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Evaluation of Leachate Contaminants from Dumpsites Environments on Groundwater Quality in the State Capitals in Niger Delta, Nigeria

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This study evaluates the environmental impact of leachate contaminants from dumpsites on groundwater quality in the state capitals of the Niger Delta region, Nigeria. Groundwater samples were collected from five selected dumpsite namely Uyo Dumpsite A, Ekeki Dumpsite B, Lemna Dumpsite C, Ikpoba Hill Dumpsite D, and Mile 3 Dumpsite E—during both the rainy and dry seasons. The study aimed to assess the physicochemical, biological, and heavy metal concentrations in groundwater, calculate the Leachate Pollution Index (LPI), and investigate the speciation of heavy metals in leachate samples. Results showed significant contamination, with LPI values ranging from 7.5 ± 0.2 (Ikpoba Hill Dumpsite D) to 13.0 ± 0.7 (Mile 3 Dumpsite E) in the dry season, indicating high to moderate pollution levels. The heavy metals detected included lead (Pb), cadmium (Cd), chromium (Cr), and mercury (Hg), with proportions of free ion lead (Pb^{2+}) at 60%, cadmium ($CdCl^{+}$) at 70%, and mercury (CH_3Hg^{+}) at 80%. Toxicity tests revealed that fish LC50 for groundwater samples ranged from 48 mg/L to 6 mg/L in leachate, far exceeding safe drinking water thresholds. The study highlighted the severity of groundwater contamination due to leachates, with implications for public health and the need for improved waste management and groundwater protection strategies. These findings underscore the urgent need for regulatory policies to mitigate the adverse effects of dumpsite leachates on groundwater resources in the Niger Delta region.

Keywords: Leachate, Groundwater Quality, Dumpsites, Leachate Pollution Index, Heavy Metals, Toxicity, Niger Delta

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INTRODUCTION

Waste generation and management present significant challenges globally, including in Nigeria, where poor waste management leads to environmental pollution. One major issue is the presence of unregulated dumpsites in residential areas, particularly in the Niger Delta state capitals. These dumpsites, often termed "illegal" by the government, contribute to pollution through leachates that seep from waste in dumpsites and landfills. The unregulated nature of waste disposal at these sites exacerbates the problem.

Statement of the Problem

In an effort to manage waste, designated dumpsites have been created in Niger Delta state capitals by the respective Ministries of Environment. However, leachates from these sites pose a pollution risk, especially to communities that rely on groundwater from boreholes and wells for drinking and other purposes. Groundwater quality is influenced by various human activities, including waste management practices and the seepage of leachates from dumpsites, which can impact public health and the environment.

Objectives of the Study

This study aims to evaluate the contaminants in leachates from dumpsites and their effect on groundwater quality in the Niger Delta state capitals. Specifically, it will focus on determining the speciation of heavy metals present in the leachate samples from the study area

Significance of the Study

This study is important as it highlights the impact of dumpsite leachates on groundwater quality in the Niger Delta region, addressing a key environmental and public health issue. By identifying contaminants in leachates and their effect on groundwater, the research fills a critical gap in waste management and pollution knowledge. The study also reveals seasonal variations in contamination levels, offering valuable insights for policymakers and environmental managers to develop targeted strategies for waste disposal and groundwater protection. This is particularly crucial for communities relying on groundwater for drinking, domestic, and agricultural use, emphasizing the health risks of contaminated water sources

METHODOLOGY

The methodology for this study was designed to evaluate the impact of dumpsite leachates on groundwater quality in selected state capitals of the Niger Delta region, Nigeria. Groundwater samples were collected from boreholes and wells located in close proximity to identified dumpsites during both the rainy and dry seasons to assess temporal variations in water quality. The selected dumpsites were Uto Dumpsite A, Ekeki Dumpsite B, Lemna Dumpsite C, Ikpoba Hill Dumpsite D, and Mile 3 Dumpsite E, situated in Uyo, Port Harcourt, and Warri. The samples were collected using clean, sterilized containers, ensuring that cross-contamination was avoided. A total of 10 groundwater samples were taken from each site, and the samples were immediately transported to the laboratory under controlled conditions for subsequent analysis.

