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Assessment of Physicochemical, Heavy Metals and Microbial Parameters in Leachate and Groundwater around Solid Waste Dumpsites at Onne, Rivers State, Nigeria

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ABSTRACT: The study assessed groundwater contamination from dumpsite leachate in Onne, Nigeria, over 12 months (May 2022–May 2023). Physicochemical (pH, EC, DO, BOD, TDS, turbidity, sulphate, phosphate, nitrate), heavy metals (Cr, Cd, Pb, Hg, Fe, Cu), and microbial (faecal and total coliform) parameters were analyzed in leachate and groundwater samples using standard methods. Statistical analysis (ANOVA, Tukey's HSD post-hoc, Pearson correlation) evaluated spatial variations and relationships between leachate and groundwater characteristics. Results showed significant contamination, with EC (232.3 ± 25.9 µs/cm), sulphate (3.77 ± 0.38 mg/L), phosphate (6.14 ± 0.36 mg/L), nitrate (1.19 ± 0.25 mg/L), Fe (0.32 ± 0.12 mg/L), Pb (0.02 ± 0.03 mg/L), and Hg (0.01 ± 0 mg/L) in groundwater samples, some exceeding WHO/NSDWQ limits. Leachate contained significantly higher levels of heavy metals, particularly Fe (77.4 ± 16.3 mg/L), Cu (23.1 ± 4.73 mg/L), and Cr (1.23 ± 0.4 mg/L), suggesting potential leachate migration influencing groundwater quality. Microbial counts (<2 MPN/g) remained within acceptable limits, with no significant variation. The analysis revealed significant spatial variations in the physicochemical, heavy metal, and microbial parameters across the dumpsites. The following recommendations are made; implement waste segregation and recycling programs at the source to reduce the amount of waste reaching the dumpsites and develop and implement leachate treatment systems to prevent contamination of groundwater and soil.

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Leachate from dumpsites is primarily influenced by the types of trash that are handled and stored in landfills as well as the hydrological and chemical features of such landfills (Schiopu and Gavrilescu, 2010). In general, municipal solid waste leachate may be measured by quantifying variables including dissolved organic carbon (DOC), biochemical oxygen demand (BOD), and chemical oxygen demand (COD) (Bhalla *et al.*, 2012). The characteristics of leachate, however, differ from site to site depending on the waste content (chemicals) and time (Bundela *et al.*, 2012). Water pollution occurs when there are too many contaminants present for the water to be used for other purposes, such as

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bathing, cooking, or drinking (Nwinyi *et al*., 2020). The hydrological cycle, natural occurrences, industrial activity, and other factors can cause contamination of ground and surface water sources. Areas with a shallow water table and heavy precipitation pose the greatest threat to the groundwater system. Leachate might flow into surrounding groundwater systems at various locations that were historically built using the "dilute and scatter" design philosophy (Bhalla *et al.,* 2012). Containment sites also provide evidence of leachate pollution of the groundwater with leachate plumes (Atuanya *et al*., 2016).

Groundwater has long been regarded as one of the cleanest water sources found in nature Ayedun *et al.* (2015). However, because of anthropogenic activity, it becomes polluted with contaminants from both natural occurrences and human daily activities. The weathering of minerals, erosions, and volcanic eruptions are natural events that can also cause the release of contaminants and subsequent contamination of water sources. The major components of ground water contamination are contaminants, such as dissolved minerals and trace and heavy metals.

Because of leachate's natural attenuation, the concentrations of leachate-derived contaminants in public groundwater sources are substantially lower than those of leachate, albeit they may still be significantly higher than those of pure water. Pollutants in water sources may not be harmful to people's health at very low concentrations. The USEPA refers to these pollutants as main contaminants because they are present in drinking water at levels that might be harmful to human health (USEPA, 2013). Other compounds like chlorides, EC, potassium, and sodium, which are not known to cause any health issues, may make water tasteless, smell bad, or have an unfavourable colour, making it unfit for residential use. These substances are referred to as secondary pollutants. The risk presented by landfill sites is greatly influenced by the presence of pollutants in both drinking water and groundwater. It does not, however, explain what impact, if any, drinking tainted water has on one's health.

