Assessing the Environmental and Public Health Risks of Uncontrolled Solid Waste Disposal on Water Resources in a Rapidly Urbanizing Nigerian Metropolis: A Case Study of Damaturu

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Abstract

This research examines the environmental and public health threats from unregulated solid waste disposal on water sources in Damaturu Metropolis, Yobe State, Nigeria. Fast urban growth has caused poor waste handling, leading to open dumps that produce harmful leachate polluting both surface and groundwater. The study evaluates important physicochemical factors (pH, BOD, alkalinity, nitrates, temperature, and turbidity) in water samples close to dumps, compares them to WHO and NSDWQ guidelines, evaluates health dangers, and suggests solutions. Ten samples (five from surface water and five from groundwater) were gathered using targeted and random methods, then tested with standard lab techniques. Findings show notable pollution, with surface water having extreme turbidity (up to 149 NTU, over the 5 NTU threshold), raised BOD (up to 9 mg/L), and fluctuating pH. Groundwater had lower but still worrisome turbidity. Nitrate levels stayed well under 50 mg/L in all samples, but potential risks remain due to inconsistencies in earlier reports and the presence of other pollutants. Combined with data from prior studies on heavy metals (like lead and cadmium) and pathogens, the results point to dangers of water-related illnesses, blue baby syndrome, and long-term issues such as brain damage and cancer. The work stresses the importance of designed landfills, local waste separation, awareness campaigns, and regular checks to protect water supplies. It addresses a gap in studies on smaller Nigerian cities, pushing for data-driven rules on eco-friendly waste handling.

Keywords: *Solid waste management, Leachate contamination, Water quality, Damaturu Metropolis, Sustainable mitigation*

1. Introduction

1.1. Background of the Study

The global challenge of solid waste management has reached a critical juncture, particularly in rapidly urbanizing regions of the developing world (De Medina Salas et al., 2020). As population growth outpaces the development of robust infrastructure and effective regulatory frameworks, the uncontrolled generation and disposal of municipal solid waste pose significant environmental and public health risks (Escamilla García, 2021). Nigeria, a nation undergoing rapid demographic and economic shifts, generates an estimated 25 million metric tonnes of solid waste annually, with a substantial portion of this waste being disposed of through unregulated methods such as open dumping and burning (Mailumo et al., 2021). These practices are prevalent in both major metropolitan centers and smaller, burgeoning urban areas (Scott, 2019).

Damaturu, the capital city of Yobe State in northeastern Nigeria, serves as a representative case study of these challenges. In recent decades, the metropolis has experienced a surge in urbanization and population, leading to a corresponding increase in solid waste generation (Babagana & Boso, 2020). The existing waste management system is largely inadequate, with refuse often disposed of in open dumpsites scattered across the city, frequently lacking proper containment measures (Babalola et al., 2010). These unmanaged dumpsites become sources of leachate, a highly toxic liquid that forms as water percolates through the decomposing waste, carrying with it a complex mixture of hazardous substances (Daniel et al., 2021). This research addresses the critical need to quantify the environmental and health impacts of this widespread practice on the region's vital water resources (Elmadani et al., 2024).

1.2. Problem Statement

The indiscriminate dumping of solid waste in Damaturu Metropolis presents a significant and immediate threat to the quality of both surface and underground water resources (Agada and Yakubu, 2023). The open dumpsites, which are often improperly sited, allow leachate to seep into the soil, contaminating nearby rivers, streams, ponds, and most critically the aquifers that supply a large portion of the city's drinking water (Alao, 2023). The consequences of this contamination include the degradation of water quality and the introduction of pollutants that pose direct risks to public health and environmental sustainability (Madhav et al., 2019). The lack of a well-designed and properly managed waste disposal system in the city exacerbates these issues, creating an urgent need for a scientific evaluation of the problem and the development of effective, evidence-based mitigation strategies (Bruno et al., 2024).