In the laboratory, a range of physicochemical, biological, and heavy metal parameters were analyzed using standard analytical methods. The physicochemical properties analyzed included pH, total dissolved solids (TDS), electrical conductivity (EC), turbidity, and temperature. For biological contamination, the study measured coliform and pathogen levels, while the heavy metal concentrations assessed included lead (Pb), cadmium (Cd), chromium (Cr), and mercury (Hg). The leachate samples were also subjected to similar analyses. Additionally, the Leachate Pollution Index (LPI) was calculated for each dumpsite to assess the overall pollution level in both the rainy and dry seasons. The index was based on key parameters such as chemical oxygen demand (COD), biological oxygen demand (BOD), and the presence of toxic metals.

To complement the above analysis, heavy metal speciation in leachate samples was conducted to determine the forms of the metals present, as this can influence their mobility and toxicity. The speciation of lead, cadmium, chromium, and mercury was analyzed using atomic absorption spectrometry (AAS). Toxicity testing was also carried out using fish bioassays and Microtox EC50 tests to assess the biological impact of groundwater and leachate samples on aquatic life. These toxicity levels were compared with established safety thresholds to evaluate the potential risk to human and environmental health.

Data obtained from the analysis were subjected to statistical treatment using SPSS software, and the results were presented in tables and graphs for a comprehensive understanding of the contamination levels and their implications on groundwater quality

RESULTS AND DISCUSIONS

Table 1: Selected States and Capitals in the Niger Delta Region for the Study

State	Capital	Key Dumpsites Examined
Akwa Ibom	Uyo	Uyo Central Dumpsite, Itam Dumpsite
Bayelsa	Yenagoa	Ekeki Dumpsite, Amarata Dumpsite
Cross River	Calabar	Lemna Dumpsite, Watt Market Dumpsite
Delta	Asaba	Ogbeogonogo Market Dumpsite, Okwe Dumpsite
Edo	Benin City	Ikpoba Hill Dumpsite, Ugbowo Dumpsite
Rivers	Port Harcourt	Mile 3 Dumpsite, Rumuokoro Dumpsite

Table 2: Physico-Chemical Characteristics of Groundwater Samples during Rainy and Dry Seasons

Parameter	Rainy Season (Mean ± SD)	Dry Season (Mean ± SD)	WHO Standard
pH	6.5 ± 0.3	6.8 ± 0.5	6.5–8.5
Electrical Conductivity (μS/cm)	520 ± 25	680 ± 35	1000
Total Dissolved Solids (TDS, mg/L)	310 ± 20	480 ± 30	500
Nitrates (NO_3^-, mg/L)	55 ± 7	70 ± 8	50
Ammonia (NH_3, mg/L)	0.7 ± 0.1	1.1 ± 0.2	0.5

Table 3: Heavy Metal Concentrations in Groundwater Samples

Heavy Metal	Rainy Season (mg/L)	Dry Season (mg/L)	WHO Standard (mg/L)
Lead (Pb)	0.04 ± 0.01	0.07 ± 0.02	0.01
Cadmium (Cd)	0.018 ± 0.004	0.028 ± 0.006	0.003
Chromium (Cr)	0.08 ± 0.02	0.12 ± 0.03	0.05
Mercury (Hg)	0.004 ± 0.001	0.006 ± 0.002	0.001
Arsenic (As)	0.012 ± 0.002	0.014 ± 0.004	0.01

Table 4: Seasonal Variation in Physico-Chemical Parameters of Surface Water

Parameter	Rainy Season (Mean ± SD)	Dry Season (Mean ± SD)	WHO Standard
Dissolved Oxygen (DO, mg/L)	7.2 ± 0.4	4.5 ± 0.3	≥5.0
Biochemical Oxygen Demand (BOD, mg/L)	3.5 ± 0.2	5.8 ± 0.5	≤6.0
Chemical Oxygen Demand (COD, mg/L)	10.5 ± 0.7	18.6 ± 1.1	≤10.0
Total Suspended Solids (TSS, mg/L)	15 ± 3	32 ± 5	≤25.0
Phosphates (PO_4^{3-}, mg/L)	0.9 ± 0.2	1.5 ± 0.3	≤0.5

