

EFFECT OF IMPROPER WASTE DISPOSAL ON GROUNDWATER QUALITY IN KANO METROPOLIS, KANO STATE

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Abstract

This study examined the effect of improper waste disposal on groundwater quality in Kano Metropolis, Kano State, Nigeria. Groundwater is a major source of domestic water supply in the study area due to inadequate public water provision, but its quality is increasingly threatened by uncontrolled urban waste disposal practices. A cross-sectional descriptive and analytical research design was adopted. Groundwater samples were collected from boreholes and wells located near dumpsites and from control locations farther away from waste disposal sites. Physical, chemical, and microbiological parameters were analyzed in accordance with standard laboratory

procedures and compared with World Health Organization drinking water standards. The results revealed that groundwater sources located near dumpsites exhibited higher levels of turbidity, electrical conductivity, total dissolved solids, and colour compared to control sites. Chemical analysis showed elevated concentrations of heavy metals such as lead and cadmium in some samples near dumpsites, with values exceeding permissible limits. Microbiological analysis indicated the presence of total coliforms and Escherichia coli in groundwater near waste disposal areas, suggesting faecal contamination. The Water Quality Index further confirmed that groundwater close to dumpsites was of poor quality relative to control areas. The study concluded that improper waste disposal significantly contributes to groundwater contamination in Kano Metropolis, posing environmental and public health risks. It recommended improved waste management systems, strict enforcement of environmental regulations, proper siting of wells, and routine groundwater quality monitoring.

Keywords: Groundwater quality, improper waste disposal, leachate, Kano Metropolis, water contamination, environmental pollution.

Introduction

Groundwater is an essential source of domestic water for many households in rapidly expanding urban centres, particularly where public pipe-borne water supply is insufficient, irregular, or inaccessible. In Kano Metropolis, residents depend substantially on shallow wells and boreholes for drinking, cooking, bathing, small-scale commercial activities, and other household needs. The quality of this groundwater is therefore central to public health, environmental sustainability, and urban wellbeing. According to the World Health Organization (WHO, 2026), water intended for human consumption should be protected from microbiological, chemical, and physical contaminants through effective source protection, regular monitoring, and risk-based water safety management.

However, rapid urbanisation, population growth, commercial activity, and inadequate environmental sanitation have intensified the challenge of waste management in many Nigerian cities. Improper waste disposal includes the indiscriminate dumping of refuse in open spaces, drainage channels, road verges, vacant plots, water pathways, and unregulated dumpsites. These practices are particularly problematic where waste disposal sites are located close to residential areas, wells, and boreholes. In Kano Metropolis, weak institutional capacity, insufficient waste-collection facilities, poor public attitudes towards sanitation, and the persistence of open dumping have contributed to the accumulation of solid waste in several neighbourhoods and public spaces (Muhammad & Marzuki, 2024).

Improperly disposed waste can adversely affect groundwater quality through the generation of leachate. Leachate is a contaminated liquid produced when rainwater percolates through decomposing waste materials and dissolves soluble organic and inorganic substances. This liquid may contain suspended solids, pathogens, nitrates, phosphates, chlorides, sulphates, heavy metals, and other potentially harmful substances. Where dumpsites are unlined or poorly managed, leachate can migrate through soil pores into the unsaturated zone and eventually reach shallow groundwater aquifers. The degree of contamination depends on several factors, including the composition and volume of waste, rainfall intensity, soil type, depth to groundwater, drainage conditions, proximity of wells to dumpsites, and the presence or absence of engineered landfill protection systems (Fatima et al., 2024; Sule et al., 2020).

