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Exploring the Effects of Waste Disposal on Groundwater Quality in Port Harcourt, Nigeria

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Abstract: The excessive dependence on landfill methods for waste disposal is a prevalent practice in Nigeria. Physicochemical and microbial investigations of groundwater sources near waste dumpsites and a mechanic workshop in Port Harcourt were performed to evaluate the quality of groundwater for drinking and other domestic uses. Ten (10) samples were collected in total. The acquired values for each parameter were contrasted with the suggested thresholds established by the World Health Organization (WHO) and the Nigeria Standard for Drinking Water Quality (NSDWQ). The results indicated a low pH across all sites, ranging from 4.01 to 5.97 and 3.45 to 4.66 during the dry and rainy seasons, respectively. The pH fell short of the acceptable standards set by WHO and NSDWQ. The observed temperature during the dry season was 29.9℃-30℃, above the recommended standard, however in the rainy season, it ranged from 26.1℃-26.8℃, falling below the recommended standard of 27℃-28℃. COD, BOD, and DO exceeded the acceptable standards at all locations. The water quality index varied from 321.34 to 605.7 during the dry season and from 154.0 to 713.5, indicating that the groundwater is unsuitable for consumption. Cadmium, chromium, and iron concentrations varied from 0.027 ppm to 0.089 ppm and 0.017 ppm to 0.045 ppm, 0.088 ppm to 0.205 ppm and 0.018 ppm to 0.054 ppm, 0.491 ppm to 0.722 ppm, and 0.00 to 0.116 ppm, respectively, exceeding the required criteria. The bacterial analysis indicates that the total heterotrophic count peaked at PHD1, with 4.25 x 10^{-1} CFU/100 ml, but no growth was observed at sites PHC and PHD1 during the dry season. The elevated values have unequivocally demonstrated concerning, unacceptable, and inappropriate physicochemical properties and microbiological contamination from the dumpsite into the groundwater, thereby rendering it unsuitable for drinking and other domestic use in its current state.

Keywords: *Groundwater. Heavy Metals. Water Quality Index. Contamination.*

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I. INTRODUCTION

A landfill designated for the disposal of solid waste is termed a dump. Waste management, or waste disposal, encompasses the procedures and actions required to regulate trash from its inception to its final disposal [1]. This encompasses waste collection, transportation, treatment, and disposal, along with the monitoring and regulation of waste management processes, as well as waste-related legislation, technologies, and economic mechanisms [2]. There are numerous methods for the disposal and management of diverse waste kinds, including solid, liquid, and gaseous forms. Garbage management addresses all types of garbage, including organic, radioactive, biological, residential, municipal, and industrial trash. Waste can sometimes pose a threat to human health [3]. The comprehensive waste management procedure is associated with health issues. Furthermore, health issues can arise in two manners: directly from the management of solid waste and indirectly through the consumption of food, water, and soil [3]. Human activity generates waste, particularly during the extraction and processing of raw resources [4]. The objective of waste management is to mitigate the detrimental impacts of trash on the environment, human health, natural resources, and visual appeal. The objective of waste management is to mitigate the detrimental impacts of such garbage on the environment and public health. Waste management is a substantial component of managing municipal solid waste generated by residential, commercial, and industrial operations. Different nations employ varying strategies for waste management, influenced by their development status, regional characteristics (urban versus rural), and distinctions between residential and industrial sectors [5]. Establishing sustainable and habitable cities necessitates efficient waste management; nonetheless, numerous developing nations and urban areas continue to face challenges in this regard. A report indicates that effective trash management generally constitutes 20% to 50% of municipal budgets. Effective, durable, and socially advantageous integrated systems are essential for the operation of this crucial city service. The refuse produced by residences, enterprises, and industries predominantly consists of municipal solid waste (MSW), which is the primary concern of most waste management practices. The Intergovernmental Panel on Climate Change (IPCC)

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forecasts that global municipal solid waste generation will attain 3.4 gigatonnes by 2050 [6]. Health complications arising from the consumption of contaminated groundwater near filthy landfills have been associated with the transmission of diseases such as cholera and typhoid [7]. Moreover, consuming water contaminated with heavy metals can lead to non-communicable diseases such as cancer, gastrointestinal and renal issues, neurological disorders, vascular damage, and immune system impairment. It may also result in various congenital anomalies in early children [8]. Numerous research studies have investigated the impact of dumpsites on groundwater quality, highlighting the potential health hazards associated with the utilization of water sources. Adeolu et al. [9] examined the impact of a dumpsite on the quality of adjacent groundwater sources in the Federal Capital Territory of Abuja, Nigeria. The majority of nations have implemented various strategies to mitigate the detrimental consequences of environmental pollution by either preventing or restricting existing damage through proper waste management. One method is landfills, which are excavated sites equipped with specialized liners designed to contain compacted solid waste and prevent contamination of groundwater resources. Numerous studies propose diverse strategies to enhance solid waste management in developing nations, encompassing waste-to-energy initiatives and technologies, the integration of waste-to-energy with the recycling of glass, metals, and other inert materials, energy generation from biomass waste, and the engagement of waste pickers [10]. Owing to the elevated contamination levels in surface water and the unreliable water delivery from government-sanctioned water board agencies, individuals are resorting to groundwater sources such as boreholes as a supplementary source of potable water. The escalating need for groundwater promotes the indiscriminate digging of boreholes, especially shallow ones adjacent to dumpsites in residential zones [11]. A study indicates that increased rainfall elevates the volume of leachate to which groundwater is subjected. As a result, there will be an increase in preventable waterborne diseases and groundwater susceptibility to contamination [11]. The southeastern parts of Nigeria are also impacted by this unclean landfill system and the exploitation of groundwater supplies adjacent to dumpsites. Given its distinctive rainforest climate that promotes leachate infiltration from dumpsites into freshwater aquifers, it is essential to regularly assess groundwater quality in the vicinity of these sites against the standards set by the World Health Organization (WHO) and the Nigerian Standard of Drinking Water Quality (NSDWQ). This study sought to assess the impact of groundwater quality on human health.

