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# Hydrochemical response of groundwater to seasonal rainfall-induced deep percolation around a dumpsite

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## Abstract

Groundwater quality for wet and dry seasons around an active dumpsite in Aluu, Port Harcourt, was evaluated using a combination of pollution indices, microbial count, and statistical models. Water samples were collected and analyzed for physicochemical and microbial parameters using standard methods. Dilution factor (DF) and correlation heatmap were used to synthesize the source of the contamination while heavy metal pollution Index (HPI) and Nemerow comprehensive pollution index ($CPI_{Nemerow}$) were used to evaluate magnitude of groundwater contamination. Results show that electrical conductivity, total hardness, magnesium, lead, cadmium, and total heterotrophic bacteria (THB) exceeded the Nigeria Standard for Drinking Water Quality allowable limits for both seasons. The HPI values for the dry (476.76) and wet (3849.4) seasons and the $CPI_{Nemerow}$ values for the dry (31.69) and wet (107.37) seasons greatly exceeding the critical values of 100 and 3 respectively. THB counts were also high, however a drop in count occurred from $2.8 \times 10^3$ CFU/mL during the dry to $3.2\times 10^2$ CFU/mL during the wet season. An indication that the effect of rainfall on groundwater quality is different for chemical and microbial parameters. While for chemical contaminants, rainfall enhanced mobilization, for microbes rainfall enhanced dilution. The correlation heatmap and the DF showcased the measured parameters in two distinct categories based on hydrochemical control and contaminant source. The study concludes that groundwater from the study area is severely polluted and unsuitable for domestic or agricultural use without advanced treatment.

**Keywords:** Deep percolation; Groundwater pollution; Pollution Indices; Rainfall; Seasonal Variation

## 1. Introduction

Uncontrolled dumpsites represent persistent and highly variable sources of groundwater contamination due to leachate generation. Leachate is a complex liquid formed from the percolation of water through decomposing waste materials. It typically contains a mixture of dissolved organic matter, inorganic ions, heavy metals, and microbial pathogens. It's composition evolves over time depending on waste characteristics and environmental conditions [1]. The infiltration of leachates through soil layers allows hazardous substances to percolate into the aquifer system, posing a significant threat to groundwater resources [2]. Once contaminated, groundwater may remain polluted for extended periods often beyond feasible remediation. Such contamination can lead to the spread of waterborne diseases due to the natural movement and interconnectivity of groundwater systems [3]. Contaminated groundwater source therefore endangers human health and the environment.

Heavy metals represent a critical aspect of groundwater contamination due to their toxicity, persistence, and potential for bioaccumulation [4,5]. Metals such as lead, cadmium, and chromium are commonly associated with landfill leachate and can enter groundwater systems through leaching processes. Their mobility is influenced by geochemical conditions,

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including pH and redox potential, with increased solubility often observed under acidic or oxidising conditions [6 -8]. Microbial contamination further compounds groundwater quality deterioration, particularly in areas where waste disposal practices are poorly regulated. The infiltration of microbial contaminants into groundwater is facilitated by the percolation of leachate and the absence of effective natural filtration barriers. Despite the significant health risks associated with microbial contamination, including waterborne diseases, it is frequently underrepresented in groundwater studies, leading to incomplete assessments of water quality in dumpsite-impacted environments [9].

Rainfall infiltration is the principal driver of leachate generation, promoting the dissolution and mobilisation of contaminants. In the absence of engineered containment systems such as liners and leachate collection facilities, this contaminated fluid migrates through the vadose zone and eventually reaches the groundwater table. Although natural attenuation processes, including adsorption and biodegradation, may reduce contaminant concentrations to some extent, their effectiveness is often limited in highly permeable soils, allowing significant quantities of pollutants to reach the aquifer [10 – 12].

Seasonal variation plays a crucial role in influencing groundwater contamination, particularly tropical regions characterised by distinct wet and dry seasons. During the wet season, increased precipitation enhances groundwater recharge and promotes the mobilisation of contaminants from the surface. Increased precipitation also leads to increased leachate generation and facilitates deeper infiltration into aquifers. The resulting rise in hydraulic gradients accelerates advective transport, thereby increasing the spatial extent and concentration of contamination. Conversely, the dry season is often associated with reduced recharge and limited dilution, which may result in the increase of concentration of contaminants within the aquifer [13]. The interaction between these processes produces complex temporal dynamics, with contaminant levels varying significantly between seasons.