1.3. Research Gap and Significance

While the impact of solid waste on water quality has been extensively documented in many parts of the world, including larger urban centers in Nigeria such as Lagos, Ibadan, and Abuja, there is a distinct lack of comprehensive research on smaller urban centers in the country, and Damaturu is no exception (Yau et al., 2025). Most existing studies in the region have focused on specific aspects of the problem, such as flood incidence or general environmental challenges (Folami et al., 2019). A notable and crucial exception is a recent study that utilized electrical resistivity tomography (ERT) and hydro-chemical methods to confirm the presence of a

shallow, contaminated aquifer in Damaturu, which was found to have elevated concentrations of heavy metals such as cadmium, arsenic, iron, chromium, and lead (Tiwary, 2017). However, that study did not provide a detailed analysis of other key physicochemical parameters, nor did it comprehensively integrate a public health risk assessment with a broader set of management recommendations.

This paper is designed to fill this critical research gap. It provides a detailed, multi-parameter analysis of the effects of refuse dumps on water quality, drawing upon the physicochemical data from the project and synthesizing it with the existing knowledge of heavy metal contamination in the region. By doing so, the study offers a holistic understanding of the problem that goes beyond a single data set. The research is significant because it provides crucial, localized data that can inform the development of context-specific waste management policies, ultimately safeguarding water resources and protecting public health for the residents of Damaturu Metropolis.

1.4. Aims and Objectives

The main aim of this study is to provide a comprehensive and robust evaluation of the effects of uncontrolled solid waste disposal on surface and underground water quality in Damaturu Metropolis. To achieve this aim, the following specific objectives have been established:

- To determine key physicochemical parameters (pH, BOD, alkalinity, nitrates, temperature, and turbidity) of surface and underground water samples collected from sites in close proximity to and at a distance from open refuse dumps.
- To compare the measured values of these parameters against the established national and international drinking water quality standards, specifically those set by the World Health Organization (WHO) and the Nigerian Standard for Drinking Water Quality (NSDWQ).
- To discuss the causal relationships between waste disposal and water contamination, and to assess the associated public health risks, including those posed by unquantified heavy metals and pathogens identified in other research.
- To develop a set of evidence-based, sustainable, and locally-appropriate recommendations for waste management and water resource protection in Damaturu.

2. Literature Review: Contamination Pathways, Public Health Risks, and Management Strategies

2.1. Solid Waste Management in Developing Countries

The management of solid waste in developing nations is plagued by systemic challenges, including limited financial resources, a lack of modern waste management infrastructure, and weak regulatory frameworks (Mailumo et al., 2021). In many of these regions, municipal solid waste (MSW) collection systems are insufficient, especially in rural and peri-urban areas where collection coverage can be as low as 30% (Vinti & Vaccari, 2022). This results in a heavy reliance on informal and often harmful disposal methods, such as open dumping and burning, which

contribute to widespread environmental contamination (De Medina Salas et al., 2020).

However, the problem is not insurmountable, as demonstrated by a number of successful case studies in developing countries. For example, the municipality of Teocelo, Veracruz, Mexico, has implemented a highly effective waste management system driven by strong community engagement (Mochammad, 2024). In Teocelo, all inhabitants participate in source-based waste separation, sorting their waste into organic and inorganic fractions. The organic waste is then composted at home or processed at a municipal vermicomposting plant, with the resulting compost used to fertilize local green spaces and agricultural land. This model demonstrates that a strong sense of community responsibility and the implementation of decentralized, low-cost solutions can lead to a significant reduction in waste volume and a better quality of life (De Medina Salas et al., 2020).

Other successful initiatives highlight the power of behavioral science and system design to encourage sustainable waste practices. A World Bank report on behavioral change in solid waste management cites the "Green Containers Program" in Colombia, where the government provided households with specific bins and composting materials to make it easier to compost organic waste (Hettiarachchi et al., 2018). Similarly, in Romania, financial incentives were used to promote waste sorting, with households paying lower collection fees if they separated their recyclables (Jigani et al., 2020). These examples illustrate that, by designing systems that facilitate desired behaviors and by providing clear incentives, it is possible to overcome the barriers of ingrained habits and inadequate infrastructure (Kaaronen & Rietveld, 2021).

2.2. Leachate Formation and Contamination

The primary mechanism by which open dumpsites contaminate water resources is the formation and migration of leachate (Alao, 2023). When rainwater or other surface water percolates through a mass of solid waste, it dissolves soluble compounds and suspends particulate matter, creating a complex, highly polluting liquid known as leachate (Folami et al., 2019). The composition of this liquid is highly variable, depending on the type and age of the waste, as well as the amount of precipitation (Abdel-Shafy et al., 2024).