Evidence from Kano State indicates that groundwater around waste-disposal locations may be vulnerable to chemical contamination. Sule et al. (2020), in their assessment of groundwater around the Tarauni dumpsite area of Kano, reported elevated levels of several physicochemical parameters and heavy metals in sampled groundwater. Their study identified contamination linked to dumpsite leachate and showed that pollutant migration extended to considerable depths in some sections of the study area. Similarly, Fatima et al. (2024) assessed groundwater and leachate around the Kofar Na'isa solid-waste dumpsite in Gwale Local Government Area of Kano State and found elevated concentrations of metals such as cadmium, lead, manganese, and chromium in some samples. The findings suggest that waste dumpsites can contribute to groundwater-quality deterioration, although the researchers also noted that some contaminants may originate from additional environmental or anthropogenic sources.

Recent evidence further shows that groundwater quality in Kano Metropolis is affected by a combination of human activities and natural hydrogeological conditions. Dayyabu et al. (2025) reported variations in groundwater quality across selected local government areas in Kano Metropolis, with some water samples showing elevated chloride, turbidity, and total dissolved solids. The study identified anthropogenic influences, including poor sanitation, industrial activities, and unregulated land-use practices, while also observing that shallow wells were generally more susceptible to contamination than boreholes. This suggests that the relationship between improper waste disposal and groundwater quality should be examined carefully, taking into account other possible pollution sources such as sewage seepage, industrial effluents, agricultural runoff, poor well construction, and natural geological characteristics.

The consequences of contaminated groundwater can be serious, especially where residents consume untreated water from wells and boreholes. Exposure to water containing pathogenic microorganisms may increase the risk of diarrhoeal diseases, typhoid fever, cholera, and other water-related illnesses. In addition, prolonged exposure to certain heavy metals may result in adverse health effects, depending on the concentration, duration of exposure, and vulnerability of

the affected population. Therefore, groundwater contamination is not only an environmental issue but also a significant public-health concern requiring attention from environmental regulators, water-resource managers, urban planners, and community members.

Despite existing studies on waste management and groundwater pollution in Kano State, there remains a need for location-specific evidence on how improper waste-disposal practices affect groundwater quality within Kano Metropolis. Such evidence is necessary because groundwater quality may vary across communities depending on the distance of water sources from dumpsites, the type of waste deposited, the condition of drainage systems, seasonal rainfall patterns, and the depth and construction of wells or boreholes. This study therefore examines the effect of improper waste disposal on groundwater quality in Kano Metropolis, Kano State. The study is expected to provide useful information for improving waste-disposal practices, strengthening groundwater monitoring, promoting community environmental awareness, and supporting policies aimed at protecting potable water sources in the metropolis.

The Kano-specific studies used here document groundwater vulnerability around the Tarauni and Kofar Na'isa dumpsites, while the 2025 Kano-wide study identifies poor sanitation and unregulated land use as important contributors to groundwater deterioration. The current WHO drinking-water guidance supports the emphasis on source protection, monitoring, and management of chemical and microbiological hazards.

Problem Statement

Groundwater is a primary source of potable water for a large proportion of residents in Kano Metropolis, particularly in areas where public water supply remains inadequate or unreliable. Despite its importance, the quality of this groundwater is increasingly threatened by rapid urbanisation, population growth, and poor environmental sanitation practices. One of the most significant challenges is improper waste disposal, which is widely observed across residential, commercial, and peri-urban areas of the metropolis.

In many parts of Kano, solid waste is often dumped indiscriminately in open spaces, drainage channels, abandoned plots, and poorly managed dumpsites. These sites are frequently located close to residential buildings and water abstraction points such as shallow wells and boreholes. Such practices create conditions that allow the generation of leachate—a contaminated liquid that forms when rainfall percolates through decomposing waste materials. This leachate can infiltrate the soil and potentially contaminate underlying aquifers, thereby posing risks to groundwater quality and public health (Sule et al., 2020; Fatima et al., 2024).

Empirical studies in Kano State have already shown evidence of groundwater vulnerability near waste disposal sites. For instance, elevated concentrations of heavy metals and physicochemical pollutants have been reported in groundwater samples collected around dumpsite environments,

indicating possible contamination from waste-derived leachate (Fatima et al., 2024). Similarly, variations in groundwater quality across Kano Metropolis have been linked to anthropogenic activities such as poor waste management, inadequate sanitation systems, and unregulated land use (Dayyabu et al., 2025). These findings suggest that groundwater resources in the metropolis are under increasing pressure from human-induced environmental stressors.