The assessment of groundwater quality has evolved from reliance on individual parameter analysis to the use of composite indices that provide a more integrated evaluation. The Water Quality Index is widely used to summarise overall water quality by combining multiple parameters into a single value, thereby facilitating comparison across locations and time periods. More specialised indices, such as the Heavy Metal Pollution Index, focus specifically on the combined effects of toxic metals and incorporate weighting factors based on their relative significance. The Nemerow Comprehensive Pollution Index ($CPI_{Nemerow}$) further extends this approach by integrating multiple physicochemical parameters to classify water quality into defined categories [14]. Many studies are based on single-season data and do not adequately capture the temporal variability associated with seasonal recharge [1-3, 5, 8]. Furthermore, the integration of hydrochemical, microbial, pollution indices, and statistical approaches remains limited, reducing the robustness of contamination assessments. The present study addresses these limitations by adopting an integrated approach that combines hydrochemical analysis, microbial assessment, and pollution indices with explicit consideration of seasonal variation. This approach provides a more comprehensive and realistic evaluation of groundwater quality in dumpsite-impacted environments and contributes to improved understanding of contaminant dynamics in vulnerable aquifer systems. The aim of this study is therefore to evaluate the seasonal variation of groundwater quality in the vicinity of an active dumpsite, using an integrated hydrochemical and pollution index model.

## 2. Materials and methods

### 2.1. Study Area

The study location is an active landfill open dump site situated at the new airport road, Aluu, Port Harcourt, Rivers State. The site lies within Latitude: 2$^{o}$ 28' 48.333"N and Longitude: 9$^{o}$ 23' 0.849"E. The average elevation of the site is 17m. A picture of the site is shown in Figure 1. Geologically, the study area is situated in the Niger Delta Basin. The Niger Delta basin is found on the continental margin of the Gulf of Guinea in equatorial West Africa between latitude 4°00 to 7$^{o}$00'N and longitude 5°00'E to 8$^{o}$00'E covering an area of about 108,900 km$^2$.

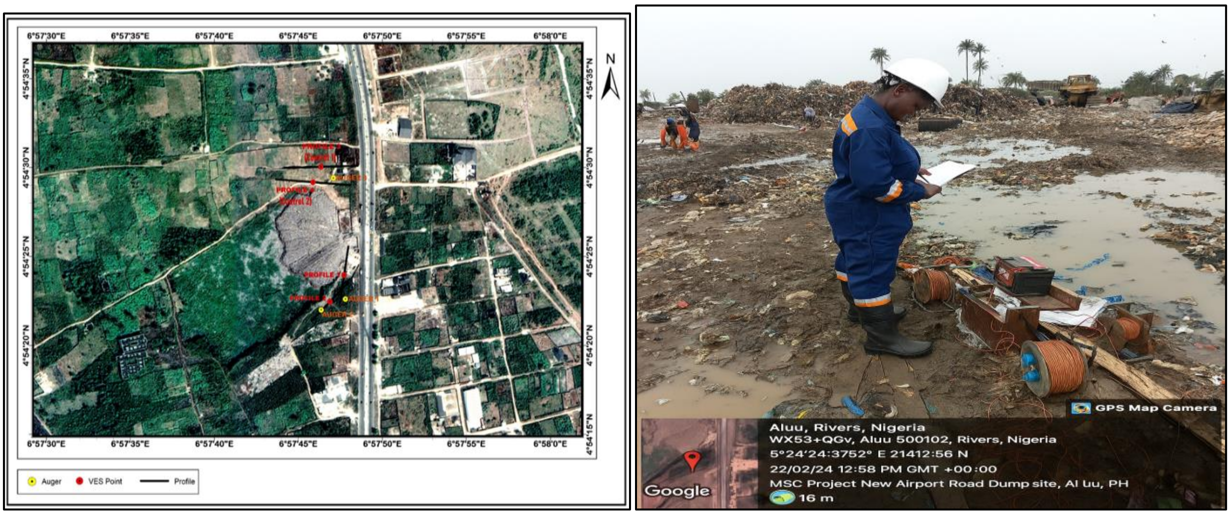


**Figure 1** Satellite Image of the Study Site and Direct Dumpsite Image

## 2.2. Water Parameter Analysis

In determining the quality of groundwater in both seasons (dry and wet seasons), standard procedures and methods were employed in the analysis of several parameters. Conductivity and pH were determined using a handheld multi-parameter tester (pH-W3988). Total hardness of water was determined by titrating the water sample against a standard solution of ethylene diamine tetra acetic acid (EDTA) using Eriochtome Black-T (EBT) indicator. Heavy metals (Fe, Pb, Cd, and Cr) were analyzed using atomic absorption spectrophotometer (Shimadzu AA-6650, China). Microbial analysis for total coliform was also achieved by the membrane filtration method, according to the APHA standard (APHA, 2017).