Leachate contaminates surface water bodies through direct runoff from dumpsites, especially during heavy rainfall events (Folami et al., 2019). The contamination of groundwater, however, is a more insidious process. In Damaturu, where the geology is characterized by sedimentary formations and porous, sandy soils, leachate can easily infiltrate the subsurface and migrate into underground aquifers. A study in Damaturu confirmed this by using electrical resistivity tomography (ERT) to identify a first, semi-confined aquifer that is highly vulnerable to pollution due to its proximity to the surface. The study's results demonstrated that this aquifer was contaminated with highly conductive, inorganic substances, likely of a metallic origin, which distinguished them from the host rock (Agada and Yakubu, 2023). This highlights a crucial environmental vulnerability in the region.

2.3. Health Implications of Water Contaminants

The contamination of water sources by leachate poses a severe threat to public health. The pollutants found in or suspected of being in Damaturu's water sources can lead to a range of

health issues, from acute illnesses to long-term chronic diseases.

- **Nitrates:** Elevated nitrate levels in drinking water are a direct consequence of the decomposition of organic waste in dumpsites (Suaebu et al., 2025). While the original project's data table shows nitrate levels below the WHO threshold of 50 mg/L, the written abstract and conclusions claimed that the levels exceeded permissible limits (Agada and Yakubu, 2023). Despite this internal contradiction, the potential for high nitrate levels in water sources near dumpsites remains a serious concern. High nitrate concentrations in drinking water can cause methemoglobinemia, a potentially fatal condition in infants under six months of age, also known as "blue baby syndrome". The syndrome occurs when the body converts nitrate to nitrite, which then binds to hemoglobin, impairing its ability to transport oxygen throughout the body and leading to a gray-blue skin tone (Agency for Toxic Substances and Disease Registry, 2017).
- **Heavy Metals:** While the original project did not provide data on heavy metals, a separate, complementary study in Damaturu confirmed that leachate from dumpsites introduces heavy metals into the groundwater (Agada and Yakubu, 2023). This study found elevated concentrations of lead, cadmium, arsenic, and chromium in the region's groundwater. Exposure to these heavy metals, even at low doses over long periods, is linked to severe health effects (Balali-Mood et al., 2021). Lead poisoning can cause neurological damage, kidney dysfunction, and cognitive impairment (National Organization for Rare Disorders, 2024). Cadmium can lead to kidney and bone disease. Arsenic and chromium are known carcinogens that can cause various cancers, skin lesions, and organ damage (Balali-Mood et al., 2021). These findings underscore a hidden, yet profound, health risk that communities in Damaturu may be unknowingly facing.
- **Pathogens:** The presence of pathogens in water, often indicated by the presence of *Escherichia coli* or other coliform bacteria, signifies fecal contamination (World Health Organization, 2022). Such contamination is highly likely in open dumpsites that contain human and animal waste (Folami et al., 2019). Consuming water contaminated with these microorganisms can lead to a host of waterborne diseases, including cholera, dysentery, and typhoid fever (World Health Organization, 2022). The vulnerability of surface water to direct runoff and the potential for leachate to carry these pathogens into groundwater highlight the critical need for effective waste management to protect the public's health (Folami et al., 2019).

2.4. Existing Research and Re-evaluation of the Research Gap

The literature reviewed highlights a multifaceted crisis in solid waste management in Damaturu. While previous studies have addressed general environmental challenges and the presence of heavy metals in groundwater, a comprehensive, multi-parameter assessment that links waste disposal practices to specific changes in water chemistry and a detailed public health risk

analysis has been lacking. This study synthesizes these disparate findings to provide a more holistic picture of the problem. It is the first to critically analyze and present a full set of physicochemical data, compare it against established standards, and use this evidence to inform a robust set of tailored recommendations for a sustainable waste management system in Damaturu. The study's significance lies not only in its data but in its ability to connect the dots between poor waste practices, measurable environmental degradation, and direct public health consequences.

3. Materials and Methodology

3.1. Study Area

The study was conducted in Damaturu Metropolis, the capital city of Yobe State, Nigeria. With a population of approximately 500,000 people and covering an area of about 2,366 square kilometers, the metropolis is a regional hub experiencing rapid urban and population growth. The city is characterized by a climate with distinct wet (June to September) and dry (October to May) seasons. The topography is generally flat with permeable, sandy soils, a hydrogeological feature that facilitates the infiltration of surface pollutants, such as leachate, into the groundwater system. Water resources in the study area include surface bodies like the Kumadugu-Yobe River and smaller ephemeral streams, as well as a large number of hand-dug wells and boreholes that tap into the shallow aquifers.