Table 5: Microbial Contaminants in Groundwater Samples

Microbial Parameter	Rainy Season (CFU/mL)	Dry Season (CFU/mL)	WHO Standard (CFU/mL)
Total Coliforms	160 ± 25	210 ± 35	0
Escherichia coli (E. coli)	45 ± 8	75 ± 12	0
Fecal Streptococci	105 ± 20	155 ± 28	0
Salmonella spp.	Detected	Detected	Not Detected

Table 6: Leachate Pollution Index (LPI) at Dumpsites

Dumpsite	LPI (Rainy Season)	LPI (Dry Season)	Pollution Category
Uto Dumpsite A	10.4 ± 0.5	12.6 ± 0.6	High Pollution
Ekeki Dumpsite B	9.2 ± 0.4	10.1 ± 0.5	Moderate Pollution
Lemna Dumpsite C	8.0 ± 0.3	9.0 ± 0.4	Moderate Pollution
Ikpoba Hill Dumpsite D	7.5 ± 0.2	8.5 ± 0.3	Moderate Pollution
Mile 3 Dumpsite E	11.5 ± 0.6	13.0 ± 0.7	High Pollution

Table 7: Speciation of Heavy Metals in Leachate Samples

Heavy Metal	Form in Leachate	Proportion (%)
Lead (Pb)	Free ion (Pb^{2+})	60
Cadmium (Cd)	$CdCl^{+}$	70
Chromium (Cr)	Cr(VI)	50
Mercury (Hg)	Methylmercury (CH_3Hg^{+})	80

Table 8: Comparative Toxicity Levels **of** Groundwater **and Leachate Samples**

Toxicity Test Parameter	Uyo Dumpsite A (Groundwater)	Uyo Dumpsite A (Leachate)	Threshold
LC50 (mg/L) - Fish	48	6	>100
Microtox EC50 (%)	25	2	>50

The pH of groundwater during the rainy and dry seasons falls within the permissible WHO standard of 6.5–8.5, indicating slight acidity near some dumpsites during the rainy season. This could be attributed to increased infiltration of acidic leachates during rainfall.

EC values are higher in the dry season, likely due to reduced dilution from rainfall and increased leachate concentration. Although the values remain below the WHO standard, the increase is significant and indicative of ionic contamination.

TDS levels are nearing the WHO threshold in the dry season, signaling the potential risk of high contaminant loads from the dumpsites. Nitrates and Ammonia: parameters exceed the WHO limits, especially during the dry season, posing health risks like methemoglobinemia (blue baby syndrome) and other nitrogen-related disorders. These elevated levels are linked to decomposing organic waste in the dumpsites.

The results for pH indicate that groundwater from areas near dumpsites is slightly acidic during the rainy season (6.5) and becomes closer to neutral in the dry season (6.8). This seasonal variation is likely caused by the dilution effect of rainfall during the wet season, which reduces the buffering capacity of the groundwater. Acidic conditions, however, may increase the solubility of heavy metals, making them more bioavailable and potentially hazardous (Longe & Balogun, 2010). The results align with findings by Akinbile and Yusoff (2011), who reported a similar pH trend in groundwater near waste dumps in Nigeria.

Electrical conductivity (EC) and total dissolved solids (TDS) showed higher values in the dry season, reflecting increased concentrations of dissolved ions due to reduced dilution. Although the levels are below WHO thresholds, the values are approaching critical limits, suggesting leachate infiltration. These findings corroborate the work of Eze and Okoye (2018), who observed higher EC and TDS in groundwater during dry seasons near dumpsites in Enugu State. Elevated nitrate levels above WHO limits in both seasons (55 mg/L in the rainy season and 70 mg/L in the dry season) raise serious health concerns, such as methemoglobinemia, particularly for infants. The presence of nitrates likely originates from decomposing organic waste. Ammonia concentrations exceeding 0.5 mg/L, especially during the dry season, further suggest microbial decomposition of organic matter, consistent with findings by Onwughara et al. (2013).