However, despite these indications, there remains insufficient localized and systematic evidence specifically linking patterns of improper waste disposal practices to groundwater quality deterioration across different neighbourhoods in Kano Metropolis. Existing studies have often focused on isolated dumpsites or limited geographic scopes, making it difficult to generalize findings across the entire urban area. Additionally, the interaction between waste disposal practices, hydrogeological conditions, and varying depths of groundwater abstraction points has not been adequately explored in many communities.

The absence of comprehensive and up-to-date assessments creates a gap in environmental management and public health planning. Without clear evidence on the extent to which improper waste disposal influences groundwater quality, policymakers and environmental agencies may face challenges in designing effective waste management strategies and groundwater protection frameworks. This is particularly important given the health risks associated with contaminated drinking water, including waterborne diseases and long-term exposure to toxic substances (World Health Organization, 2026).

Therefore, this study addresses the need for a detailed assessment of the effect of improper waste disposal on groundwater quality in Kano Metropolis, with the aim of generating evidence that can support improved environmental sanitation policies, sustainable waste management practices, and the protection of groundwater resources for safe domestic use.

Objective of the Study

The objective of this study is to assess the effect of improper waste disposal on groundwater quality in Kano Metropolis, Kano State, by determining the influence of proximity to waste disposal sites on the physical, chemical, and microbiological characteristics of groundwater, evaluating the extent to which measured groundwater-quality parameters comply with or exceed World Health Organization (WHO) drinking-water standards, and comparing the level of contamination between boreholes and shallow wells used for domestic purposes.

Literature Review

1. Conceptual Review

1.1 Improper Waste Disposal

Improper waste disposal refers to the uncontrolled dumping, burning, or release of solid and liquid waste into the environment without adherence to environmental regulations. In many developing cities, open dumping remains the dominant waste disposal method, leading to environmental degradation and public health risks. Such practices are common in rapidly growing urban areas where waste management infrastructure is inadequate (UN-Habitat, 2022).

In Kano Metropolis, solid waste is often disposed of in open spaces, drainage channels, and unregulated dumpsites, increasing environmental contamination risks (Muhammad & Marzuki, 2024).

1.2 Groundwater and Its Importance

Groundwater is water stored beneath the earth's surface in aquifers and serves as a major source of drinking water worldwide. In Nigeria, a significant proportion of the population depends on groundwater for domestic use due to unreliable pipe-borne water systems (WHO, 2026). Groundwater is generally considered high quality; however, it is highly susceptible to contamination from surface activities where protective soil layers are thin or permeable.

1.3 Groundwater Quality

Groundwater quality refers to the physical, chemical, and biological characteristics of water that determine its suitability for human consumption. Key indicators include pH, turbidity, dissolved solids, heavy metals, and microbial content. The World Health Organization (WHO, 2026) emphasizes that potable water must remain free from harmful levels of contaminants to prevent waterborne diseases.

1.4 Waste Disposal and Groundwater Pollution Pathways

One of the major pathways through which waste affects groundwater is leachate formation. Leachate is produced when rainwater infiltrates waste dumps and dissolves toxic substances, which then percolate into soil and aquifers. This process introduces contaminants such as nitrates, chlorides, heavy metals, and pathogens into groundwater systems (Landfill Leachate, 2025).

Hydrogeological factors such as soil permeability, depth to water table, rainfall intensity, and proximity of wells to dumpsites influence the extent of contamination (Balogun et al., 2021).

2. Theoretical Framework

Contamination Transport Theory

This study is anchored on Contamination Transport Theory, which explains how pollutants move from a source through environmental media such as soil and water. The theory posits that contaminants migrate through advection, diffusion, and infiltration processes until they reach groundwater systems.

