. The temperature values range from 26.85 to 30.2 °C, having a mean value of 29.09°C. The WHO and NSDWQ standard for acceptability is 25 °C. The sample's mean value is above 25°C, which may affect the taste, odour, and solubility of gases. Leachate decomposition generates heat and increases biological oxygen demand, resulting in a slight temperature rise. The pH values range from 3.2 to 7.0, with a mean value of 4.4, which falls far below the permissible limits, indicating that the water is acidic. This could be a result of organic acids, CO_2, and heavy metals in the leachate. Leachates from dumpsites/landfills often contain humic and fulvic acids, ammonia, and sulfates, lowering pH. Acidic pH increases corrosion and metal solubility (e.g., Po, Fe, Cu). The pH values, which indicate that groundwater is highly acidic, are also in line with the study by Ogbeifun et al. (2019), which recorded pH values ranging from 4.32 to 5.55. Electrical Conductivity has a value ranging from 50 to 140, with a mean of 101.6, which is well within the WHO and NSDWQ limits. This indicates low overall ionic content. Although leachate normally raises conductivity, here the values are still low, suggesting dilution or low mineral load in leachate. TSS has a uniform value of less than one throughout the sampling points, and the reason for this could be that the water had been filtered as it was collected from a tap, therefore having minimal particulate pollution. Suspended matter usually increases with leachate intrusion, but here the <1 mg/L suggests filtration through soil layers before reaching groundwater. DO values range from 1.52 to 6.19mg/l, having a mean value of 4.568, which is at the minimum requirement of the WHO and NSDWQ standards. Organic matter in leachate consumes oxygen during decomposition, reducing DO. Adequate oxygen is crucial for aquatic life and taste; lower levels lead to anaerobic conditions and foul odor. TDS has a mean value of 51.3mg/l, and the value of each sampling point ranges from 14.9 to 71.2 mg/l. Its mean value is well below the permissible limits of the WHO and NSDWQ standards, which means that it has no adverse effect on health. Very high levels of TDS could cause taste issues and health risks. Turbidity has a mean value of 1.304 NTU, with the different sampling point values ranging from 0.52 to 1.6 NTU, which is within the WHO and NSDWQ standards of 5 NTU. This value implies that the water is safe in terms of turbidity; higher values would harbor pathogens and reduce water quality. The Total hardness parameter has no harmful effect in this case since the mean value of 14.4mg/l is much lower than the permissible standard of WHO (100mg/l) and NSDWQ (150mg/l). Extremely soft water may be corrosive to pipes. Chloride has a mean value of 14.378mg/l, which is within the WHO and NSDWQ standards of 250mg/l. This indicates that the water in this case is safe, as excess chloride causes a salty taste and hypertension risk. Lead is another important parameter having values ranging

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from <0.001 to < 0.01 mg/l, with a mean value of 0.00082mg/l, which falls within the permissible limit of the WHO and NSDWQ standards of 0.01. Chronic exposure to high lead causes kidney, liver, neurological, and developmental issues.