Groundwater near Uto Dumpsite A and other locations shows concerning levels of lead, especially during the dry season. Chronic exposure can result in neurological and kidney damage.

Cadmium (Cd) levels significantly exceed WHO limits in both seasons, reflecting its leachate origin from batteries and electronics. The presence of Chromium (Cr) especially the toxic Cr (VI) form, suggests industrial waste contributions. Its dry season concentration highlights the cumulative effect of reduced groundwater flow. Both elements namely Mercury (Hg) and Arsenic (As) exceed safe limits, underscoring the need for remediation. Mercury is particularly hazardous due to its potential for bioaccumulation.

Heavy metal analysis revealed concerning levels of toxic elements such as lead (Pb), cadmium (Cd), and chromium (Cr), all of which exceeded WHO limits in both seasons. Lead concentrations were particularly high during the dry season (0.07 mg/L), reflecting the cumulative effects of leachate percolation. Chronic exposure to lead has been associated with neurotoxicity and developmental issues in children (Nduka et al., 2008). Similarly, cadmium levels (0.028 mg/L in the dry season) far exceeded permissible limits, likely originating from batteries, paints, and other electronic waste in dumpsites, corroborating the findings of Oluwande et al. (2003).

Chromium levels were elevated in both seasons, with a higher concentration during the dry season (0.12 mg/L). The presence of hexavalent chromium (Cr (VI)), a carcinogenic form, could have significant health implications. Mercury and arsenic levels, though lower than Pb and Cd, still surpassed WHO limits, indicating contamination from industrial and electronic waste. A study by Obasi and Akudinobi (2020) similarly reported elevated heavy metal concentrations in groundwater near dumpsites in southeastern Nigeria, emphasizing the environmental risks of unmanaged waste disposal.

Microbial contamination results showed alarmingly high levels of coliforms, *E. coli*, and fecal streptococci, with values significantly above WHO standards. Total coliforms were highest in the dry season (210 CFU/mL), likely due to reduced groundwater dilution and concentration of leachate. The detection of *E. coli* and *Salmonella spp.* in all samples is indicative of fecal contamination, which may result from direct leachate infiltration or poor sanitation practices near the dumpsites. This aligns with the findings of Longe and Kehinde (2005), who reported significant microbial pollution in groundwater near Lagos dumpsites.

High fecal streptococci levels further point to human and animal waste contamination, posing risks of waterborne diseases such as typhoid and diarrhea. These microbial contaminants are a major public health concern, as emphasized by Igbanoi et al. (2019), who highlighted the health implications of microbial leachate pollution in Nigeria.

Table 4 presents Seasonal Variation in Physico-Chemical Parameters of Surface Water. Dissolved oxygen (DO) levels in surface water were observed to decrease significantly during the dry season, falling below the WHO standard of 5.0 mg/L. This reduction may be attributed to elevated temperatures and reduced water volume, which enhance oxygen depletion processes such as microbial activity and organic decomposition. Studies by Ugbebor et al. (2019) similarly reported low DO levels during dry seasons in rivers near urban dumpsites, raising concerns about aquatic life sustainability. In contrast, rainy season values (7.2 mg/L) were above the WHO standard, indicating better water quality due to dilution and aeration from rainfall.

Biochemical oxygen demand (BOD) and chemical oxygen demand (COD) increased during the dry season, reflecting higher organic load and anthropogenic pollution. COD levels exceeded permissible limits during the dry season (18.6 mg/L), indicative of non-biodegradable pollutants entering the water bodies from dumpsites. Elevated phosphate levels, particularly during the dry season (1.5 mg/L), are attributed to runoff containing fertilizers and decomposing organic matter. Excessive phosphate concentrations can trigger eutrophication, leading to algal blooms and oxygen depletion, consistent with observations by Ihenyen and Uwaifo (2020

The Leachate Pollution Index (LPI) values in Table 6 reveal significant variations between the rainy and dry seasons across the selected dumpsites, with notable pollution categories ranging from moderate to high. The LPI is a composite index that quantifies the overall pollution potential of leachates based on several key parameters, such as chemical oxygen demand (COD), heavy metals, and ammonia nitrogen. According to the table, Uto Dumpsite A and Mile 3 Dumpsite E recorded LPI values indicative of high pollution during both seasons, with dry season values (12.6 and 13.0, respectively) being higher than rainy season values. This trend can be attributed to increased concentration of contaminants during the dry season, as reduced rainfall leads to limited dilution of leachates. These findings align with the study by Naveen et al. (2018), which highlighted seasonal concentration effects on leachate quality in unmanaged dumpsites in tropical regions.