Drinking polluted water can have a detrimental impact on one's health and shorten one's life expectancy or ability (Li *et al*., 2010). Numerous environmental and health risks are produced by open landfills. Methane is created from chemical breakdown, and it can cause fires and explosions as well as leachate which contaminates surface and ground water (Oyelola *et al.,* 2009). Pb has been linked to a number of illnesses, including anaemia, brain damage, anorexia, mental deficiencies, vomiting, and even human mortality (Oyinloye *et al*., 2016). In addition, Cd has been linked to both agonistic and antagonistic effects on hormones and enzymes, which can result in a variety of abnormalities including lung cancer, kidney and liver damage, bone loss or weakening, and kidney and liver damage (Titilawo *et al*., 2018). Infants between the age of three to six months have negative consequences from high nitrate content in water (Longe and Balogun, 2010). It inhibits the movement of oxygen throughout the body, because nitrate decreases to nitrite, which can oxidise haemoglobin (Hb) to methaemoglobin (metHb) (Al Sabahi *et al.,* 2009; Longe and Balogun, 2010).

Despite the recognized dangers of leachate contamination, many regions still grapple with inadequate landfill management and monitoring. The objective of this paper was to assess the physicochemical, heavy metals and microbial parameters in leachate and groundwater around solid waste dumpsites at Onne, Rivers State, Nigeria with the view of assessing groundwater for contamination.

MATERIALS AND METHODS

Study Area: Onne Town is in Eleme Local Government Area of Rivers State in the south-south geopolitical zone of Nigeria; with coordinates 4.7238° N and 7.1516° E. The stations of study (fig. 1) and their characteristics wastes are stations 1, 2, and 3 as dumpsites and station 4 as control with no dumpsite. Weather conditions over the area are governed by the moist tropical maritime currents from the Atlantic Ocean wave fronts and dry wind and dust-laden tropical continental air mass from the northern part of Nigeria. Prevalent wind direction in the area is south-westerly, with speed ranging from 0.3 to 4.5 m/s and north-easterly, with speed between 0.3 and 1.5 m/s. Relative humidity is usually above 85 per cent in rainy season but decreases to 45% in dry season. Ambient air temperature ranges from 24.5 to 32.1 °C in the rainy season and from 25 to 36.1 °C in dry season (Dike *et al*., 2013). The vegetation of the area is predominated by the tropical rainforest regime, which is comparatively uniform throughout the proximity of the region to the Atlantic Ocean. The other vegetation type is the farmland/fallow mosaic regime that had been modified by agriculture and construction activities (Dike *et al*., 2013).