## 2.3. Water Pollution Indices

Two pollution indices were employed in the assessment of the impact of dumpsite leachate on groundwater including heavy metal pollution index (HPI) and Nemerow comprehensive pollution index ($CPI_{Nemerow}$) using Equations 2 to 7 and the descriptions as shown in Table 1. The microbial pollution level was assessed by the total heterotrophic bacteria (THB) count.

$$HPI = \frac{\sum_{i=1}^{n} W_i Q_i}{\sum_{i=1}^{n} W_i} \quad (2)$$

$$W_i = \frac{1}{S_i} \quad (3)$$

$$Q_i = \left(\frac{C_i - I_i}{S_i - I_i}\right) \times 100 \quad (4)$$

$$CPI_{Nemerow} = \sqrt{\frac{P_{avg}^2 + P_{max}^2}{2}} \quad (5)$$

$$P_{avg} = \frac{1}{n}\sum_{i=1}^{n} P_i \quad (6)$$

$$P_i = \frac{C_i}{S_i} \quad (7)$$

Where:
$W_i$= unit weight
$C_i$= measured concentration
$S_i$= standard permissible limit
$I_i$= ideal value
$P_{avg}$ = average of all pollution indices
$P_{max}$ = maximum pollution index

**Table 1** Classification of HPI and $CPI_{Nemerow}$ Values

| HPI Classification | | $CPI_{Nemerow}$ Classification | |
|---|---|---|---|
| $< 100$ | Low pollution (safe) | $< 0.59$ | Clean (safe) |
| | | 0.59 – 0.74 | Slight pollution |
| =100 | Threshold (critical) | - 1.0 | Moderate pollution |
| | | 1.0 – 3.5 | Heavy pollution |
| $> 100$ | High pollution (unsafe) | $\geq 3.5$ | Severe Pollution |

### 2.4. Seasonal Recharge and Dilution Effect

Seasonal effect on groundwater quality was analysed using dilution factor (DF) as shown in Equation 8

$$DF = \frac{C_{dry}}{C_{wet}} \quad (8)$$

Where $DF$= dilution factor and $C_{dry}$, $C_{wet}$= concentrations in dry and wet seasons. Values greater than unity indicate recharge and dilution during the wet season.

## 3. Results and Discussion

### 3.1. Comparing Physicochemical and Microbiological Properties of water sample of Both Wet and Dry Season with NSDWQ

The physicochemical and microbial properties of the groundwater quality at the dumpsite for both wet and dry seasons are displayed in Table 2. The results indicate that only pH, nitrate, sulphate and manganese for both seasons were within the Nigerian Standard for Drinking Water Quality (NSDWQ) guidelines while electrical conductivity (EC), total hardness (TH), magnesium (Mg), lead (Pb), cadmium (Cd), and total heterotrophic bacteria (THB) exceeded the NSDWQ allowable limits for both seasons. Chloride and chromium were found to be within the NSDWQ guidelines for the dry season only. Conversely, iron was within limit during the wet season and exceeded limit during the dry season. This implies that the water was not potable during any of the seasons.

**Table 2** Groundwater quality for dry and wet season with national guideline

| Parameter | Units | Dry | Wet | NSWDQ |
|---|---|---|---|---|
| pH | - | 8.02 | 7.32 | 6.5-8.5 |
| Electrical conductivity | µs/cm | 2710 | 2875 | 1000 |
| Total Hardness as CaCO3 | mg/l | 161.4 | 388.8 | 150 |
| Nitrate | mg/l | 0.61 | 4.89 | 50 |
| Chloride | mg/l | 135.9 | 395.2 | 250 |
| Sulphate | mg/l | 15.3 | 4.46 | 100 |
| Magnesium | mg/l | 8.9 | 1.364 | 0.2 |
| Iron | mg/l | 0.945 | 0.005 | 0.3 |
| Manganese | mg/l | 0.054 | 0.004 | 0.2 |
| Lead | mg/l | 0.052 | 1.506 | 0.01 |
| Cadmium | mg/l | 0.015 | 0.013 | 0.003 |
| Chrominum | mg/l | 0.003 | 3.167 | 0.05 |
| Total Heterotrophic bacteria (THB) | Cfu/ml | $2.8\times10^3$ | $3.2\times10^2$ | 0 |