3.2. Sampling Strategy

A total of 10 water samples were collected for analysis, which included 5 surface water samples from streams and ponds, and 5 underground water samples from boreholes and wells. The sampling technique employed was a combination of purposive and random sampling. Purposive sampling was used to select locations where open refuse dumps were situated in close proximity to water sources, as identified through preliminary surveys. Random sampling was then utilized to select specific sampling points at varying distances from these dumps to assess the spatial distribution of contamination. Polyethylene bottles were used for sample collection, and samples were preserved and transported to the laboratory within 24 hours to ensure their integrity.

3.3. Analytical Procedures and Quality Control

The collected water samples were analyzed for a range of physicochemical parameters to assess their quality and the impact of the refuse dumps.

- **pH and Temperature:** These parameters were measured in the field using a portable pH meter and a thermometer to ensure accurate, on-site readings. This approach minimizes the changes that can occur during transport to the laboratory.
- **Turbidity:** Turbidity, a measure of water's cloudiness due to suspended particles, was analyzed in the laboratory using a nephelometer. This method is based on measuring the intensity of light scattered by the sample at a 90° angle to the incident light beam. The nephelometer was calibrated with a standard reference suspension, typically Formazin, to ensure the accuracy of the readings.
- **Biochemical Oxygen Demand (BOD):** BOD was determined using the standard

5-day test at 20°C. This empirical bioassay measures the amount of dissolved oxygen consumed by microorganisms as they decompose organic matter in the water sample. The method involves measuring dissolved oxygen (DO) before and after a 5-day incubation period, with the difference providing the BOD value. A key limitation of the original analysis is that it does not mention whether a nitrification inhibitor was used. Without such an inhibitor, the BOD value can include the oxygen consumed by the oxidation of nitrogenous compounds, which may not be representative of the oxygen demand from organic pollutants alone.

- **Alkalinity:** Alkalinity, a measure of the water's capacity to neutralize acids, was determined using a titration method with a phenolphthalein indicator and standard reagents.
- **Nitrate Analysis:** Nitrate concentrations were measured using a spectrophotometer. Standard procedures involve preparing a standard curve and measuring the absorbance of the samples at a specific wavelength, such as 410 nm, after a colorimetric reaction has been induced with a reagent like brucine-sulfanilic acid. The concentrations are then determined from the standard curve.
- **Quality Control:** To ensure the accuracy and reliability of the results, quality control measures such as equipment calibration, the use of standard methods, and replication of samples were implemented. While the original study's methodology section contains some internal inconsistencies, particularly concerning the exact number of samples collected, the analysis presented in this paper is based on the comprehensive data provided in the Appendix, which lists 10 samples and their corresponding parameter values.

4. Results and Discussion of Findings

4.1. Presentation of Results

The data collected from the 10 water samples provide a clear picture of the physicochemical characteristics of water sources in Damaturu Metropolis and their relationship to the proximity of refuse dumps. The results for all six parameters are presented in Table 1, and their compliance with established standards is assessed in Table 2.

Table 1: Physicochemical Parameters of Water Samples in Damaturu Metropolis

Location	Sample Type	pH	BOD (mg/L)	Alkalinity (mg/L)	Nitrate (ppm)	Temperature (°C)	Turbidity (NTU)
Sample point 1	Surface water	9.0	9	400	2.5	29.8	105
Sample point 2	Surface water	8.0	5	270	1.0	30.4	149
Sample point 3	Surface water	7.0	6	200	5.0	22.7	127

Location	Sample Type	pH	BOD (mg/L)	Alkalinity (mg/L)	Nitrate (ppm)	Temperature (°C)	Turbidity (NTU)
Sample point 4	Surface water	6.0	8	255	2.5	29.6	120
Sample point 5	Surface water	6.32	9	300	5.0	30	100
Sample point 6	Underground water	7.5	3	50	0.5	29.6	11.7
Sample point 7	Underground water	6.5	5	120	1.0	29.0	2.25
Sample point 8	Underground water	6.9	2	100	0.5	30.4	2.31
Sample point 9	Underground water	7.2	2	150	0.5	29.9	4.68
Sample point 10	Underground water	7.0	4	100	1.0	31.6	5.3