II. MATERIALS AND METHOD

A. Study Area

B. Description of Study Area

Port Harcourt serves as the capital and the most populous city of Rivers State in Nigeria. It ranks as the fifth most populous city in Nigeria, following Lagos, Kano, Ibadan, and Benin. It is situated on the Bonny River within the oil-rich Niger Delta region. In 2023, the urban population of Port Harcourt is around 3,480,000. The population of the Port Harcourt metropolitan area is about double that of its urban area, with a 2015 United Nations estimate of 2,344,000. In 1950, Port Harcourt's population was 59,752. Since 2015, Port Harcourt's population has increased by 150,844, reflecting an annual growth rate of 4.99%.

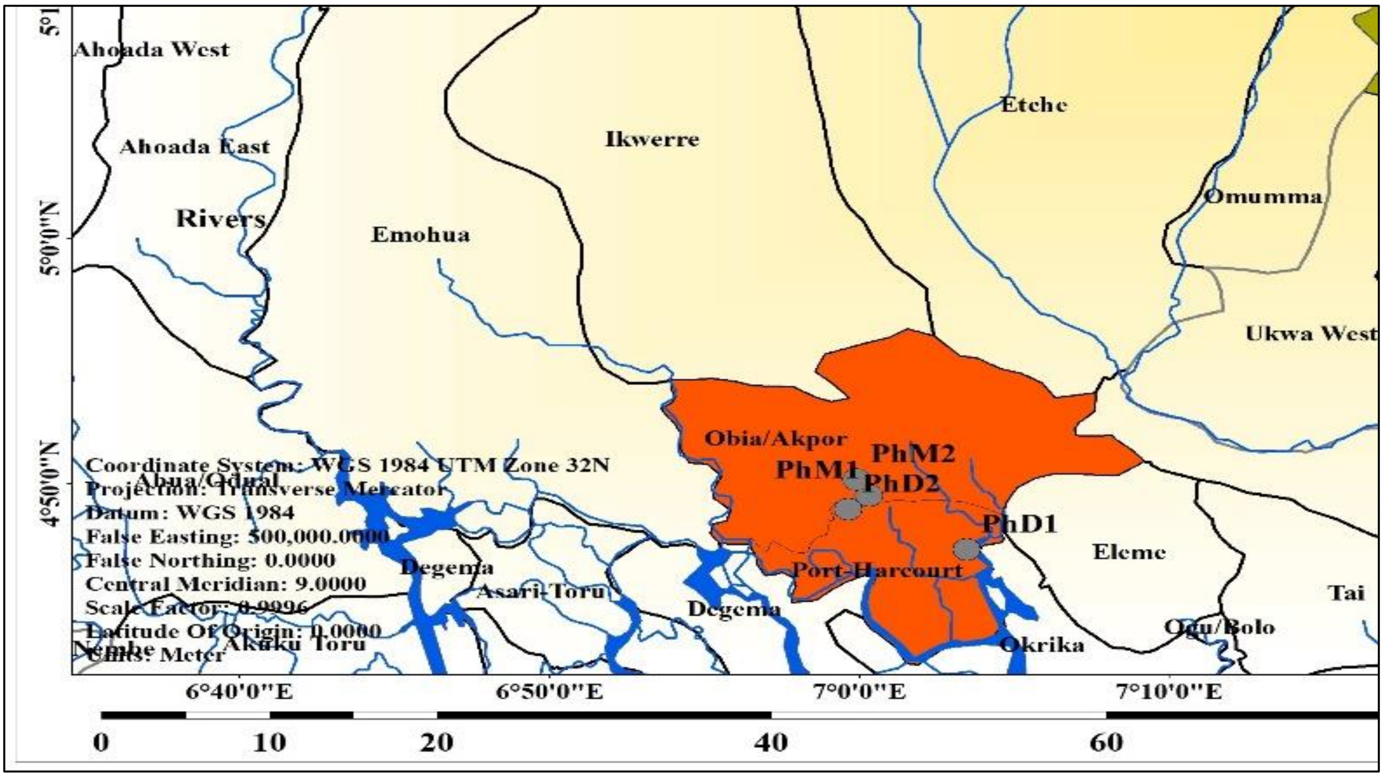

Fig 1: Location Map of the Study Area

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Table 1: Site Description

S/N	Sample Points Code	Longitude	Latitude
1	PHD1	7.057354	4.790178
2	PHD2	6.993486	4.817503
3	PHM1	7.004786	4.826806
4	PHM2	6.997899	4.83755