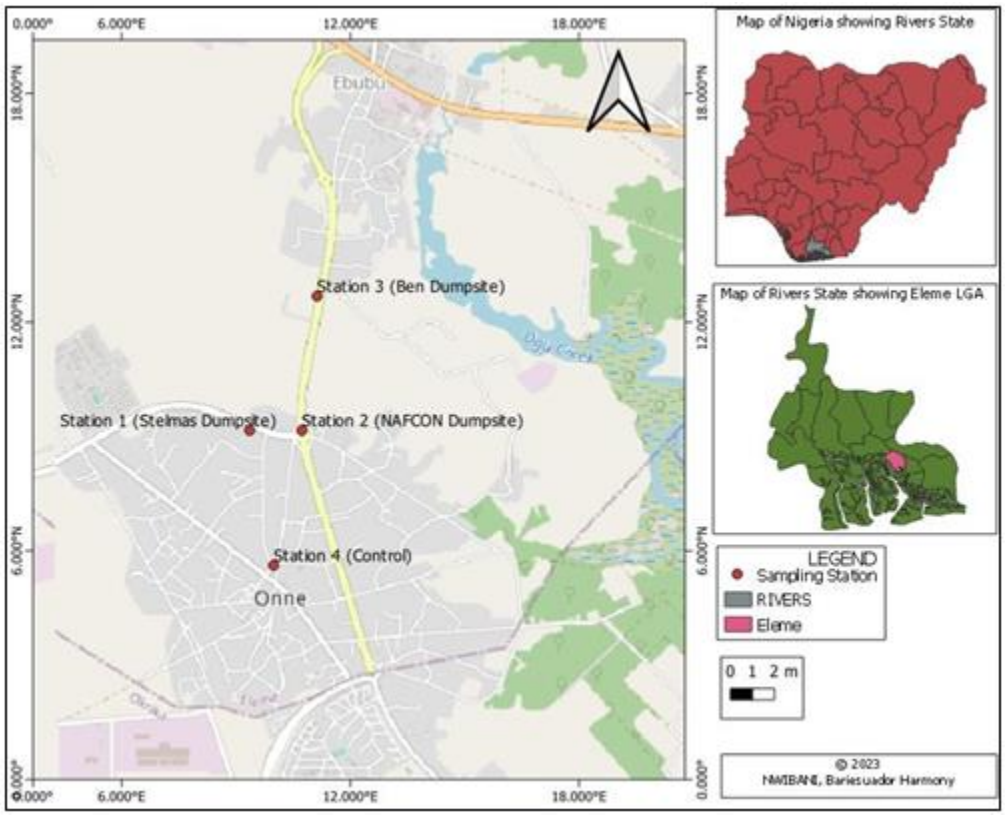

Fig. 1: Map showing study area in Eleme LGA

This study investigated the impact of three landfill sites (Stelmas, NAFCON, and Ben) on groundwater quality in Onne, Nigeria.

Stelmas Dumpsite: Located 140m from the control station with coordinates 4.727594° N and 7.151945° E, receives a mix of domestic, market, agricultural, hospital, and industrial waste. Borehole sampled 15m away.

NAFCON Dumpsite: Located 900m from the control station with coordinates 4.735812° N and 7.153399° E, receives a similar waste composition. Borehole sampled 22m away.

Ben Dumpsite: Located 950m from the control station with coordinates 4.744055° N and 7.154753° E, on the outskirts of town, receives a mix of waste types. Borehole sampled 15m away.

Control Station: A relatively pristine site within Onne town, used as a reference point for comparison with coordinates 4.727605° N and 7.152043° E

Groundwater Sampling: Samples were collected after some volume of water was wasted from 3 active wells. Groundwater sample for microbial test was filled into sterile glass bottle and immediately sealed, while sample for heavy metals was filled into PVC bottles, previously soaked in 10% nitric acid, and rinsed with diluted ionized water and sealed. All the water samples were labeled and stored in ice. Gloves were changed at each sampling point to ensure sampling bottles were not contaminated. Samples for Biochemical Oxygen Demand (BOD_5) were collected in 250 ml brown BOD bottles, and were held to exclude air bubbles, and then incubated in the laboratory for five days before analysis.

Leachate Sampling: Leachate samples were collected from the dumpsites using clear bottles by avoiding overflow and trapping of air bubbles. The bottles were carefully labelled, placed on ice and transported to the laboratory in Rivers State University. Gloves were changed at each sampling point to ensure sampling bottles were not contaminated.

Determination of Physicochemical Parameters in Groundwater and Leachate samples: Physical chemicals parameters (pH, turbidity, total dissolved solids (TDS), electrical conductivity (EC), and dissolved oxygen (DO)) were determined on site for leachate and groundwater samples using in-situ probe model (PC60 Premium multi parameter). For BOD_5, Samples were incubated at 20°C for 5 days. Dissolved oxygen (DO) was measured initially and

after incubation. BOD_5 was computed from the difference in DO (APHA, 2012). For Nitrate (NO_3^-), 10 mL of the sample was mixed with Nitra Ver 5 Reagent (prepared sample). A blank sample was used for zeroing the DR 5000 UV Spectrophotometer, and nitrate (mg/L NO_3^--N) was recorded (APHA, 2012). For Sulphate (SO_4^{2-}), 25 mL of the sample was mixed with barium chloride reagent, stirred, and left for 5 minutes. The prepared sample was analyzed using the DR 5000 UV Spectrophotometer, with a detection limit of 0.10 mg/L (APHA, 2012). For Phosphate (PO_4^{3-}), 10 mL of the sample was mixed with phosphate reagent and allowed to react. A blank sample was used for zeroing the DR 5000 UV Spectrophotometer, and phosphate concentration (mg/L) was recorded (APHA, 2012).