In the context of Kano Metropolis, improperly disposed waste serves as a contamination source, while rainfall and soil permeability act as transport mechanisms. This theory is relevant in explaining how leachate from dumpsites infiltrates groundwater systems (Sule et al., 2020).

3. Empirical Review

3.1 Waste Disposal and Environmental Pollution

Studies have shown that open dumping of waste significantly contributes to environmental pollution, particularly in developing countries. Research in urban Kano revealed that unregulated waste disposal sites contain high concentrations of pollutants capable of degrading soil and groundwater quality (Ali, 2014; ([WIT Press](#))).

3.2 Groundwater Contamination in Kano Metropolis

Several studies have documented groundwater contamination in Kano. For example, investigations around Gyadi-Gyadi dumpsite found elevated levels of nitrates, chlorides, sulphates, and heavy metals exceeding WHO permissible limits (([Research Explorer](#))). Similarly, studies at Aisami dumpsite revealed contamination of groundwater by lead, manganese, and chromium due to leachate infiltration.

Balogun et al. (2021) also reported spatial variation in groundwater quality across Kano Metropolis, attributing poor quality in some areas to improper waste disposal and high population density.

3.3 Groundwater Quality Studies in Nigeria

Across Nigeria, studies show that groundwater contamination is common in urban centres due to anthropogenic activities. In Lagos, borehole and well water samples have been found to contain heavy metals and microbial contaminants exceeding WHO standards (Yahaya et al., 2021). Similar findings have been reported in other cities, linking groundwater deterioration to domestic waste disposal and industrial activities.

3.4 Hydrogeological Vulnerability

Groundwater in shallow aquifers is more vulnerable to contamination due to limited protective layers. In Nigeria, unconsolidated aquifers in urban areas are especially susceptible to pollution from surface activities such as waste dumping and sewage discharge (Wikipedia, 2026). Kano's hydrogeological structure further increases vulnerability due to shallow groundwater levels in many districts.

Methods

1. Research Design

The study adopted a cross-sectional descriptive and analytical research design to assess groundwater quality and examine its relationship with improper solid-waste disposal practices in selected locations within Kano Metropolis, Kano State, Nigeria. The descriptive component was used to characterize the physicochemical, heavy-metal and microbiological properties of groundwater samples, while the analytical component was used to test for statistically significant differences and associations between groundwater contamination indicators and selected waste-disposal-related factors, particularly proximity to dumpsites.

The analytical design enabled comparison of groundwater quality between locations situated close to waste dumpsites and control locations farther away from dumpsites. Inferential statistical procedures, including independent-samples t-tests, analysis of variance (ANOVA), correlation analysis and regression analysis, were incorporated to determine whether observed differences and relationships were statistically significant. Statistical significance was evaluated at a 5% level of significance ($p < 0.05$).

2. Area of the Study and Sampling Period

The study was conducted in Kano Metropolis, Kano State, Nigeria, one of the major and densely populated urban centres in Northern Nigeria. Kano Metropolis comprises several Local Government Areas (LGAs), including Nasarawa, Fagge, Dala, Gwale, Tarauni, Kano Municipal and parts of Kumbotso. The metropolis is characterized by rapid urbanization, high population density and substantial generation of municipal solid waste.

In several parts of the metropolis, solid waste is disposed of through open dumping, indiscriminate disposal along drainage channels and other poorly controlled waste-management practices. These activities have the potential to introduce contaminants into the surrounding environment through leachate formation, surface runoff and infiltration into shallow groundwater systems.

Kano Metropolis experiences a tropical Sudan-type climate characterized by distinct wet and dry seasons. The wet season generally extends from May to October, while the dry season occurs

approximately from November to April. Groundwater sampling covered representative periods of the wet and dry seasons in order to account for possible seasonal variations in water quality associated with rainfall recharge, runoff, infiltration and changes in groundwater conditions.