NSDWQ – Nigeria Standard for Drinking Water Quality

### 3.2. Correlation Heatmap

The correlation Heatmap reflects two very strong water-quality clustering blocks (Figure 2). Cluster one consists of pH, sulphate, Mg, Fe, and Cd while EC, TH, nitrate, chloride, Pb, Cr, and THB make up Cluster two. The presence of two distinct clusters suggests that the groundwater quality is influenced by several factors including seasonal leachate generation, contaminant transport behavior through the vadose zone, and substrata geochemistry [15]. It was observed that a positive correlation exists within clusters while a strong negative correlation exists between the two clusters. The strong positive correlation observed among: (i) EC, TH, chloride, nitrate and (ii) Pb and Cr indicate a common contamination source, consistent with landfill leachate composition.

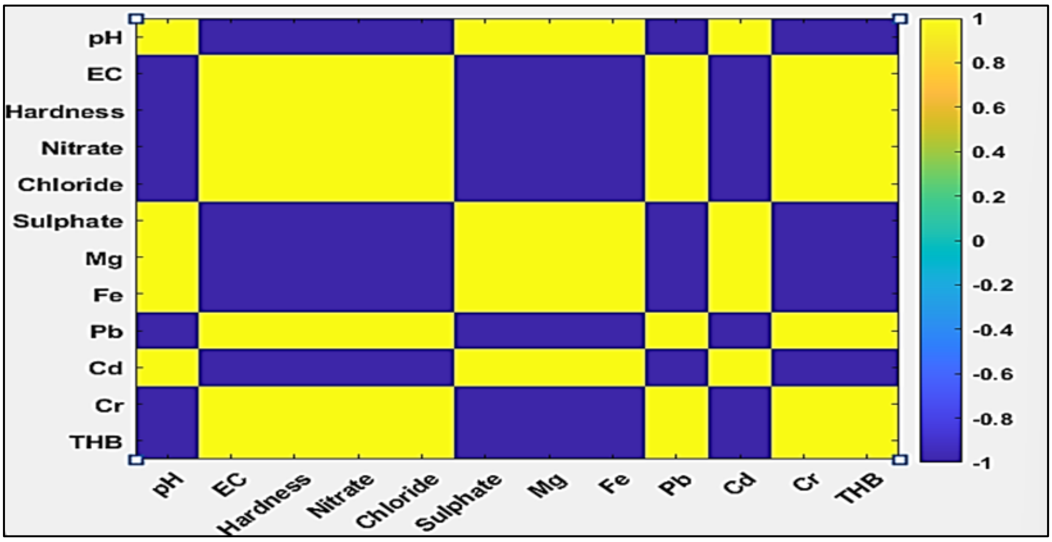


**Figure 2** Correlation Heatmap

### 3.3. Pollution indices

The heavy metal pollution index (HPI) and the Nemerow comprehensive pollution index ($CPI_{Nemerow}$) were used to describe the level of chemical pollution. Figure 3 presents the HPI and $CPI_{Nemerow}$ values for the sample during dry and wet seasons. Both water samples showed HPI and $CPI_{Nemerow}$ greater than the critical values of 100 and 3.5 respectively as displayed in Table 1 indicating severe pollution. This is similar to other works [16, 17]. The 70.49% increase of $CPI_{Nemerow}$ values from dry (31.69) to wet (107.37) season reflects cumulative contamination effects and enhanced transport under high recharge. The HPI data confirmed that heavy metals are the dominant chemical contaminants and that the dumpsite is a major source of heavy metal pollution of groundwater within the dumpsite vicinity. This supports the suggestion presented in Figure 2 that Pb and Cr may contribute substantially to elevated HPI values.