Determination of Heavy Metals in Groundwater and Leachate samples: Heavy metals (Manganese (Mn), Iron (Fe), Cadmium, (Cd), Copper (Cu), Lead (Pb), Mercury (Hg), and Chromium (Cr)) in leachate and groundwater were analyzed following APHA (2012). A 100 mL sample was transferred to a 150 mL volumetric flask, and 5 mL of 1:1 HCl and distilled water was added. The sample was heated via steam until reduced to 20 mL, then filtered to remove insoluble materials. The pH was adjusted to 4 using 5.0 N NaOH, and deionized water was added to restore 100 mL volume.

Heavy metal concentrations were determined using Atomic Absorption Spectrophotometry (ASTM D3557) with AAS Model 210 VGP (Buck Scientific, detection limit: 0.001 mg/L). Calibration was done with known standards, and dissolved metals were analyzed by directly aspirating a filtered sample into the AAS. Results were recorded in mg/L.

Estimation of Microbial Counts in Groundwater and Leachate samples: Coliforms were enumerated using the IDEXX Quanti-Tray™ method. A 100 mL water sample (or dilution) was placed in a sterile container, and Colilert-18 reagent was added and mixed until dissolved. The sample was then dispensed into a Quanti-Tray, sealed, and incubated at 37°C for 18–12 hours for total coliforms and 44.5°C for 18–12 hours for faecal coliforms. After incubation, yellow wells were counted, and Most Probable Number (MPN) was determined using the MPN table, adjusting for dilution if applied.

Statistical Analyses: One-way analysis of variance (ANOVA) was done to test for spatial differences ($p < 0.05$) among the parameters measured, then Tukey-Kramer HSD post-hoc was done to separate means. Correlation between the physicochemical properties of leachate and groundwater quality was carried out. The analysis was carried out using SPSS 25 and Microsoft Excel 2020.

RESULTS AND DISCUSSION

Physicochemical parameters in Groundwater: From the stations sampled, Station 4 (Control) had low pH values (7.0) and high (7.81) pH values. Station 4 (Control) had low DO values (4.33 mg/L) and high (5.18 mg/L) DO values. Station 2 had low BOD values (0.43 mg/L) and Control had high (0.77 mg/L) BOD values. Station 2 had low EC values (152.2 µs/cm) and Station 3 had high (380.4 µs/cm) EC values. TDS values (15 mg/L) and Station 1, Station 2 and Station 3 had high (25 mg/L) TDS values. All had same turbidity values none was higher or lower (1 NTU) than the other for stations and the months sampled. Station 4 (Control) had low sulphate values (1.19 mg/L) and Station 2 had high (5.93 mg/L) sulphate values. Station 4 (Control) had low phosphate values (3.04 mg/L) and Station 2 had high (9.32 mg/L) phosphate values. Station 4 (Control) had low nitrate values (0.44 mg/L) and Station 2 had high (2.19 mg/L) nitrate values. This indicates spatial variation in leachate characteristics across the dumpsites. However, statistically significant differences ($p<0.05$) were observed between the stations for DO, BOD, EC, sulphate, phosphate, and nitrate values. This implies that the overall differences between the stations are substantial. Despite the variations between the stations, statistically significant differences ($p>0.05$) were not observed between the stations for pH, TDS and turbidity values. This implies that while there are spatial trends in pH, T.D.S. and turbidity values, the overall differences between the stations are not substantial.

The pH, TDS, turbidity DO, BOD, EC, sulphate, phosphate, and nitrate levels for ground water in these locations were well within the WHO (2017) limits for drinking water. EC is an indirect measurement of TDS in solutions, thus, higher EC values in groundwater imply high concentrations of anions and cations in groundwater that might have leached from dumpsite's leachates. The higher EC levels in water can significantly exacerbate the aesthetic properties such as taste, odour, colour, turbidity, salinity, hardness, softness, and temperature of water. Saheed *et al.* (2020) reported higher values of EC (225–586 µS/cm) than those of this study in groundwater near a municipal dumpsite in Ibadan Metropolis, Nigeria. Lower TDS values implied less impact on groundwater contamination by leachate migration from dumpsites through groundwater aquifers. The pH of ground water recorded in this study corroborates with Olukanni *et al.* (2017) in

Nigeria, pH values in groundwater near dumpsites ranged from 6.5 to 8.2.