C. *Sample Collection*

Samples of water were collected from local boreholes situated near the waste dumpsites and mechanic workshop in Port Harcourt. Water samples were collected randomly from 10 boreholes located within residential areas, approximately 20 m to 100 m away from the dumpsite. A total of 10 samples were gathered, with 5 collected in the dry season and 5 during the rainy season. A total of five samples were collected from each location: two samples from boreholes adjacent to a solid waste dump, two from boreholes near a mechanic workshop or mechanic village, and one control sample. Aseptically collected samples for bacteriological and physicochemical analysis were placed in one-liter sterile containers. Samples were preserved at 4°C in an ice box and transported to the laboratory for analysis within a six-hour timeframe [12].

D. *Physicochemical Analysis*

The following physicochemical parameters were examined. The physical parameters consist of pH and temperature. The chemical parameters to be analyzed include Biochemical Oxygen Demand (BOD), Chemical Oxygen Demand (COD), Dissolved Oxygen (DO), Total Dissolved Solids (TDS), chloride, magnesium, and nitrate. The levels of heavy metals including cadmium (Cd), iron (Fe), zinc (Zn), lead (Pb), copper (Cu), and chromium (Cr) were assessed utilizing an Atomic Absorption Spectrophotometer [13]. All parameters were analyzed utilizing established methods and procedures [14]. All results will be compared with the World Health Organization [15] and the Nigeria Standard Drinking Water Quality [16].

E. *Water Quality Index*

This idea was introduced by Horton [17] using mathematical formulas to assess the state of the water quality and later modified by Brown et al. [18]. In evaluating the water quality index, nine parameters are considered. The initial step involves estimating the weight vector, accomplished by applying the standard values specified by WHO [15] for the nine parameters, utilizing Eq (1–2).

$$K = \frac{1}{\Sigma\left(\frac{1}{S_n}\right)} \quad \ldots\ldots(1)$$

The unit weight vector was then deduced using Eq. (2)

$$Wi = \frac{K}{S_n} \quad \ldots\ldots(2)$$

Where,
Wi is the ith parameter's unit weight.
Sn is the ith parameter's standard WHO value
K is the constant of proportionality.

From Eq. (2), it was clearly observed that the unit weight (Wi) varies directly with the permissible standard (Sn).

Using the relationship provided by Anjum et al. [19] in Eq. (3), the quality rating or sub index (Qi) was calculated.

$$Qi = \left(\frac{V_o - V_i}{S_n - V_i}\right) x\ 100 \quad \ldots\ldots(3)$$

Vo is the ith parameter's measured concentration value
Vi is the ideal values of ith parameter.
Sn is the typical recommended value of the ith parameter.

In this study, with the exception of pH and DO, which has an ideal value of 7.0 and 14.6 respectively, all parameters must have an ideal value of zero.

The water quality index (WQI) was calculated by summing up sub index of all ith parameters using Eq. (4) given by Duc et al. [20].

$$WQI = \frac{\sum Q_i W_i}{\sum W_i} \quad \ldots\ldots(4)$$

The five suggested water categories listed by Brown et al. (1972); Excellent (0–25%), Good (26–50%), Poor (51–75%), Very poor (76–100%), and Unsuitable (>100%), can be used to estimate the water quality index for domestic suitability.

F. *Analysis of Bacteriological Quality*

G. *Sample Preparation and Isolation*

The membrane filtration technique was employed. The apparatus was positioned, and the vacuum pump was connected. The funnel was removed, and sterile smooth-tipped forceps were employed to collect the membrane filter paper, which was subsequently placed on the porous disc of the filter base. The sterile funnel was thereafter replaced on the filter base with care and precision. The water sample was well mixed by inverting the container twenty-five times. One hundred milliliters (100 ml) of the water sample was introduced into the funnel and gradually filtered through the membrane filter paper, which was meticulously extracted using sterile smooth-tipped forceps and positioned with the grid side facing upward on nutrient agar (total heterotrophic count), MacConkey agar (coliform count), Eosin Methylene blue agar (faecal coliform count), TCBS agar (*Vibrio* count), *Salmonella-Shigella* agar (*Salmonella* and *Shigella* count), and Mannitol salt agar (*Staphylococcus* count). The plates were incubated at 30°C for 24 hours, while the brain heart infusion agar was incubated in an anaerobic jar for the same duration.

H. *Purification of the Isolates*

Colonies that developed on the agar plates were subcultured severally onto freshly prepared nutrient agar plates. The plates were incubated at 30^0C for 24 hours. Colonies which developed after incubation, was picked and inoculated into freshly prepared nutrient agar slants.

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I. Identification of the Isolates

The isolates were identified through morphology, microscopy, and biochemical characterization using the ABIS online software for bacterial identification [21] [22].