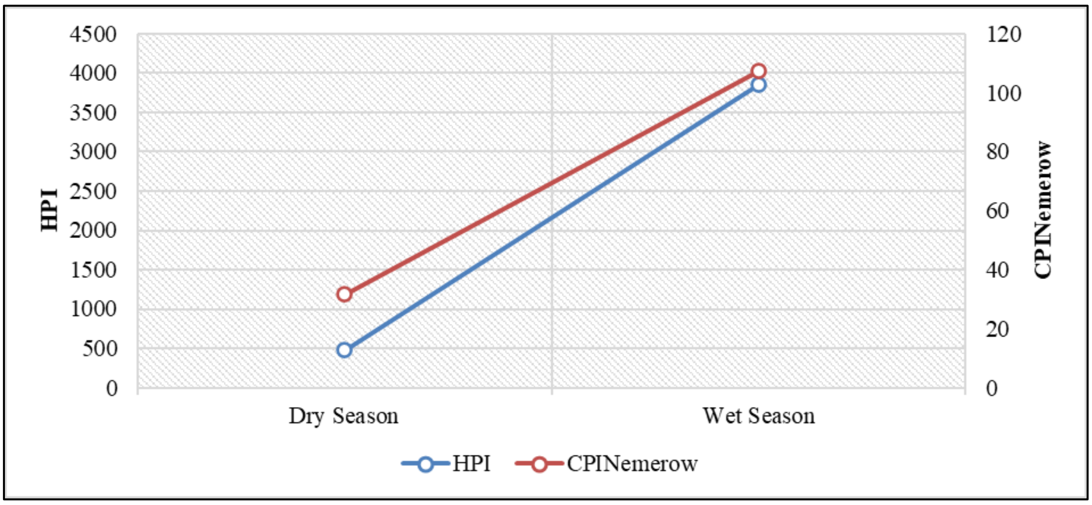


**Figure 3** Effect of seasonal variability on groundwater heavy metal pollution

The microbial quality of the water samples was assessed based on THB counts. Both samples recorded the presence of THB much greater than the zero limit of NSDWQ (Table 2). The microbial and heavy metal quality of this borehole imply that the borehole is a high-risk borehole and advanced water treatment technologies (e.g. adsorption, reverse osmosis, etc.) may be required in treating water from this borehole, as conventional filtration may not be effective for the removal the heavy metals.

### 3.4. Seasonal variation of Dumpsite borehole water quality

As illustrated in Table 2, 46% of the measured parameters for the dumpsite borehole water samples, were higher during the wet season compared to the dry season. These include EC, TH, , $NO_3^-$, $Cl^-$, Pb, and Cr, similar to the work of Suleiman and Hanafiah [18]. The remaining parameters (54%) showed higher values during the dry season. The results show substantial seasonal amplification of contamination such that (a) EC by 5.7%, (b) TH increased by 58%, (c) Nitrate increased by 88%, (d) Chloride increased by 66%, (e) Pb increased by 97%, and (f) Cr increased by 99.9%. The extreme increase in Cr and Pb is particularly significant, indicating strong mobilisation of heavy metals during rainfall events. These results confirm that contaminant transport is highly sensitive to seasonal recharge, with rainfall acting as a primary driver of leachate percolation and solute migration.

The wet season is associated with increased rainfall which plays a dual purpose – it enhances leachate generation and also allows for dilution of leachate. Increased concentration of measured parameters during the wet season was therefore attributed to enhanced infiltration and deep percolation of dumpsite leachate into the ground water table. While the higher concentration of parameters during the dry season was attributed to dilution effect of the wet season and this is when the dilution factor (DF) is greater than unity. Figure 4A and 4B show the parameters with $DF > 1$ and $DF < 1$ and their hierarchy respectively. These figures suggest that dilution effect due to seasonal variability is selective. Fe was observed to have the highest value (DF = 189). This is attributable to the fact that the dumpsite was an abandoned pit used for laterite extraction for construction purposes. Laterite soil contains high concentrations of Fe and Al [19] which is often transferred into the groundwater through leachate percolation.