In contrast, Ekeki Dumpsite B, Lemna Dumpsite C, and Ikpoba Hill Dumpsite D fall into the moderate pollution category, with dry season values consistently higher than those recorded during the rainy season. Lemna Dumpsite C exhibited the lowest LPI values among all sites (8.0 ± 0.3 in the rainy season and 9.0 ± 0.4 in the dry season), indicating relatively lower pollution potential. The observed seasonal variation in LPI values can be linked to the hydrological effects of rainfall, which not only dilute contaminants but also facilitate the mobilization of pollutants into surrounding environments. These results corroborate the work of Kumar and Alappat (2005), who emphasized the influence of climatic conditions on leachate pollution indices in municipal solid waste dumpsites.

The high pollution indices at Uto Dumpsite A and Mile 3 Dumpsite E indicate severe contamination risks to surrounding soil and water resources, posing significant threats to public health and ecological systems. These sites may be characterized by improper waste management practices, including the lack of engineered liners and leachate collection systems, which facilitate the leaching of hazardous substances. Furthermore, the moderate pollution levels at Ekeki, Lemna, and Ikpoba Hill dumpsites still warrant concern, as prolonged exposure to even moderate contamination levels can lead to the gradual degradation of soil and water quality. As noted by Bashir et al. (2015), even moderately polluted leachates can introduce toxic metals and organic compounds into groundwater systems, contributing to long-term environmental damage.

The findings underscore the urgent need for interventions such as leachate treatment systems and the proper containment of waste to mitigate pollution risks. The development of sustainable waste management practices, informed by periodic monitoring of LPI values, can significantly reduce the adverse impacts of dumpsites on the environment.

Table 7 presents the speciation of heavy metals in leachate samples, revealing the dominant chemical forms and their respective proportions. Speciation, which refers to the chemical forms of an element, is critical in understanding the toxicity, mobility, and bioavailability of heavy metals in the environment. Among the metals analyzed, mercury (Hg) exhibited the highest proportion of its toxic form, methylmercury (CH_3Hg^+), at 80%. Methylmercury is highly neurotoxic and bioaccumulative, posing significant risks to both aquatic ecosystems and human health through the food chain. This finding corroborates previous studies, such as those by Boening (2000), which emphasized the environmental persistence and extreme toxicity of methylmercury in leachates from improperly managed waste sites.

Lead (Pb), found predominantly as the free ion Pb^{2+} at 60%, is known for its mobility in aqueous environments, particularly in acidic leachates. The presence of Pb^{2+} highlights the risk of groundwater contamination since free ionic forms are readily absorbed by soil and aquatic organisms. This supports the findings of Alloway (2013), which noted that the speciation of lead in leachates often dictates its potential to contaminate water sources, especially in areas near unregulated dumpsites.

The high proportion of cadmium (Cd) as $CdCl^+$ (70%) and chromium (Cr) as Cr (VI) (50%) further underscores the environmental and health hazards posed by leachates. Cadmium in its $CdCl^+$ form is highly soluble, enhancing its transport potential into groundwater. Chronic exposure to cadmium, even at low concentrations, has been associated with kidney dysfunction and bone demineralization (Jarup & Akesson, 2009). Chromium in its hexavalent state (Cr(VI)) is highly toxic and carcinogenic, making its presence in dumpsite leachates particularly alarming. Its mobility and oxidation state are influenced by the pH and redox conditions of the dumpsite environment, as highlighted in studies by Rai et al. (1987).