III. RESULTS AND DISCUSSION

A. Physicochemical Characteristics of Groundwater Samples

The findings from the physicochemical analysis of groundwater in the vicinity of the Port Harcourt dumpsite and mechanic are presented in table 2. The pH value of drinking water should ideally be neutral. This study recorded the mean pH for the dry and rainy seasons as 4.66 and 3.842, respectively, both of which are below the recommended standards set by WHO [15] and NSDWQ [16]. The average pH values indicate the acidic characteristics of the groundwater in this region across the sampling periods. This suggests the existence of harmful metals in the water [23]. The observed variations for BOD, COD, and DO are as follows: BOD ranges from 61.0 mg/l to 74.0 mg/l, COD from 79.1 mg/l to 94.4 mg/l, and DO from 32.0 mg/l to 64.0 mg/l during the dry season, while in the rainy season, BOD ranges from 90.0 mg/l to 142.5 mg/l, and DO from 7.2 mg/l to 8.4 mg/l and 12.9 mg/l to 23.8 mg/l respectively. These exceed the recommended standards set by WHO [15] and NSDWQ [16]. The authors Abd El Salam and Abu-Zuid [24] and Abdullahi et al. [25] documented elevated concentrations of 74 mg/L and 726 mg/L for COD, and 52.5 mg/L and 241.2 mg/L for BOD, surpassing the WHO standards of 40 mg/L for COD and 10 mg/L for BOD. The elevated levels of COD, BOD, and DO observed in the study area indicate the potential influence of leachate from nearby dumpsites or landfills in the boreholes located in proximity to these sites, as well as the organic strength generated by this contamination.

Table 2: Mean Concentration of Physicochemical Parameters of Water Samples in Port Harcourt during dry and Rainy Season

S/N	Parameters	Min (Dry)	Min (Rani)	Max (Dry)	Max (Rain)	Mean (Dry)	Mean (Rain)	STDEV (Dry)	STDEV (Rain)	WHO 2010	NSDWQ 2007
1	Ph	4.01	3.15	5.97	4.66	4.604	3.842	0.8462	0.6616	6.5-8.5	6.5-8.5
2	Temp. °C	29.9	26.1	30	26.8	29.98	26.64	0.0447	0.305	27-28	27-28
3	TDS (Mg/l)	4	4	156	99	114	57	62.9603	37.336	500	500
4	DO (Mg/l)	7.2	12.7	8.4	23.78	7.84	18.192	0.532	4.0897	6	4-7
5	BOD (Mg/l)	61	79.12	74	94.37	67	88.436	5.4314	6.6581	4	3
6	COD (Mg/l)	32	90	64	142.5	46.926	108.25	12.739	24.552	10	NS
7	Cl^- (Mg/l)	20	13	47	39	37	27	10.464	9.3541	250	250
8	NO_3^- (Mg/l)	6.45	9.693	17.27	20.953	14.0054	16.0816	4.3253	3.9955	50	50
9	Mg^{2+}(ppm)	6.489	2.489	8.942	6.082	8.216	3.71	1.1875	1.3923	50	0.20

Key: Min= minimum, max= maximum, stdev= standard deviation, WHO= world health organization, NSDWQ= Nigeria standard for drinking water quality, Temp.= temperature, TDS= total dissolved solid, DO= dissolved oxygen, BOD=biological oxygen demand, COD= chemical oxygen demand, Cl= chloride, Mg= magnesium, NO_3= Nitrate

B. Heavy Metal Characteristics of Groundwater Samples

The heavy metals in groundwater in Port Harcourt during dry and rainy season is shown in table 3. Zinc has an average value of 0.32 ppm and 0.07 ppm that is below the recommended standard (3.0) for dry and rainy season. The WHO recommended nutritional tolerance of zinc for men is 15 milligrams/day (15 mg/day); for women 12 mg/day; for children 10 mg/day; and for infants 5 mg/day [26]. Zinc is an indispensable constituent in human diet. Inadequate zinc can result in health problems, but surplus zinc is also risky. Severe toxicity might bring about sweet taste, dryness of throat, weakness, chills, nausea, generalized aching, fever and vomiting. Chronic toxicity can result to stomach cramps, vomit, nausea, anemia and pancreas harm [27]. Chromium, cadmium and iron has a range of 0.09 ppm -0.21 ppm and 0.02 ppm – 0.05 ppm, 0.03 ppm – 0.09 ppm and 0.02 ppm – 0.05 ppm, 0.5 ppm -0.7 ppm and 0.00 ppm – 0.12 ppm for dry and rainy season respectively. The values are above the recommended standard by WHO [15] and NSDWQ [16]. Ogunsanwo et al. [28] also recorded high value of Cd and Fe above the recommended limit. Higher concentrations of the heavy metals were recorded in dry season than in rainy season. There was no significant difference (P= 0.272735) as compared to the rainy and dry season.