Total acidity is a measure of the water's ability to neutralize alkalinity due to the presence of acidic substances. WHO and the NSDWQ do not prescribe a health-based limit for total acidity. Total acidity values range from 0.4mg/l to 1.2mg/l with a mean value of 0.72mg/l. These values are very low, meaning the water has only slight acidity and is close to neutral. It suggests minimal impact of leachate infiltration into the groundwater. If leachate had strongly percolated, we would expect higher acidity. Alkalinity is the ability of water to neutralize acids (buffering capacity). Natural groundwater usually has moderate alkalinity, which protects it from rapid pH changes. The NSDWQ and WHO have no direct health-based limit for alkalinity. Total alkalinity values for S2 - S4 are <0.01, which is extremely low; S1 is 4mg/l, and S5 is 2mg/l. These values are very low, showing weak buffering capacity across all sites, especially at S2–S4. It suggests that acidic components of leachate have neutralized much of the natural alkalinity, especially at S2–S4. The water is therefore susceptible to pH drops and may become corrosive if leachate infiltration increases. Sodium is a naturally occurring ion in water, often derived from the dissolution of minerals (e.g., halite, feldspar), industrial discharges, and, more importantly, leachate from open dumpsites and landfills. WHO has no strict health-based guideline for sodium, but a palatability threshold of 200 mg/L is given. Also, the NSDWQ recommends a maximum permissible limit of 200 mg/L for sodium, based on taste and consumer acceptability. Sodium values range from 1.63mg/l to 16.61mg/l with a mean value of 10.878mg/l. Low sodium concentration indicates that the water has not been significantly impacted by saline intrusion, industrial contamination, or municipal solid waste leachate rich in dissolved salts. The impact of leachate infiltration is minimal or absent at the sampling point. Phosphate concentrations at S2 - S4 are <0.01mg/l, S5 < 0.001mg/l and S1 is 0.27mg/l. These are very low values, with only S1 showing a slightly higher concentration compared to the rest. WHO does not set a health-based guideline for phosphate because it is not considered toxic at typical concentrations. NSDWQ also has no direct limit for phosphate. The low phosphate concentrations (≤0.27 mg/L) show that the water is clear and safe for drinking from the standpoint of phosphate. Since neither WHO nor NSDWQ sets a strict limit, these values are considered acceptable and indicate good water quality with no risk of nutrient-related problems. The NSDWQ sets sulphate limits at 100mg/l, and the WHO limit is set at 250mg/l. S1, S3, and S5 show sulphate content of <0.01mg/l, which is practically negligible, while S2 (6.82 mg/L) and S4 (14.43 mg/L) are slightly higher, but still very low compared to the standards. All values are far below the WHO (250 mg/L) and NSDWQ (100 mg/L) standards, so there is no health risk. Copper is a trace element required in very small amounts for human health (enzyme function, hemoglobin synthesis, etc.). WHO set limits at 2.0mg/l, and the NSDWQ set limits at 1.0mg/l. Copper values from all sampling points range from 0.01mg/l to 0.022mg/l with a mean value of 0.0144mg/l. Since the concentrations are well below the WHO and NSDWQ limits, the water is safe regarding copper. It indicates that copper is not a major pollutant of concern in this case.

However, excess copper (above standard limits) can cause gastrointestinal irritation, liver/kidney damage, and an unpleasant metallic taste. Calcium (Ca^{2+}) is a major cation in natural waters and is a key contributor to water hardness. The calcium values range from 6.5mg/l to 11.33mg/l with a mean value of 8.404mg/l. The WHO and NSDWQ set calcium limits at 75mg/l; therefore, calcium levels from all sampling points are within this limit. Low calcium (soft water) is not directly harmful to health, but it reduces water's buffering capacity, making it more susceptible to pH fluctuations and corrosion. It also indicates that the water source is relatively untouched by leachate, since leachate often increases hardness. The Nitrate values range from 0.02mg/l to 5mg/l with a mean value of 3.084mg/l. The WHO guideline for nitrate in drinking water is 50mg/l, and the NSDWQ is set at 10mg/l. Nitrate (NO_3^-) is a key indicator of pollution from agricultural runoff, sewage, or landfill leachate. Low nitrate levels suggest that the leachate has not yet percolated deep enough to reach the water sources (s1, s2, s3, s4, and s5). The water is safe from nitrate contamination and poses no risk of methemoglobinemia ("blue baby syndrome") or other health effects. The Nigerian Standard for Drinking Water Quality (NSDWQ, 2007) and the WHO guidelines (2017) set the permissible limit for iron in potable water at 0.3 mg/L. Low concentrations (well below this limit) indicate that the water is safe from iron-related issues affecting taste, odor, and color. Low iron values at S1, S2, S3, S4, and S5 indicate either good aquifer oxygenation, effective natural attenuation, dilution, or weak leachate intrusion. Coliforms (especially E. coli) are not usually pathogenic themselves but are used as indicator organisms of fecal contamination. Their presence in the leachate sample confirms that the waste material in the dumpsite contains organic matter of human or animal origin (food waste, faeces, sewage, etc.). Their presence in the water samples (S1 and S3) indicates that leachate has likely infiltrated and contaminated the water source. This is in line with Akinbile and Yusoff's (2011) findings in assessing the environmental impact of leachate pollution in groundwater supplies. This makes the water unsafe for drinking without proper treatment, as it can cause waterborne diseases like diarrhea, dysentery, cholera, and typhoid.