Heavy Metals parameters in Groundwater: From the stations sampled (data not presented) all had same manganese values (0.01 mg/L) none was higher or lower than the other for stations and the months sampled. All stations had low chromium values (<0.01 mg/L) and Station 4 (Control) had high (0.29 mg/L) chromium values. All stations had same cadmium values (0.01 mg/L) none was higher or lower than the other for stations and the months sampled. All had low lead values (<0.01 mg/L) and Station 4 (Control) had high (0.29 mg/L) lead values. Station 3 had low mercury values (<0.001 mg/L) and all had high (<0.01 mg/L) mercury values. Station 4 (Control) had low iron values (0.01 mg/L) and Station 2 had high (0.67 mg/L) iron values. All stations had same copper values (0.01) none was higher or lower than the other for stations and the months sampled.

Fe for Station 2, Cr, and Pb levels in Station 4 (control) were higher than the WHO guideline value for drinking water. Folorunsho *et al.* (2022) recorded values (0.00 – 0.006 mg/L) as obtained within this study range in hand dug wells around dumpsites in Okene, Kogi State, Nigeria. This could be due to the geology of the area and season because value up to 0.019 mg/L was recorded in the leachates. However, higher values have been observed in related studies in Nigeria by Jagaba *et al.*, 2020 (0.01 – 0.25 mg/L) in Rafin Zurfi and Ogbonna *et al.*, 2022 (0.01 – 0.21 mg/L) in Ibadan. Jagaba *et al.* (2020) attributed the high Cr values to improper waste disposal and community markets. Okiongbo *et al.* (2020) observed that Fe concentrations more than acceptable limit (>0.03 mg/L) was very common in groundwaters of the Niger Delta. A range of 0.0 – 6.2 mg/L was recorded in groundwaters from 60 locations in eastern Niger Delta by Abam and Nwankwoala (2020) though lower values - 0.005 – 0.738 mg/L and 0.18 – 0.28 mg/L were recorded elsewhere in Akwa Ibom State by Etesin *et al.* (2021) and Umana *et al.* (2022) respectively. The finding in this study aligns with Garkuwa *et al.* (2019) in Nigeria found similar uniformity in faecal coliform values across different stations.

Table 1: Physicochemical Parameters in Groundwater and Leachate samples

	Groundwater samples	**Leachate samples**	**NSDWQ 2015**	**WHO 2010**
Parameters	$\bar{x} \pm SD$	$\bar{x} \pm SD$		
pH	7.38±0.19	6.6±0.45	6.5-8.5	6.5-8.5
DO (mg/L)	4.91±0.2	NA	5	5
BOD (mg/L)	0.61±0.09	NA	5	5
EC (µs/cm)	232.3±25.9	24.3±4.39	1000	1000
T.D.S (mg/L)	17.48±3.13	NA	500	500
Turbidity (NTU)	1±0	NA	5	5
Manganese (mg/L)	0.01±0	2.98±0.44	0.2	-
Sulphate (mg/L)	3.77±0.38	1.89±0.53	100	100
Phosphate (mg/L)	6.14±0.36	3.57±0.66	100	250
Nitrate (mg/L)	1.19±0.25	0.6±0.39	50	50

Table 2: Heavy Metals in Groundwater and Leachate samples

	Concentrations			
	Groundwater samples	**Leachate samples**	**NSDWQ 2015**	**WHO 2010**
Parameters	$\bar{x} \pm SD$ **(mg/L)**	$\bar{x} \pm SD$ **(mg/L)**		
Chromium (mg/L)	0.03±0.03	1.23±0.4	0.05	0.05
Cadmium (mg/L)	0.01±0	0.63±0.25	0.003	0.05
Lead (mg/L)	0.02±0.03	0.52±0.15	0.01	0.01
Mercury (mg/L)	0.01±0	0±0	0.001	0.01
Iron (mg/L)	0.32±0.12	77.4±16.3	0.3	0.3
Copper (mg/L)	0.01±0	23.1±4.73	1	2