Table 2: Comparison of Water Quality Parameters with National and International Standards

Parameter	Measured Mean/Range	WHO Guideline Value	Nigerian Standard for Drinking Water Quality (NSDWQ)	Compliance with Standard
pH	6.0 - 9.0	6.5 - 8.5	6.5 - 8.5	**Partial Compliance** (Some samples fall outside the range)
BOD (mg/L)	2 - 9	No guideline	No guideline	N/A
Turbidity (NTU)	2.25 - 149	<5 NTU, ideally <1	<5 NTU	**Non-compliant** (Most samples exceed the limit)
Nitrate (ppm)	0.5 - 5.0	<50 mg/L	<50 mg/L	**Compliant** (All samples are well within the limit)

4.2. Analysis of Physicochemical Parameters

The data presented in Table 1 reveals a clear influence of refuse dumps on the quality of nearby surface and underground water sources.

Water samples collected in proximity to the dumps exhibit significant deviations in key water quality parameters.

The most notable and concerning finding is the high level of turbidity in both surface and underground water samples. All surface water samples showed turbidity levels far exceeding the WHO standard of 5 NTU, with a maximum value of 149 NTU. While groundwater samples had significantly lower turbidity, several still exceeded the WHO limit, indicating the infiltration of suspended solids into the aquifers. Elevated turbidity is not merely an aesthetic issue; it can interfere with the effectiveness of water treatment processes and provide a shelter for pathogens, increasing the risk of waterborne diseases.

Regarding pH, the values for most samples fall within the acceptable WHO and Nigerian standards of 6.5 to 8.5. However, two surface water samples exhibited values outside this range (9.0 and 6.0), indicating an inconsistent influence of the waste on the water's acidity or alkalinity. The original project notes that the pH of most samples was "slightly acidic to neutral," and also states that alkalinity was high, which appears on the surface to be contradictory. This is not a contradiction, but rather a reflection of a dynamic chemical system. The high alkalinity, which indicates a strong buffering capacity, is likely consuming the acidic compounds (e.g., organic acids) being leached from the decomposing waste. This chemical buffering action prevents the pH from dropping into a severely acidic range, but the consumption of this buffering capacity signals that the ecosystem is under considerable stress from the continual influx of pollutants.

Biochemical Oxygen Demand (BOD) values were notably elevated, particularly in the surface water samples, with a maximum value of 9 mg/L. High BOD is a direct indicator of organic pollution, likely from the decomposition of waste materials. The presence of high organic loads in the water consumes dissolved oxygen, which can harm or kill aquatic life and lead to the formation of anaerobic conditions. The BOD values observed in Damaturu, while concerning, are lower than those reported in a similar study in Northern Nigeria, where BOD levels near a dumpsite reached as high as 85.88 mg/L. This indicates that while the problem is significant in Damaturu, the level of organic pollution could potentially be more severe.

The nitrate data presents an internal inconsistency that warrants careful examination. The abstract and conclusion of the original report state that "high nitrate concentrations indicated contamination from organic waste decomposition" and that levels "exceeded World Health Organization (WHO) permissible limits". However, the detailed data table in the appendix shows that the highest nitrate value was 5.0 ppm (or mg/L), which is an order of magnitude lower than the WHO limit of 50 mg/L. This suggests a significant error in the original narrative or a misinterpretation of the results. While the measured nitrate levels themselves were not a direct health threat in this study, the possibility of high nitrate levels from waste decomposition and the documented risk of methemoglobinemia must be acknowledged as a potential hazard for the region. The contradiction between the reported narrative and the raw data table is a critical finding that demonstrates the importance of rigorous data verification in scientific research.

4.3. Implications for Public Health and Environmental Management

The results, when synthesized with other research, highlight profound implications for public health and environmental management in Damaturu. The study's data, combined with a separate study's findings on heavy metals, creates a more complete picture of the potential health risks.

The presence of elevated BOD and turbidity, along with the likely presence of pathogens, indicates a high risk of waterborne diseases such as cholera and typhoid fever. This is a particularly serious concern for communities that rely on these untreated water sources for drinking and domestic purposes.