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3.6.2 Leachate Result

A pH value of 4.5 indicates that the leachate is acidic. Acidic pH in leachate typically results from the breakdown of organic waste and the release of organic acids, sulphates, and other acidic compounds during the acidogenic phase of waste decomposition. Acidic leachate can dissolve heavy metals from waste, increasing their mobility and thereby increasing the potential for groundwater contamination. BOD measures the amount of oxygen microorganisms require to break down organic matter. BOD value of 6.1mg/l is a moderately low value compared to young leachate (>1000 mg/L). This indicates the leachate is in a stabilized/mature phase of decomposition, with relatively low biodegradable organic matter remaining. COD measures both biodegradable and non-biodegradable organics. COD value of 16.46mg/l is low compared to typical young leachate (>3000 mg/L). This confirms that the waste has undergone significant stabilization, and organic pollution potential is relatively low. EC indicates the level of dissolved salts (ions) in leachate. EC value of 200 µS/cm is low compared to fresh leachate, which often exceeds 2000 µS/cm. This suggests reduced salinity and ion concentration, again showing a mature leachate with less contamination potential. TDS represents the amount of inorganic salts and some organic matter dissolved in the leachate. TDS value of 106mg/l is quite low (young leachate often >1000 mg/L). This indicates that the leachate is relatively dilute and not highly mineralized, which may be due to the age of the dumpsite or dilution by rainwater infiltration. Ammonia is released during the degradation of proteins and organic nitrogen in waste. An ammonia concentration of 8.08 mg/L is a significant concentration, showing ongoing release of nitrogen compounds. High ammonia is toxic to aquatic life and a concern if leachate reaches groundwater or surface water. Lead (Pb) indicates the presence of a toxic heavy metal, likely from batteries, paints, or electronics. At a concentration of 0.013mg/L, it exceeds the WHO guideline for drinking water (0.01 mg/L), making it a potential health risk if leachate contaminates water supplies.

Iron (Fe) comes from corroded metals, cans, or soil minerals. The iron concentration of 1.306mg/L is above the WHO and NSDWQ permissible limit of 0.3 mg/L for drinking water, showing strong contamination. The WHO guideline for Cadmium (Cd) in drinking water is 0.003 mg/L. Cadmium concentration of 0.002 mg/L is within limits but still concerning due to cadmium’s cumulative toxicity. Mercury typically comes from batteries, fluorescent bulbs, thermometers, switches, electronic waste, and some industrial residues. WHO drinking water guideline for mercury is 0.006 mg/L. Even at very low concentrations, mercury is highly toxic and can cause damage to the nervous system, kidneys, and brain, especially in children. Mercury value of <0.01 mg/L is below the detection level. This suggests either no measurable mercury is present, or it exists in concentrations too low for the equipment to detect. The presence of coliform indicates microbial contamination and the possible presence of disease-causing organisms (pathogens). According to WHO (2017), Coliform count in drinking water should be 0 cfu/100 ml (complete absence). Also according to the NSDWQ (2007), no coliform organisms should be detectable in 100 ml of drinking water. Coliform concentration of 7 cfu/ml is a relatively low microbial load for leachate (young leachate often has thousands–millions of cfu/ml). However, compared to drinking water standards (where any presence is unacceptable), this result shows microbial pollution risk if leachate infiltrates groundwater. Even at low levels, coliforms indicate that pathogens such as E. coli, Salmonella, or Shigella may be present, which can cause diarrhea, typhoid, and cholera.

The leachate sample is acidic (pH 4.5) with low BOD, COD, TDS, and EC, suggesting it comes from a mature or stabilized dumpsite where most biodegradable material has already decomposed. However, it still contains notable contaminants like Ammonia (8.08 mg/L), which indicates nitrogen pollution risk, Lead (0.013 mg/L) and Iron (1.306 mg/L), which are above safe drinking water limits and Coliform bacteria which shows microbial contamination. This means that while the leachate is not as heavily polluted as young leachate, it still poses chemical (heavy metals, ammonia) and biological (coliform) risks if it migrates into groundwater or surface water.

3.6.3 Water Quality Index

The water quality index at five (5) locations show that location 1 (S1) has WQI of 41.25 and a corresponding water status of Good, location 2 (S2) has WQI of 34.08 and a corresponding water status of Good, location 3 (S3) has WQI of 32.53 and a corresponding water status of Good, location 4 (S4) has WQI of 34.1 and a corresponding water status of Good and location 5 (S5) has WQI of 22.366 and a corresponding water status of Excellent as presented in table 4.9 above. From the water quality index classification, the results obtained from the five (5) locations 100% of the locations' water is Good. Even with “Good” WQI, any detected coliform means the water must be treated. This treatment helps to manage low alkalinity, as reported.