Table 3: Microbial Counts in Groundwater and Leachate samples

Levels of Microbial Counts (MPN/g)	**Microbial Counts in Groundwater**	**Microbial Counts in Leachate samples**	**NSDWQ 2015**	**WHO 2010**
Parameters	$\bar{x} \pm SD$	$\bar{x} \pm SD$		
Faecal Coliform (MPN/g)	2±0	2±0	10	-
Total Coliform (MPN/g)	2±0	2±0	0	-

However, statistically significant differences ($p<0.05$) were observed between the stations for chromium, lead, mercury, and iron values. This implies that the overall differences between the

stations are substantial. Despite the variations between the stations, statistically significant differences ($p>0.05$) were not observed between the stations for manganese, cadmium, and copper values. This implies that while there are spatial trends in manganese, cadmium, and copper values, the overall differences between the stations are not substantial.

Microbial counts in Groundwater: From the stations smapled all had same faecal and total coliform values (<2 MPN/g) none was higher or lower than the other for stations and the months sampled. Despite the variations between the stations, statistically significant differences ($p>0.05$) were not observed between the stations for faecal and total coliform values. This implies that while there are spatial trends in faecal and total coliform values, the overall differences between the stations are not substantial.

Physicochemical parameters in Leachate: From the stations sampled, Station 2 had the lowest pH values (5.92), and Station 3 had the highest pH values (7.52). From the stations sampled Station 2 had low EC values (14.9 µs/cm) and Station 3 had high (35.2 µs/cm) EC values. Station 3 had low sulphate values (1.07mg/L) and had high (2.79 mg/L) sulphate values. Station 2 had low phosphate values (1.61 mg/L) and Station 3 had high (4.50 mg/L) phosphate values. Station 2 had low nitrate values (0.61 mg/L) and had high (2.92 mg/L) nitrate values. This indicates spatial variation in leachate characteristics across the dumpsites. However, statistically significant differences ($p<0.05$) were observed between the stations for EC and sulphate values. This implies that the overall differences between the stations are substantial. Despite the variations between the stations, statistically significant differences ($p>0.05$) were not observed between the stations for pH, phosphate and nitrate values. This implies that while there are spatial trends in pH, phosphate and nitrate values, the overall differences between the stations are not substantial.

The reported pH range in this study aligns with findings from Wuave (2021) with values of pH and EC (5.66 – 8.23 and 9.02 – 80.01 us/cm respectively) in an Open Dumpsite in Jos Plateau State, Nigeria. Studies such as Ezemonye *et al.*, (2022) in municipal solid waste dump sites on soil properties in Akure metropolis have reported similar variations in pH across dumpsites, attributing these differences to variations in waste composition and decomposition rates. The differences in electrical conductivity (EC) across dumpsites align with Ulakpa's *et al.* (2021) in a dumpsite at Boji-Boji Owa, Delta State, Nigeria. This could be attributed to the diverse waste composition and varying stages of decomposition at each landfill. Similarly, Oluyori and Oluyori (2020) analysed leachate from dumpsites in Abuja, Nigeria and observed spatial variations in nitrate concentrations. They linked these variations to the presence of industrial waste at some dumpsites and the overall age and management practices employed. Similarly, sulphate variations were noted by Ferreira *et al.* (2023) in Lagos Nigeria, where the differences were linked to varying rates of organic matter decomposition and leachate generation. While the study did not find statistically significant differences in phosphate and nitrate concentrations between stations, trends in these parameters have been reported by Anietie and Labunmi (2015) in two dumpsites in Akure metropolis, Nigeria, who noted varying levels of phosphate and nitrate based on waste characteristics and environmental conditions.