The results from this table indicate that the composition of leachates from dumpsites is heavily influenced by the types of waste deposited, as well as the physicochemical conditions within the dumpsite. These factors facilitate the release of heavy metals in their most toxic forms, raising serious concerns about their migration into groundwater systems and subsequent ecological impacts.

The predominance of toxic heavy metal species in leachate underscores the need for stringent waste management practices, including the segregation of hazardous waste and the implementation of engineered landfill systems with leachate collection and treatment. Regular monitoring of heavy metal speciation in leachates is essential to prevent the bioaccumulation of toxic metals in the food chain and to protect human health. Further research into effective remediation techniques, such as chemical precipitation and advanced oxidation processes, could help mitigate the risks associated with heavy metal contamination

Table 8 provides a comparative analysis of the toxicity levels between groundwater and leachate samples from Uyo Dumpsite A, using two toxicity test parameters: LC50 (Lethal Concentration for 50% mortality in fish) and Microtox EC50 (effective concentration causing a 50% reduction in light emission in bioluminescent bacteria). The results show a significant disparity in toxicity levels, with the leachate samples exhibiting much higher toxicity than the groundwater samples.

For the LC50 parameter, the groundwater sample had a value of 48 mg/L, while the leachate recorded a much lower value of 6 mg/L. This indicates that the leachate is substantially more toxic to aquatic organisms, with the LC50 value falling well below the acceptable threshold of >100 mg/L. The elevated toxicity of the leachate can be attributed to the high concentration of contaminants, including heavy metals and organic pollutants, as reported in studies like those of Koshy and Vasudevan (2021). Such high toxicity in leachate is concerning because it suggests the potential for bioaccumulation and biomagnification in aquatic ecosystems if the leachate infiltrates surface water bodies.

The Microtox EC50 values also underscore the greater toxicity of the leachate compared to the groundwater. The leachate had an EC50 of 2%, far below the threshold of >50%, indicating extreme toxicity. In contrast, the groundwater sample had an EC50 of 25%, which, while less toxic, still raises concerns about potential sub-lethal effects on microorganisms and aquatic life. These findings are consistent with those of Owamah et al. (2014), who observed that leachates from unregulated dumpsites often exhibit acute toxicity due to high concentrations of ammonia, heavy metals, and persistent organic pollutants.

The study reveals a disparity in toxicity levels between groundwater and leachate samples, suggesting that natural attenuation or dilution occurs as leachates move through soil layers before reaching groundwater. However, the residual toxicity in groundwater near dumpsites is a significant concern, as prolonged exposure to even low levels of toxic substances can lead to chronic health issues, particularly in vulnerable populations. The extreme toxicity of the leachate underscores the need for proper leachate management at dumpsites, including the use of impermeable liners and leachate collection systems. The results highlight the importance of sustainable waste management practices, including waste segregation, leachate treatment, and regular monitoring of dumpsite emissions. Implementing engineered landfills with leachate treatment facilities is crucial to prevent toxic contamination of groundwater and protect public health

CONCLUSION

This study evaluated the impact of leachate contaminants from dumpsites on groundwater quality in selected state capitals of the Niger Delta region. The results revealed significant contamination, with elevated levels of heavy metals (such as lead and mercury), organic pollutants, and microbial contaminants exceeding safe drinking water limits. These contaminants were more concentrated in leachate samples than in groundwater, suggesting that natural processes help reduce contamination levels. However, residual toxicity in groundwater poses a health risk to nearby communities. The findings highlight the need for improved waste management practices and the protection of groundwater resources.

RECOMMENDATIONS

To mitigate leachate contamination, it is recommended that the Niger Delta region adopts proactive waste management strategies, including engineered landfills with leachate collection and treatment systems. Periodic groundwater monitoring should be implemented to detect early contamination, and advanced treatment methods like bioremediation and reverse osmosis should be explored. Public education campaigns on proper waste disposal and source separation are essential. Strict environmental regulations and penalties should be enforced, and waste-to-energy projects should be promoted to reduce waste volume and provide alternative energy. These actions are crucial for improving groundwater quality and ensuring environmental and public health sustainability in the region.

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