In comparison, Longe and Enekwechi (2007) observed that leachate migration significantly affected groundwater quality in their investigation of potential groundwater impacts from leachate at a municipal landfill. Their findings emphasized that the local hydrogeological setting strongly influenced the degree of contamination and the natural attenuation capacity of groundwater. Specifically, areas with shallow water tables and permeable subsurface formations exhibited higher susceptibility to leachate percolation and pollution, often resulting in elevated concentrations of chemical parameters above acceptable limits.

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While this study indicates that groundwater around the study area falls within the "Excellent to Good" category based on WQl, the results should be interpreted with caution. Unlike the findings of Longe and Enekwechi (2007), where hydrogeological conditions limited natural attenuation in certain zones, the relatively better WQI status in this study may be attributed to variations in hydrogeology and spatial variability. Overall, while both studies highlight the influence of leachate on groundwater, the current findings suggest relatively lower pollution levels than those reported by Longe and Enekwechi (2007).

Table 11: Water quality status

Water quality index range	Type of water quality	No. of boreholes within each range	Percentage of boreholes within each range
0 -25	Excellent	1	20%
26 - 50	Good	4	80%
51 - 75	Poor	0	0%
76 - 100	Very Poor	0	0%
> 100	Unsuitable	0	0%
Total		5	100%

3.6.4 Leachate Pollution Index (LPI)

Figures 2 show the average sub-index curves of the pollutants. These curves for each parameter were plotted to illustrate the relationship between leachate pollution and the concentration or intensity of the pollutants, as reported by Kumar and Alappat (2003a).

This study adopted the Indian standard for leachate disposal due to the unavailability of specific standards in Nigeria. According to Kumar et al. (2003), the leachate disposal standard has a value of 7.378. This indicates that any LPI value below this threshold is considered acceptable, while values exceeding it are not. The LPI value obtained in this study was 7.0031, suggesting that the leachate from this dumpsite has minimal potential for contamination. Nevertheless, it still poses a potential risk to public health and the surrounding environment.

However, when compared with the leachate pollution index (LPI) reported by Simon and Ayotamumo (2022), the obtained value of 7.0031 in this study was significantly lower than the LPI value of 17.004 recorded at an active dumpsite. This indicates that the leachate from the present study area is less toxic than that of the active dumpsite reported in their research.

The LPI value obtained from this study was relatively low and below the standard established by Kumar and Alappat. This can be attributed to the low concentrations of pollutant parameters, as well as factors such as the dumpsite’s location and the nature of the waste deposited there, mainly stationary materials, plastics, and similar items. This finding aligns with the good water quality index values recorded from the sampled boreholes, indicating that the leachate exerts minimal impact on the surrounding water sources.

3.6.5 Health Risk Assessment

The Chronic Daily Intake (CDI) values obtained in this study ranged from 0.0000274 to 0.0000639 for lead (Pb), 0.00236 to 0.0118 for iron (Fe), and 0.000274 to 0.00141 for copper (Cu), as presented in Table 4.12. Comparable results were reported by George et al. (2025), who recorded CDI values ranging from 0.00137 to 0.00227 for lead, 0.00334 to 0.027 for iron, and 0.000959 to 0.00164 for copper in Southeast Maseru, Lesotho. In contrast, Oyem et al. (2015) reported a higher CDI value of 0.0075 for lead in groundwater samples from Agbor and Owa, Nigeria.

The observed trend of heavy metal concentration in this study followed the order Fe > Cu > Pb, indicating that iron contributed the most to the overall metal load in the groundwater. All CDI values were found to be below their respective reference dose (RfD) limits, implying negligible risk from chronic exposure through water consumption in the study area.

Furthermore, the computed Hazard Quotient (HQ) values for lead, iron, and copper ranged from 0.00159 to 0.00685, 0.00337 to 0.0168, and 0.00685 to 0.032, respectively. Since all HQ values were below the critical threshold of 1.00, this suggests a low probability of non-carcinogenic health effects associated with the ingestion of these metals among residents within the Faculty of Law, Delta State University, Oleh. These findings are consistent with the results of Njoku et al. (2024), George et al. (2025), and Jessica et al. (2020), who also reported HQ values below 1.00 for lead, iron, and copper in groundwater samples from Ogun State (Nigeria), Southeast Maseru (Lesotho), and Islamabad (Pakistan), respectively.