Heavy Metals parameters in Leachate: From the stations sampled Station 2 and Station 1 had low manganese values (2.71 mg/L) and Station 3 had high (3.06 mg/L) manganese values. Station 2 had low chromium values (0.31 mg/L) and Station 1 had high (1.77 mg/L) chromium values. Station 2 had low cadmium values (0.25 mg/L) and had high (0.94 mg/L) cadmium values. Station 2 had low lead values (0.23 mg/L) and Station 1 had high (0.89 mg/L) lead values. All stations sampled low mercury values (0.001 mg/L). Station 2 had low iron values (50.3 mg/L) and Station 3 had high (182.4 mg/L) iron values. Station 1 had low copper values (15 mg/L) and Station 3 had high (38.7 mg/L) copper values. This indicates spatial variation in leachate characteristics across the dumpsites. However, statistically significant differences ($p<0.05$) were observed between the stations for lead values. This implies that the overall differences between the stations are substantial. Despite the variations between the stations, statistically significant differences ($p>0.05$) were not observed between the stations for manganese, chromium, cadmium, mercury, iron, and copper values. This implies that while there are spatial trends in manganese, chromium, cadmium, mercury, iron, and copper values, the overall differences between the stations are not substantial.

The low manganese in leachate at Station 2 and Station 1, compared to the high values at Station 3, indicate a spatial variation possibly influenced by different waste composition and decomposition rates at each site. This finding aligns with Adeinni *et al.* (2022), which showed similar spatial variability in manganese concentrations across dumpsites in Oke-Tage, Ondo. The high chromium concentration at

Station 2 suggests potential industrial inputs, while the low concentrations at Stations 1 and 3 indicate different waste sources and management practices. This finding is consistent with a study by Onwukeme and Eze (2021) in southeastern, Nigeria, with varying chromium levels across dumpsites due to different waste compositions.

Cadmium concentration at Station 2 suggests a possible influence of industrial or electronic waste, while the levels at Station 1 and 3 aligns with a study on E-waste by Olafisoye *et al.* (2013) in Alaba International Market, Nigeria, that found varying cadmium levels across the market area as concentrations of heavy metals also decreased as the sampling distance from the dump increased.

A study by Ga *et al.* (2019) in Nigeria found similar spatial variations in faecal coliform values across different dumpsites. They noted that while there were differences in microbial loads, these differences were not statistically significant, which is consistent with findings from this study. This suggests that factors other than microbial contamination might be influencing the overall leachate characteristics. Furthermore, a study by Adewole *et al.* (2020) in Africa observed similar trends in total coliform values, with no significant differences among dumpsites. They highlighted the importance of considering other factors such as waste composition and hydrogeological conditions, that could contribute to the overall leachate characteristic.

Microbial counts in Leachate: From the stations sampled all same faecal coliform values as none was higher or lower (<2 MPN/g). All had same total coliform values none was higher or lower (<2 MPN/g) than the other for stations and the months sampled. Despite the variations between the stations, statistically significant differences ($p>0.05$) were not observed between the stations for faecal and total coliform values.

Correlation between leachate and groundwater parameters: The Pearson correlation analysis revealed (Figure 2 -a) for Station 1 groundwater EC and TDS exhibited positive correlations with leachate copper, nitrate, phosphate, and sulphate. The Pearson correlation analysis at station 2 revealed (Figure 2 -b) positive correlations between groundwater EC and TDS with leachate copper, nitrate, and phosphate. The Pearson correlation analysis at station 3 (Figure 2 -c) revealed positive correlations of groundwater EC with copper and phosphate.