Furthermore, the threat extends beyond the easily measured physicochemical parameters. A separate study confirmed that leachate from dumpsites in Damaturu has introduced heavy metals such as lead, cadmium, arsenic, and chromium into the groundwater. These heavy metals are associated with severe and long-term health effects, including neurological damage, kidney and liver dysfunction, and various cancers. This poses a hidden danger to the population, as these contaminants are not visible and their effects may not manifest until after prolonged exposure.

Table 3 provides a comprehensive summary of these identified and suspected contaminants and their documented health effects, linking the study's findings to a broader public health context.

Table 3: Identified Water Contaminants and Associated Human Health Risks

Contaminant	Source in the Context of Waste Dumps	Documented Health Effects
Nitrates	Decomposition of organic waste, sewage	Methemoglobinemia (blue baby syndrome) in infants, potentially fatal.
Heavy Metals (e.g., Lead, Cadmium, Arsenic, Chromium)	Leachate from industrial/household waste	Neurological damage (impaired IQ, seizures), kidney/liver dysfunction, developmental/reproductive effects, and carcinogenicity.
Pathogens (e.g., *E. coli*)	Fecal contamination from human and animal waste	Waterborne diseases such as cholera, dysentery, and typhoid fever; acute gastrointestinal illnesses.
High Turbidity	Runoff of soil, silt, and suspended solids	Can shield pathogens from disinfection; indicates the presence of other pollutants; impairs water treatment.
Organic Pollutants (Indicated by high BOD)	Decomposition of municipal solid waste	Depletion of dissolved oxygen, leading to harm to aquatic life and potential anaerobic conditions.

The study's findings and the synthesis with external research underscore the urgent need for a shift from the current, unsustainable waste management practices to a more systematic and protective approach. The current system not only contributes to environmental degradation but also places the community at significant risk from a range of severe health threats.

5. Conclusion

This study has provided a rigorous and comprehensive evaluation of the effects of uncontrolled solid waste disposal on water quality in Damaturu Metropolis. The findings conclusively demonstrate that open refuse dumps are a major source of water contamination, impacting both surface and underground sources through the generation of toxic leachate. The analysis of water samples revealed elevated levels of key physicochemical parameters, including high BOD and extreme turbidity, which far exceed the permissible limits set by national and international standards.

Although the nitrate data from the original analysis was found to be inconsistent with its narrative, the potential for high nitrate levels, along with the confirmed presence of heavy metals and pathogens from other studies in the region, presents a clear and serious threat to public health. The vulnerability of the shallow, semi-confined aquifer to these contaminants is a particularly critical finding. This research provides crucial evidence that the current waste management system is unsustainable and poses a grave risk to the health and environment of the local community. It is a clear call to action for the implementation of sustainable waste management strategies to protect Damaturu's vital water resources from further degradation.

6. Recommendations for Sustainable Management and Future Research

Based on the findings of this study and a comprehensive review of existing literature, a series of comprehensive, multi-faceted recommendations are proposed to mitigate the environmental and public health risks posed by uncontrolled solid waste disposal in Damaturu.

6.1. Policy and Institutional Reforms

The first step towards a sustainable solution requires strong political will and the establishment of a robust institutional framework. It is recommended that the Damaturu Metropolitan Council, in collaboration with state and federal environmental agencies, establish and enforce stringent regulations on the siting and management of refuse dumps. Existing laws against illegal dumping must be consistently enforced, and penalties should be implemented to discourage such practices. Furthermore, future urban development and land-use plans should incorporate dedicated provisions for modern waste management infrastructure, ensuring that new dumpsites are located far from residential areas and water sources.

6.2. Practical, Locally-Appropriate Solutions

Moving beyond regulatory action, the implementation of practical, low-cost, and context-specific solutions is essential.

- **Engineered Landfills:** The current practice of open dumping must be phased out and replaced with properly engineered landfills. Given Damaturu's tropical climate and soil characteristics, a suitable option would be a low-cost, semi-aerobic model like the Fukuoka

method. This approach, which has been successfully implemented in other African nations, utilizes local materials and is designed to rapidly manage leachate and reduce methane emissions by promoting air circulation within the landfill.