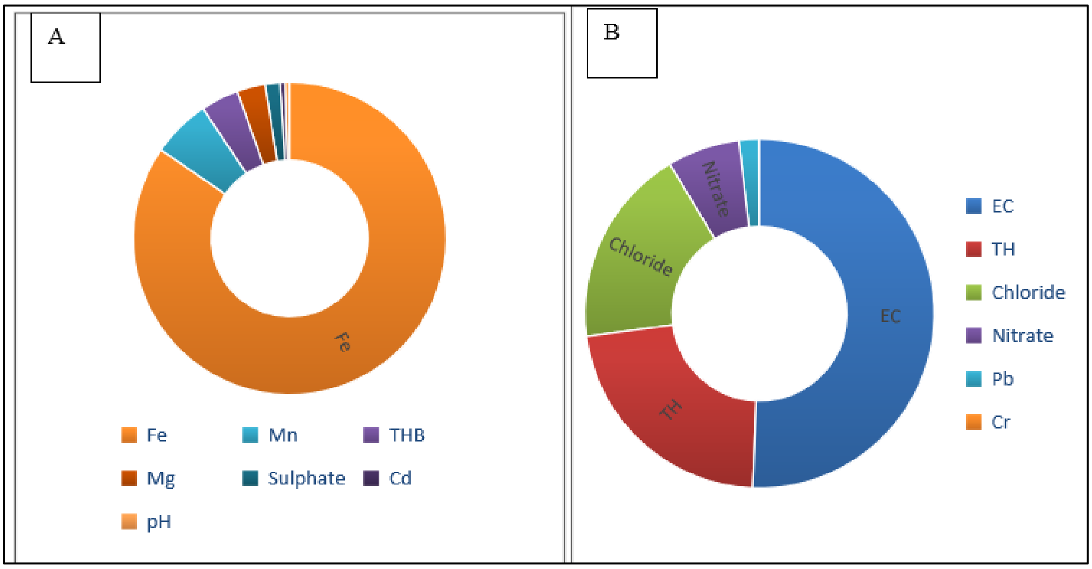


**Figure 4** Hierarchical Distribution of dilution factor for seasonal variability of graoundwater parameters: A - DF>1 and B - DF<1

The graphical analysis provides a robust, data-driven confirmation that groundwater quality in the study area is severely compromised. The integration of hydrochemical, pollution indices, and statistical approaches offers a comprehensive framework for assessing and managing groundwater contamination in landfill-impacted environments.

## 4. Conclusion

Groundwater quality in the vicinity of an open dumpsite is severely degraded, with contamination strongly influenced by seasonal hydrological processes and clearly establishing the dumpsite as a major source of toxic pollutants. Heavy metals showed extreme enrichment, with lead increasing by 97% and chromium 99.9% surpassing standards by over two orders of magnitude. The Heavy Metal Pollution Index (HPI) confirmed that heavy metals are the dominant chemical contaminants Microbial counts also remained high, with values up to $2.8\times10^3$ and $3.2 \times 10^2$ CFU/mL for dry and wet seasons respectively. Seasonal variation is due to strong rainfall-driven mobilization of contaminants and dilution. Overall, the findings confirm that groundwater in the study area is unsuitable for potable and agricultural use without advanced treatment and that contamination may extend beyond the immediate dumpsite due to subsurface transport processes.

## Compliance with ethical standards

### *Disclosure of conflict of interest*

No conflict of interest to be disclosed.

## References

[1] Okwuchukwu, C., & Akiri-Obaroakpo, T. (2022). Groundwater Quality Around Active and Non- Active Dumpsites in Benin City, Nigeria. Jordan Journal of Earth and Environmental Sciences, 13(4), 271–277.

[2] Lateef, T. A., Eluwole, A. B., & Adewa, D. J. (2015). Geoelectrical Assessment of the Impact of the Ilokun Dumpsite, Ado- Ekiti Southwestern Nigeria, on Surrounding Groundwater Aquifers. International Letters of Natural Sciences, 40(15), 41–47. https://doi.org/10.18052/www.scipress.com/ILNS.40.41

[3] Tovide, O., Adewale, P. S., and Oladimeji, I. E. (2024). Physicochemical and toxicological characteristics of leachates and water quality around dumpsites in Lagos Nigeria. CTU Journal of Innovation and Sustainable Development, 16(3):84-89. https://doi.org/10.22144/ctujoisd.2024.309

[4] Chojnacka K (2010). Biosorption and Bioaccumulation – The Prospects For Practical Applications. Environmental International, 36(3):299 https://doi.org/10.1016/j.envint.2009.12.001

[5] Mansourri, G. and Madani, M. (2016). Examination of the level of heavy metals in wastewater of Bandar Abbas Wastewater Treatment Plant. Open Journal of Ecology 6(2):55-61. https://doi.org/10.4236/oje.2016.62006

[6] Alloway, B. J. (2013). Heavy metals in soils (3rd ed.). Springer, https://doi.org/10.1007/978-94-007-4470-7

[7] World Health Organization. (2017). Guidelines for drinking-water quality. WHO.