Table 3: The Heavy Metals Variations in Water Samples for Both Rainy and Dry Seasons in Port Harcourt

S/N	Parameters	Min (Dry)	Min (Rani)	Max (Dry)	Max (Rain)	Mean (Dry)	Mean (Rain)	STDEV (Dry)	STDEV (Rain)	WHO 2010	NSDWQ 2007
1	Cd (ppm)	0.027	0.017	0.089	0.045	0.0664	0.0272	0.0263	0.012	0.003	0.003
2	Cr (ppm)	0.088	0.018	0.205	0.054	0.1522	0.0322	0.0428	0.0142	0.005	0.005
3	Zn (ppm)	0.189	0.045	0.422	0.083	0.3214	0.0708	0.1002	0.01482	3.0	3.0
4	Pb (ppm)	0.093	0.0016	0.132	0.059	0.1084	0.0231	0.01762	0.0234	0.3	0.01
5	Fe (ppm)	0.491	0.00	0.722	0.1161	0.5924	0.4402	0.1041	0.8288	0.3	0.3
6	Cu (ppm)	0.394	0.047	0.522	0.8089	0.4782	0.3254	0.0502	0.3382	2.0	1.0

Key: Min= minimum, max= maximum, stdev= standard deviation, WHO= world health organization, NSDWQ= Nigeria standard for drinking water quality, Cd= cadmium, Cr= chromium, Zn= zinc, Pb= lead, Fe= iron, Cu= copper.

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C. Water Quality Index (WQI)

The statistical analysis of borehole water concentration values yielded the results presented in Table 4. Nine physicochemical parameters were taken into account to assess the water quality index. The estimated WQI was observed to range from 321.3 to 605.7 % during the dry season and from 154.0 to 713.5 % during the rainy season. The findings indicated that the Water Quality Index determined for all the groundwater falls within the unfit for consumption classification as outlined by Brown et al. [18], rendering the water inappropriate for both domestic and agricultural use. The measured Water Quality Index at the study sites indicated elevated levels of Dissolved Oxygen and Biochemical Oxygen Demand across all samples, highlighting a significant cause for concern. The findings align with those of Oko et al. [29], who examined the water quality index of borehole and well water in Wukari town, Taraba State, Nigeria, and reported that the water quality was unsuitable for drinking, with a well water WQI of 136 in Wukari Town, Taraba State. This aligns with the findings of Ishaku [30] regarding the evaluation of the groundwater quality index for the Jimeta Yola region in North-eastern Nigeria, which indicated a WQI of 138.5, deeming it unfit for human consumption without treatment. In their study on groundwater quality assessments for appropriate drinking and agricultural irrigation, Mohammad et al. [31] reported a Water Quality Index (WQI) for borehole water ranging from 115.45 to 279.72, and for well water, the WQI values were between 312.76 and 201.14, based on physicochemical water analysis conducted in the Rancaekek Jtinangor District, West Java, Indonesia. Amaibi et al. [32] documented a WQI value of 358.78 at a sampling site in Rivers State, Nigeria.

Table 4: Water Quality Index (WQI)

S/N	Sample	WQI (dry)	Water quality status	WQI (rain)	Water quality status
1	PHC	385.6	Unsuitable for drinking	217.3	Unsuitable for drinking
2	PHM1	605.7	Unsuitable for drinking	274.10	Unsuitable for drinking
3	PHM2	378.7	Unsuitable for drinking	713.5	Unsuitable for drinking
4	PHD1	321.3	Unsuitable for drinking	154.0	Unsuitable for drinking
5	PHD2	346.6	Unsuitable for drinking	228.8	Unsuitable for drinking

D. Bacteriological Quality

Figures 1 through 4 illustrate the bacterial count in Port Harcourt across both seasons. The counts for *Salmonella Shigella* (SSC) and Total *Staphylococcus* (TSC) showed no growth in either season. The Total heterotrophic count (THC) exhibited the highest growth in both seasons, with recorded values of 1.20 x 10-1 CFU/100 ml (PHM1) during the dry season and 4.25 x 10-1 CFU/100 ml (PHD1) in the rainy season. The bacteria count in both seasons shows no significant difference (0.19).

Safe drinking water should be devoid of harmful microorganisms and toxic chemical substances that pose risks to health [33]. Drinking water must be free from bacteria that indicate faecal pollution or the presence of pathogens. A nuanced approach to evaluating the quality of drinking water involves identifying faecal indicator bacteria, as it is impractical to test for every potential pathogen that could be present [34]. The primary factor contributing to water pollution is human activity [35]. The total heterotrophic counts of the borehole water samples fall within the permissible limit of 100 cfu/ml for potable water; however, certain sites surpassed the established limit as per NSDWQ [16]. The findings indicate a significant correlation between microbial concentrations in groundwater and rainfall patterns. The wet season samples exhibited a higher concentration than those from the dry season, indicating that runoff plays a crucial role in the temporal distribution of bacteria in the area, given that certain indicator organisms are linked to particles carried by runoff [36]. This aligns with the findings of Ochelebe et al. [37]. The identification of the isolates relies on their morphological characteristics, microscopy observations, and biochemical analysis. The isolates recognized in the dry season include *Staphylococcus* sp., *Bacillus* sp., *Aneurinibacillus* sp., *Micrococcus* sp., *Lysinibacillus* sp., *Psueodomonas* sp. The organisms identified during the rainy season are *Paeniacillus* sp., *Providencia* sp., *Klebsiella* sp., *Enterobacter* sp., *Staphylococcus* sp., *Achromobacter* sp., *Bacillus* sp., *Micrococcus* sp., *Vibro* sp., *Cronobacter* sp., *Pseudomonas* sp., and *Areomonas* sp.