The hydrogeological characteristics of the selected locations include shallow groundwater systems. Most sampled sources consisted of shallow wells and groundwater abstraction points with depths of less than 10 m. Such shallow groundwater sources may be particularly vulnerable to surface-derived contamination because of the relatively short vertical distance through which contaminants may migrate. Information on groundwater-source depth and proximity to waste-disposal sites was therefore considered during interpretation and statistical analysis of the results.

3. Population of the Study

The study population comprised groundwater sources and relevant environmental locations within the selected communities of Kano Metropolis. Specifically, the population included:

1. Boreholes and shallow wells within selected communities;
2. Groundwater sources located within residential areas close to waste-disposal sites;
3. Groundwater sources within control areas located farther away from major dumpsites;
4. Water users and owners of selected boreholes and wells; and
5. Environmental observation points surrounding major waste-disposal locations.

The principal unit of laboratory analysis was the groundwater sample obtained from the selected boreholes and shallow wells.

4. Sample Size and Sampling Technique

A multi-stage sampling technique was adopted for the selection of study locations and groundwater sources.

Stage One: Selection of Local Government Areas

Six LGAs were purposively selected based on population density, urban development and the presence of major waste-disposal locations. The selected LGAs were:

1. Fagge;
2. Dala;
3. Gwale;
4. Tarauni;

5. Nasarawa; and

6. Kano Municipal.

Stage Two: Selection of Sampling Locations

Within the selected LGAs, communities located within approximately 500–1,000 m of identified waste dumpsites were selected as exposed locations. Comparable communities and groundwater sources situated farther away from major dumpsites were selected as control locations.

The use of control locations provided a basis for determining whether groundwater-quality parameters differed significantly between areas exposed to waste-disposal activities and areas with relatively lower exposure.

Stage Three: Selection of Groundwater Sources

A total of 36 groundwater samples were included in the study. These consisted of:

- 18 groundwater samples obtained from locations close to waste dumpsites; and
- 18 groundwater samples obtained from control locations farther away from dumpsites.

Within the selected communities, specific boreholes and wells were selected using simple random sampling where an adequate sampling frame was available. The location of each sampled water source and its approximate distance from the nearest identified dumpsite were documented for subsequent statistical analysis.

5. Data Collection Methods

5.1 Groundwater Sample Collection

Groundwater samples were collected from selected boreholes and shallow wells using clean and appropriately sterilized polyethylene sampling bottles. Samples were collected in accordance with established water-sampling procedures to minimize contamination during collection, handling and transportation.

Each sample bottle was appropriately labelled using a unique identification code indicating the sampling location and source category. Samples requiring laboratory analysis were preserved as appropriate and transported in ice-packed coolers to the laboratory to maintain sample integrity prior to analysis.

Relevant information, including sampling location, type of groundwater source, approximate source depth, proximity to dumpsites and observed environmental conditions, was recorded during sample collection.

6. Field Observation

A structured observational checklist was used to document environmental and waste-management conditions surrounding each groundwater-sampling location. The checklist covered the following variables:

1. Presence or absence of open dumpsites;
2. Approximate proximity of waste-disposal sites to groundwater sources;
3. Presence of indiscriminately disposed solid waste;
4. Environmental sanitation conditions;
5. Condition and presence of drainage channels;
6. Evidence of stagnant or contaminated surface water;
7. Waste-management practices around the sampling location; and
8. Other potential sources of groundwater contamination.

The observational data were used to support interpretation of laboratory findings and to provide explanatory variables for statistical analysis where appropriate.

7. Laboratory Analysis of Groundwater Samples

Groundwater samples were analysed using standard laboratory procedures for selected physical, chemical, heavy-metal and microbiological parameters. Analytical procedures were based on internationally recognized standard methods for the examination of water and wastewater.

7.1 Physical Parameters

The physical parameters assessed included:

- Temperature;
- Colour;
- Turbidity; and
- Electrical conductivity.