[8] Maiti, S. K., Hazra, T., Debsarkar, A., & Dutta, A. (2017). Appraisal of Seasonal Variation of Groundwater Quality Near an Uncontrolled Municipal Solid Waste Landfill in Kolkata, India. Global NEST Journal, 19(3), 367–376. https://doi.org/10.30955/gnj.002172

[9] Edberg, S.C., Rice, E.W., Karlin, R.J. and Allen, M.J. (2000), Escherichia coli: the best biological drinking water indicator for public health protection. Journal of Applied Microbiology, 88: 106S-116S. https://doi.org/10.1111/j.1365-2672.2000.tb05338.x

[10] Christensen, T. H., Kjeldsen, P., Bjerg, P. L., Jensen, D. L., Christensen, J. B., Baun, A., Albrechtsen, H.-J., & Heron, G. (2001). Biogeochemistry of landfill leachate plumes. Applied Geochemistry, 16(7–8), 659–718. https://doi.org/10.1016/S0883-2927(00)00082-2.

[11] Kjeldsen, P., Barlaz, M. A., Rooker, A. P., Baun, A., Ledin, A., & Christensen, T. H. (2002). Present and Long-Term Composition of MSW Landfill Leachate: A Review. Critical Reviews in Environmental Science and Technology, 32(4), 297–336. https://doi.org/10.1080/10643380290813462

[12] Fetter, C. W. (2001). Applied hydrogeology. 4th Edition, Prentice Hall, Upper Saddle River.

[13] Odipe, O., E., Ogunleye, R., A., Sulaiman, M., Abubakar, S. S. and Olorunfemi, M. O. (2018). Integrated Geophysical and Hydro-chemical Investigations of Impact of the Ijemikin Waste Dump Site in Akure, Southwestern Nigeria, on Groundwater Quality. Journal of Health & Pollution, 8(18): 180604. https://doi.org/10.5696/2156-9614-8.18.180604

[14] Tripathi, P., Varma, K., Srivastava, V., Dlamin, S. N., and Jha, P. K. (2025). Heavy Metal Contamination and Associated Health Risk Assessment in Groundwater of Mirzapur, Uttar Pradesh. Frontiers in Water, 7:1694963. https://doi.org/10.3389/frwa.2025.1694963

[15] Alao, J. O., Otorkpa, O. J., Abubakar, F., Eshimiakhe, D., Aliyu, A., Abdulsalami, M., and Abdulmalik, D. O. (2024). Geoelectrical Resistivity and Geochemistry Monitoring Of Landfill Leachates Due To The Seasonal Variations And

The Implications On Groundwater Systems And Public Health. Scientific Reports, 14, 26542. https://doi.org/10.1038/s41598-024-77727-6

[16] Lin, Y., Liu, J., Zou, S., Wang, J., Fan, L., Zhou, C., and Lu, L. (2025). Characteristics Of Heavy Metal Element Content And Health Risk Assessment In Groundwater In Zhaojue Area, Sichuan Province, China. Scientific Report, 15:31773. https://doi.org/10.1038/s41598-025-13731-8

[17] Olowojuni, O. A., Amulejoye, F. D., Ikuesan, B. B., Maulu, S. Bwalya, H and Hasimuna, O. J. (2025). Water quality, heavy metal contamination, andecological risk assessment in Asejire reservoir, Nigeria. Journal of Freshwater Ecology, 40(1) 2516505. https://doi.org/10.1080/02705060.2025.2516505

[18] Suleiman, H. A. and Hanafiah, M. M. (2022). Seasonal Dynamics in relation to Groundwater Quality in Sharada Industrial Area of Kano Metropolis, Nigeria. IOP Conference Series: Earth and Environmental Science, 1167:012021. https://doi.org/10.1088/1755-1315/1167/012021

[19] Li, Z., Peng, C., Yichao, Wu., Andreas, K., Qiaoyun, H., & Wenli, C. (2022). Quantifying the contribution of biotic and abiotic processes to the formation of Fe–Mn nodules in a subtropical loess derivative laterite. Chemical Geology, 605, 120967. https://doi.org/10.1016/j.chemgeo.2022.120967