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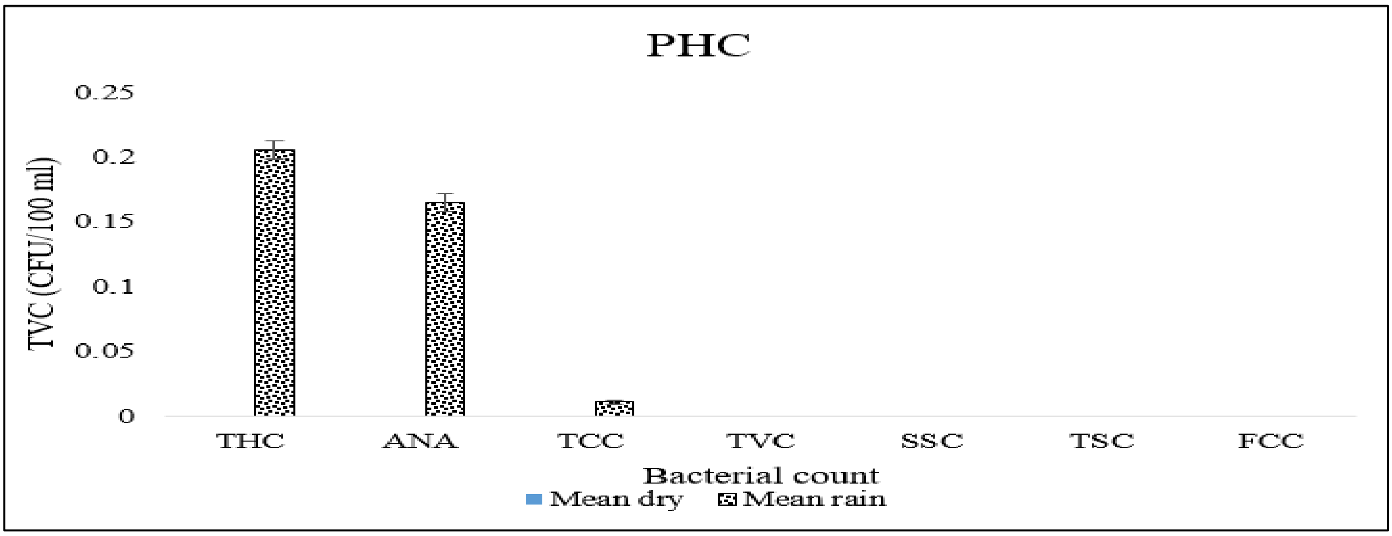