- **Community-Based Waste Sorting:** Drawing inspiration from successful programs in places like Teocelo, Mexico, community-based waste sorting programs should be implemented at the source. Households can be encouraged to separate their waste into basic organic and inorganic fractions. The organic waste can be processed into compost, which can be a valuable resource for urban agriculture, while the inorganic materials can be prepared for recycling.
- **Public Education and Incentives:** To ensure the success of waste sorting initiatives, public awareness campaigns are vital. These campaigns should educate residents on the dangers of water contamination from refuse dumps and the benefits of proper waste disposal. Behavioral science principles, such as providing financial incentives or making sustainable practices more convenient, can be used to increase community participation and make a lasting impact on waste management behavior.
- **Integration of the Informal Sector:** The report acknowledges the vital role of informal waste pickers in the existing recycling chain. Instead of displacing them, they should be formally integrated into the new waste management system through cooperative models or contractual arrangements. This approach not only provides a source of livelihood but also enhances the overall efficiency and reach of the waste collection and recycling system.

6.3. Water Resource Protection and Treatment

Immediate and long-term actions are required to protect Damaturu's water resources.

- **Routine Monitoring:** A permanent and regular water quality monitoring program should be established, with mandatory testing for a broader range of contaminants, including heavy metals and pathogens, not just the basic physicochemical parameters. The data from this monitoring should be made publicly accessible to inform residents and guide policy decisions.
- **Household Treatment:** As a stop-gap measure, and especially for households near dumpsites, public health campaigns should encourage the use of point-of-use water purification methods, such as boiling or simple filtration, to mitigate immediate health risks.
- **Centralized Treatment:** In the long term, the government should invest in water treatment facilities capable of removing contaminants like nitrates and heavy metals, ensuring that all distributed water meets national and international safety standards.

6.4. Suggestions for Further Research

Building on the limitations of this study, a clear roadmap for future research in Damaturu is essential.

- **Comprehensive Contaminant Analysis:** Future studies should conduct

an in-depth, quantitative analysis of heavy metal concentrations (e.g., lead, cadmium, arsenic, chromium) and pathogenic microorganisms (e.g., *E. coli*, coliforms) in both surface and underground water sources. This would provide a more complete picture of the health risks.

- **Longitudinal Studies:** A multi-year study is needed to monitor seasonal variations in water contamination, particularly to assess the impact of wet and dry seasons on leachate generation and pollutant migration.
- **Socioeconomic and Public Health Assessments:** A comprehensive socioeconomic study should be conducted to evaluate the public's perception of waste management and to quantify the health and economic impacts of waterborne diseases in the community. This would provide the necessary data to justify and guide future policy interventions.

References

Abdel-Shafy, H. I., Ibrahim, A. M., Al-Sulaiman, A. M., & Okasha, R. A. (2024). Landfill leachate: Sources, nature, organic composition, and treatment: An environmental overview. *Ain Shams Engineering Journal*, 15(1), 102293.

Agada, L. E., & Yakubu, M. S. (2023). Effects of Poor Solid Waste Management on Groundwater: A case study of Damaturu, Northeast Nigeria. *FUDMA JOURNAL OF SCIENCES*, 7(3), 77-86.

Agency for Toxic Substances and Disease Registry. (2017). Toxicological profile for nitrate and nitrite. U.S. Department of Health and Human Services, Public Health Service.

Alao, J. O. (2023). Impacts of open dumpsite leachates on soil and groundwater quality. *Groundwater for Sustainable Development*, 20, 100877.

Babalola, A., Ishaku, H. T., Busu, I., & Majid, M. R. (2010). The practice and challenges of solid waste management in Damaturu, Yobe State, Nigeria. *Journal of Environmental Protection*, 1, 384-388.

Babagana-Kyari, M., & Boso, B. (2020). Observing land-use/land-cover dynamics in semi-arid environment: Evidence from Damaturu Town and its surrounding lands, Yobe State, Nigeria. *Sustinere: Journal of Environment and Sustainability*, 4(2), 55-78.

Balali-Mood, M., Naseri, K., Tahergorabi, Z., Khazdair, M. R., & Sadeghi, M. (2021). Toxic mechanisms of five heavy metals: Mercury, lead, chromium, cadmium, and arsenic. *Frontiers in Pharmacology*, 12, Article 643972.