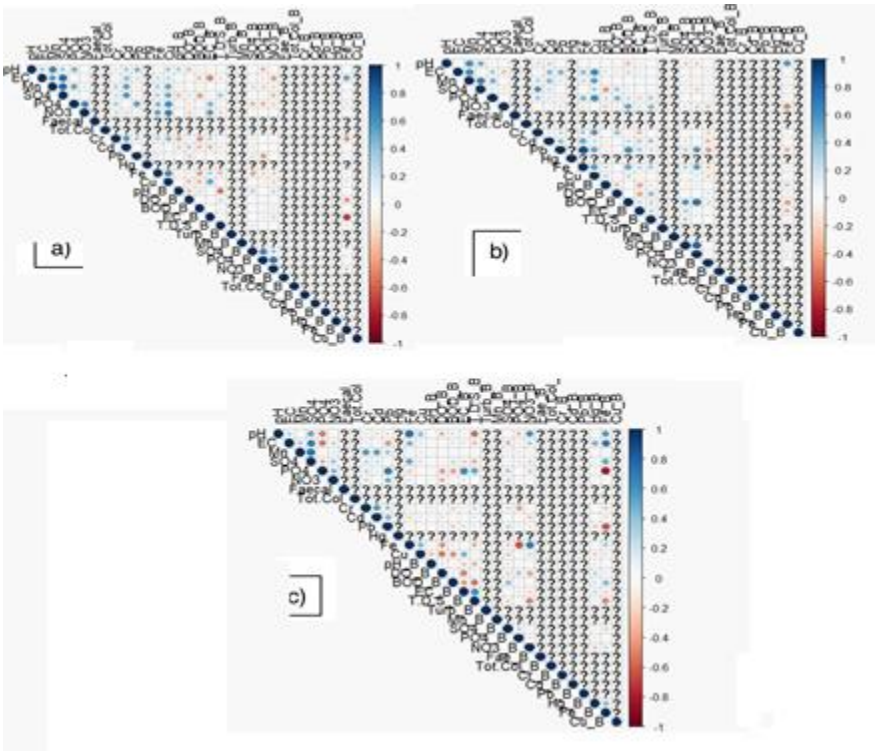

Fig 2: Correlation matrix between groundwater and leachate parameters (a -Station 1, b- Station 2, c- Station 3) *Cd-Cadmium, Cr-Chromium, Cu-Copper, EC-Electrical Conductivity, FC-Faecal Coliform, Fe-Iron, Pb-Lead, Mn-Manganese, Hg-Mercury, N-Nitrate, pH-pH, P-Phosphate, S-Sulphate, TC-Total Coliform, CY-Clay, SD-Sand, ST-Silt*

Groundwater pH displayed a negative correlation with leachate iron, manganese, and copper, though the non-significant nature requires further investigation. This trend might indicate that these leachate components are lowering groundwater pH, potentially impacting aquatic life. Non-significant correlations were observed between groundwater BOD and DO with various leachate parameters. Further analysis might be necessary to understand the interplay between organic matter degradation (BOD) and oxygen availability (DO) in the context of leachate influence. A significant finding was the lack of correlation between groundwater biological parameters (total/faecal coliform) and heavy metals in the leachate. This suggests that these microbial indicators might not directly reflect heavy metal contamination from leachate at station 1 as groundwater biological indicators (total/faecal coliform) showed no correlation with leachate heavy metals. This suggests that these microbial indicators might not directly reflect heavy metal contamination from leachate at station 2. Alternative methods for heavy metal contamination assessment at this station might be warranted. A significant aspect of the analysis was the prevalence of non-significant correlations.

Similar to stations 1 and 2, groundwater biological indicators (total/faecal coliform) showed no correlation with leachate heavy metals, suggesting these microbes might not directly reflect heavy metal contamination. A significant aspect of the analysis was the prevalence of non-significant correlations. While some trends suggest potential relationships, the lack of statistical significance necessitates cautious interpretation. Employing larger datasets or incorporating statistical tests would be crucial to strengthen the analysis and provide more definitive conclusions. This suggests potential contamination by these pollutants, warranting further investigation into leachate migration patterns and potential remediation strategies. Groundwater biological oxygen demand (BOD) and dissolved oxygen (DO) exhibited contrasting non-significant correlations with various leachate parameters. Further analysis might be necessary to elucidate the interplay between organic matter degradation (BOD) and oxygen availability (DO) in the context of leachate influence on station 2's groundwater ecosystem. Groundwater EC exhibited negative correlations with sulphate and iron. These contrasting trends suggest complex interactions between leachate constituents and background groundwater geochemistry at station 3.

Conclusion: The present study underscores the potential impact of leachate from dumpsites on groundwater quality in Onne, Nigeria. While groundwater samples generally complied with drinking water standards for most parameters, the detection of elevated Fe and Cr levels in some locations raises concerns. The observed spatial variations in leachate characteristics emphasize the importance of site-specific assessments for effective pollution management. Correlation analysis revealed potential links between leachate contaminants and groundwater quality, particularly EC, TDS, and heavy metals. However, further research is needed to establish definitive cause-and-effect relationships. There is therefore an urgent need for improved landfill management practices, including leachate collection and treatment systems, to protect groundwater resources. Regular monitoring of groundwater quality is recommended to assess the effectiveness of any mitigation measure and safeguard public health.

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Data Availability: Data are available upon request from the corresponding author.

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