Fig 2: Bacterial Count for Port Harcourt Control

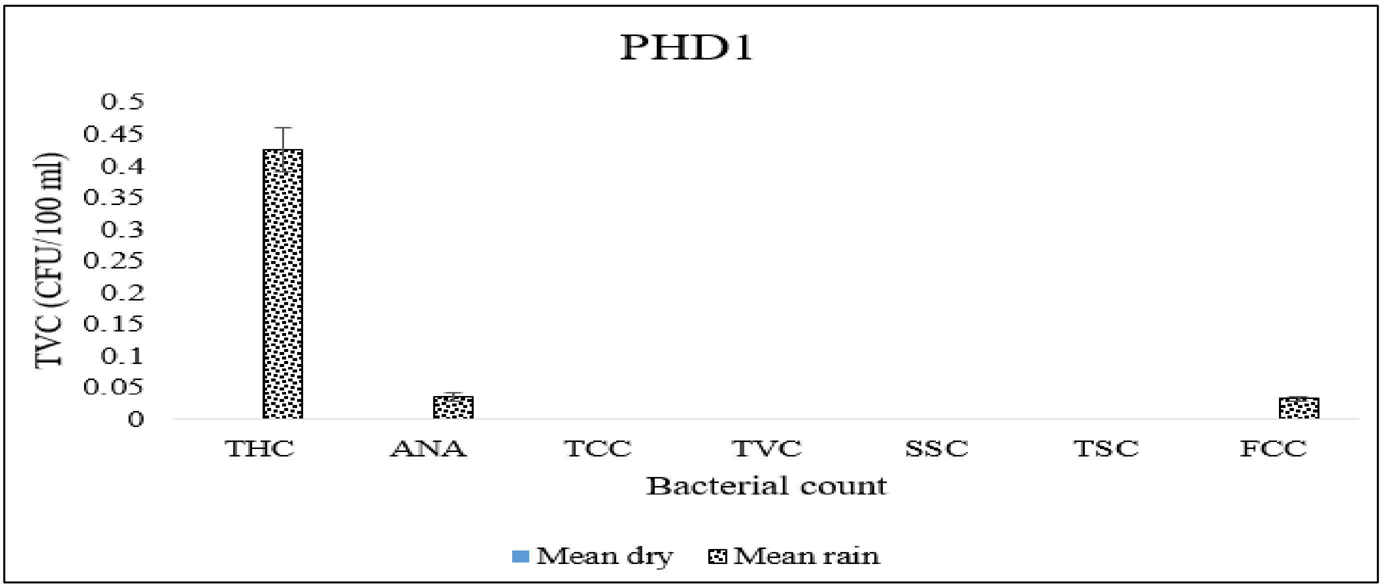

Fig 3: Bacterial Count for Port Harcourt Dumpsite 1

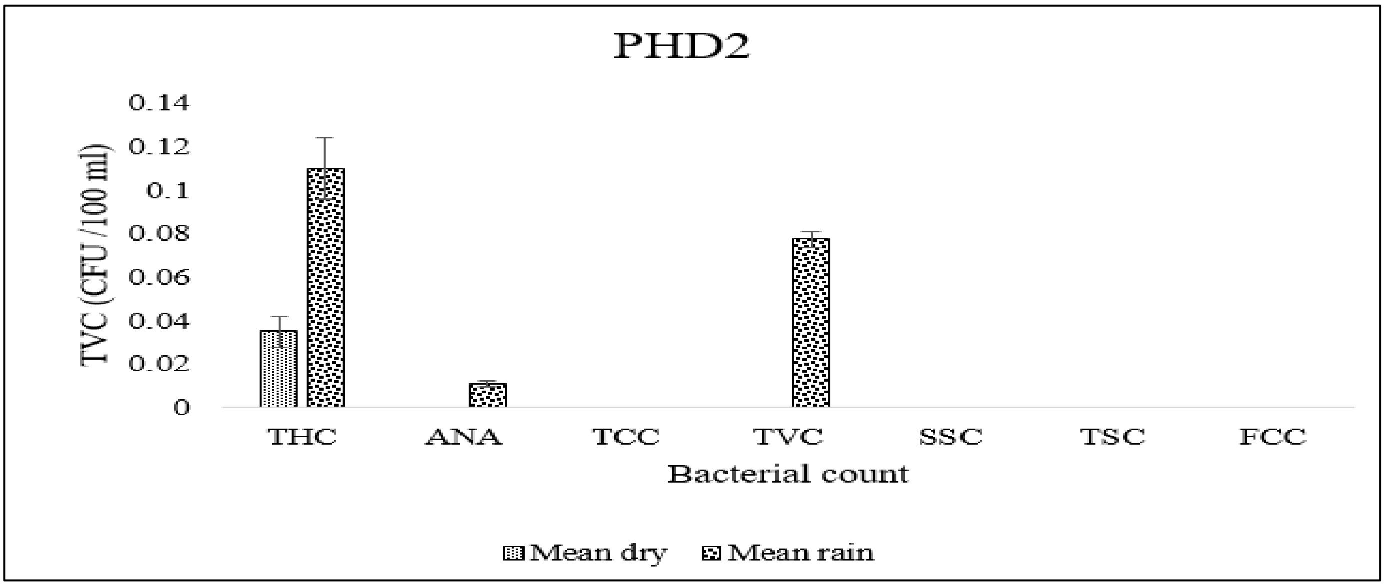

Fig 4: Bacterial Count for Port Harcourt Dumpsite 2

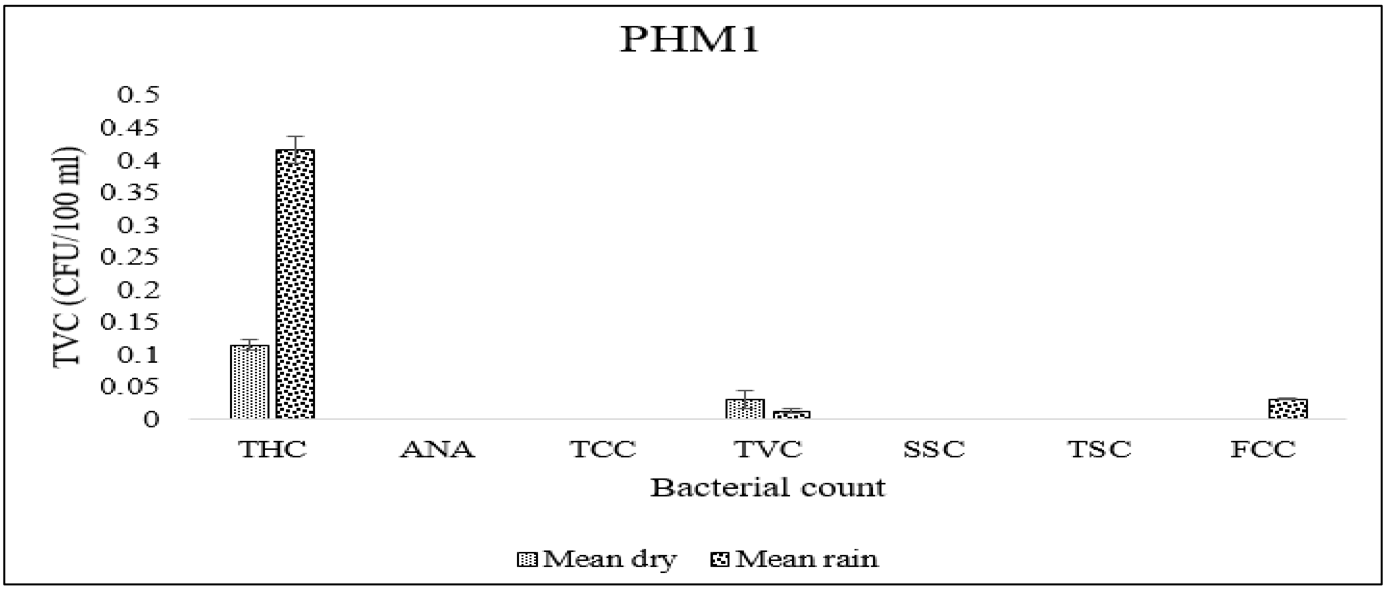

Fig 5: Bacterial Count for Port Harcourt Mechanic 1

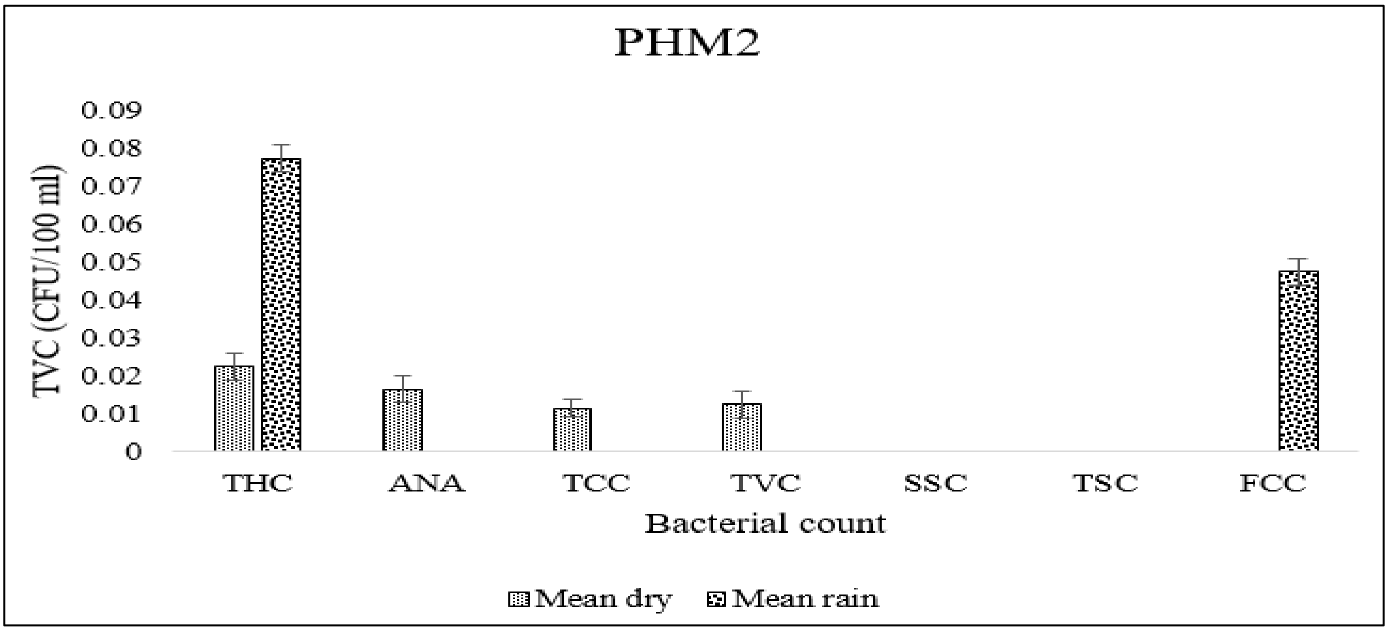

Fig 6: Bacterial Count for Port Harcourt Mechanic 2

IV. CONCLUSION

The availability of groundwater as an alternative drinking water source in Nigeria is at risk due to the increasing number of unsanitary dumpsites, particularly in urban areas. The investigation focused on the movement of leachate into groundwater near the Port Harcourt dumpsite. This clearly restricts the functions of groundwater for multiple applications. The consequences of groundwater pollution may also be linked to various health-related issues. Groundwater samples in the study area exhibited notably low pH levels, which were associated with elevated concentrations of heavy metals such as lead, cadmium, iron, chromium, copper, and zinc across all locations. The groundwater is rendered unfit for consumption.

➢ *The Study Recommends:*

Locating water sources at a considerable distance from soakaways and wastewater bodies or canals.

- The practice of boring shallow boreholes for drinking water ought to be discouraged.
- Sustainable waste management practices must be prioritized and consistently followed.
- The Nigerian government should consider implementing alternative waste management strategies, including recycling and minimizing the use of single-use products.

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