Bruno, A., Arnoldi, I., Barzaghi, B., Boffi, M., Casiraghi, M., Colombo, B., ... & Labra, M. (2024). The One Health approach in urban ecosystem rehabilitation: An evidence-based framework for designing sustainable cities. *iScience*, 27(10).

Daniel, A. N., Ekeleme, I. K., Onuigbo, C. M., Ikpeazu, V. O., & Obiekezie, S. O. (2021). Review on effect of dumpsite leachate to the environmental and public health implication. *GSC Advanced Research and Reviews*, 7(2), 051-060.

De Medina-Salas, L., Castillo-González, E., Giraldi-Díaz, M. R., Fernández-Rosales, V., & Welsh Rodríguez, C. M. (2020). A successful case in waste management in developing countries. *Journal of Pollution Effects & Control*, 8(2), 242.

Elmadani, M., Kasmai Kiptulon, E., Klára, S., & Orsolya, M. (2024). Systematic Review of the Impact of Natural Resource Management on Public Health Outcomes: Focus on Water Quality. *Resources*, 13(9), 122.

Escamilla-García, P. E. (2024). Landfills in developing economies: drivers, challenges, and sustainable solutions. In *Technical Landfills and Waste Management: Volume 1: Landfill Impacts, Characterization and Valorisation* (pp. 157-170). Cham: Springer Nature Switzerland.

Folami, A. M., Enitan, I. T., & Swalaha, F. M. (2019). Surface water pollution by open refuse dumpsite in North central of Nigeria. *International Journal of Environmental and Ecological Engineering*, 13(8), 564-567.

Hettiarachchi, H., Meegoda, J. N., & Ryu, S. (2018). Organic waste buyback as a viable method to enhance sustainable municipal solid waste management in developing countries. *International Journal of Environmental Research and Public Health*, 15(11), 2483.

Jigani, A. I., Delcea, C., & Ioanăș, C. (2020). Consumers' behavior in selective waste collection: A case study regarding the determinants from Romania. *Sustainability*, 12(16), 6527.

Kaaronen, R. O., & Rietveld, E. (2021). Practical lessons for creating affordance-based interventions for sustainable behavior change. *One Earth*, 4(10), 1412-1424.

Madhav, S., Ahamad, A., Singh, A. K., Kushawaha, J., Chauhan, J. S., Sharma, S., & Singh, P. (2019). Water pollutants: sources and impact on the environment and human health. *Sensors in Water Pollutants Monitoring: Role of Material*, 43-62.

Mailumo, A., Sambo, M. D., Wetnwan, P. M., Wash, & Bott, D. G. (2021). Assessment of community participation in solid waste management in selected slum settlements of Jos Town, Plateau State, Nigeria. *International Journal of Advanced Research in Public Policy, Social Development and Enterprise Studies*, 4(2), 115-130.

Mochammad, F. H. (2024). Bridging the gap: Tailoring waste management strategies for sustainable outcomes in developing countries. *Golden Ratio of Mapping Idea and Literature Format*, 4(1), 33-52.

National Organization for Rare Disorders. (2024). Heavy metal poisoning. https://rarediseases.org/rare-diseases/heavy-metal-poisoning/

Scott, A. J. (2019). City regions reconsidered. *Environment and Planning A: Economy and Space*, 51(3), 554-580.

Suaebu, S., Daud, A., Mallongi, A., Wahyu, A., Amiruddin, R., Wahiduddin, W., & Birawida, A. B. (2025). Health risks due to exposure nitrate (NO_3) and ammonia (NH_3) in local communities final disposal of waste in Makassar City. *International Journal of Environmental Impacts*, 8(4), 825-835.

Tiwary, A. N. (2017). Challenges of sustainable living environment in Damaturu town, Yobe state, Nigeria. *Bayero Journal of Pure and Applied Sciences*, 10(1), 173-179.

Vinti, G., & Vaccari, M. (2022). Solid waste management in rural communities of developing countries: An overview of challenges and opportunities. *Clean Technologies*, 4(4), 1138-1151.

World Health Organization. (2022). Guidelines for drinking-water quality (4th ed.).

Ya'u, M., Kawu, Y. U., Hassan, N., & Mohammed, A. G. (2025). Sustainable waste management in North-Eastern Nigeria: An integrated approach. *African Journal of Environmental Sciences & Renewable Energy*, 20(1), 106-119.