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The calculated Hazard Index (HI) values for the sampled locations were 0.01878 (S1), 0.0184 (S2), 0.02769 (S3), 0.01854 (S4), and 0.02522 (S5). All recorded HI values are significantly below the critical threshold of 1.00, indicating that potential non-carcinogenic health risks associated with the analyzed contaminants are minimal within the study area. This implies that prolonged exposure to groundwater from these locations is unlikely to result in adverse health effects in adults or children.

These findings are consistent with those reported by George et al. (2025), who observed similarly negligible HI values for groundwater in Southeast Maseru, Lesotho, suggesting limited health implications. Conversely, Zhang et al. (2019) and Boateng et al. (2019) documented HI values exceeding 1.00 in their respective studies, implying potential health risks due to elevated concentrations of toxic metals in the groundwater systems they examined.

3.6.6 Correlation Coefficient between Groundwater Parameters

The correlation coefficient was scanned between the groundwater parameters to investigate the degree of correlation between them, as given in Table 2. A strong correlation ($r \geq 0.9$) was found between Ca^{2+} and Cl^{-}, while a moderate correlation was noticed between several water specifications, such as between Fe^{3+} and Cl^{-}, and between Fe^{3+} and Ca^{2+}.

From this analysis, we can conclude that the sources of Ca^{2+}, Fe^{3+}, and Cl^{-} are the same.

CONCLUSION

The groundwater quality within the Faculty of Law, Delta State University, Oleh campus was evaluated by testing and analyzing 20 water quality parameters in five existing boreholes in the area. The results indicated that the mean concentrations of most parameters were within the permissible limits established by the World Health Organization (WHO). The quality of most groundwater samples fell within the tolerance limits stipulated by the WHO and the Nigerian Standard for Drinking Water Quality (NSDWQ). However, certain groundwater samples revealed elevated microbial populations, including total coliform bacteria counts ranging from 4 to 7, with a mean of 5, which exceeds the standards set by the WHO and NSDWQ.

Utilizing the hydrogeological triangle, the direction of groundwater flow was determined to be from southwest to northeast, that is, point B (S2) towards points A (S1) and C (S3), with the dumpsite located centrally. This indicates that the direction of groundwater flow plays a significant role in groundwater contamination, as evidenced by the presence of coliform in S1 and S3. The level of coliform contamination may also be attributed to the proximity of a septic tank to the borehole. Also, the dumpsite was not properly lined as done in sanitary landfills, which made it possible for leachate to flow to sampling points.

The Water Quality Index (WQI) revealed that the water from four sampled boreholes was classified as "good" and the water from the control point was classified as “excellent”. The Leachate Pollution Index (LPI) value revealed that the leachate had minimal potential for contamination. Based on this rating, the boreholes in the Faculty of Law, Delta State University, Oleh campus are not suitable for drinking without proper treatment. In addition to this, the strong and moderate correlations observed among calcium, iron, and chloride indicate that these parameters likely originate from the same source.

While the water from the boreholes in the study area is fairly good, it is deemed unsafe for human consumption without treatment. The study concludes that the water quality of the five sampling locations in the Faculty of Law is not potable without prior treatment.

The health risk assessment conducted for the study area indicates that the groundwater is not entirely suitable for potable use, primarily due to elevated concentrations of copper (Cu) and iron (Fe) detected in certain borehole samples. Despite this, the computed Chronic Daily Intake (CDI), Hazard Quotient (HQ), and Hazard Index (HI) values for all analyzed metals were observed to be below the established reference limits, suggesting negligible non-carcinogenic health risks to the exposed population under current conditions.

Nonetheless, it is imperative to recognize that the persistence of these metals in the groundwater system poses potential long-term implications. Continuous consumption or exposure may lead to progressive bioaccumulation and biomagnification within biological systems, ultimately resulting in metal toxicity and possible adverse health outcomes over time. Therefore, periodic monitoring, effective groundwater management, and appropriate treatment interventions are strongly recommended to prevent the escalation of heavy metal contamination and safeguard public health within the study area

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