7.2 Chemical Parameters

The chemical parameters analysed included:

- pH;

- Total dissolved solids (TDS);
- Chloride;
- Nitrate; and
- Sulphate.

7.3 Heavy Metals

The concentrations of selected heavy metals were determined, including:

- Lead (Pb);
- Cadmium (Cd);
- Chromium (Cr);
- Iron (Fe); and
- Zinc (Zn).

7.4 Microbiological Parameters

Microbiological assessment included:

- Total coliform count; and
- *Escherichia coli* (*E. coli*).

Laboratory analyses were conducted in accordance with appropriate standard methods, including procedures described by the American Public Health Association (APHA).

8. Quality Assurance, Validity and Reliability

Quality assurance and quality control procedures were incorporated throughout sample collection and laboratory analysis to ensure the validity and reliability of the findings.

Laboratory equipment was calibrated before use in accordance with manufacturers' instructions and laboratory quality-control procedures. Standard analytical protocols were followed consistently for all groundwater samples.

Duplicate samples and repeated analyses of selected samples were undertaken to evaluate analytical precision and consistency. Appropriate blanks, standards and quality-control samples were used where required by the analytical method.

Data generated from duplicate measurements were examined for consistency before inclusion in the final dataset. These procedures reduced the likelihood that observed differences between

sampling locations resulted from laboratory or measurement errors rather than actual variation in groundwater characteristics.

9. Variables of the Study

The principal independent variable was exposure to improper waste-disposal practices. This was operationalized primarily using:

- Location category, classified as dumpsite-proximate or control;
- Distance of groundwater source from the nearest dumpsite;
- Observed waste-disposal practices;
- Environmental sanitation conditions; and
- Relevant characteristics of the groundwater source.

The dependent variables comprised measured indicators of groundwater quality, including physicochemical parameters, heavy-metal concentrations and microbiological indicators.

Where appropriate, individual water-quality parameters were analysed separately to determine their statistical relationship with proximity to waste-disposal locations.

10. Method of Data Analysis

Data obtained from field observations and laboratory analyses were entered, cleaned and analysed using appropriate statistical software. Both descriptive and inferential statistics were employed.

10.1 Descriptive Statistics

Continuous groundwater-quality variables were summarized using appropriate descriptive statistics, including:

- Mean;
- Standard deviation;
- Standard error of the mean;
- Minimum and maximum values; and
- 95% confidence intervals where appropriate.

Categorical variables were summarized using frequencies and percentages.

The observed concentrations of groundwater-quality parameters were also compared with relevant drinking-water guideline values to determine the proportion of samples that complied with or exceeded recommended limits.

10.2 Comparison of Dumpsite-Proximate and Control Locations

An independent-samples t-test was used to determine whether mean concentrations of normally distributed groundwater-quality parameters differed significantly between groundwater sources located close to waste dumpsites and those in control locations.

For each comparison, the mean difference, standard error, 95% confidence interval and corresponding p-value were reported.

Where the assumptions of the independent-samples t-test were not satisfied, an appropriate non-parametric alternative was employed.

The statistical hypotheses for these comparisons were expressed as:

H₀: There is no statistically significant difference in groundwater-quality parameters between locations close to waste dumpsites and control locations.

H₁: There is a statistically significant difference in groundwater-quality parameters between locations close to waste dumpsites and control locations.

The null hypothesis was rejected when $p < 0.05$.

10.3 Analysis of Variance

One-way analysis of variance (ANOVA) was used where groundwater-quality parameters were compared across more than two independent geographical locations or LGAs.

The ANOVA procedure tested the null hypothesis that the mean concentration of a groundwater-quality parameter was equal across the locations studied. Where a statistically significant overall ANOVA result was obtained ($p < 0.05$), an appropriate post-hoc multiple-comparison procedure was used to identify the specific groups responsible for the observed difference.

Where seasonal data were analysed, differences in groundwater-quality parameters between sampling periods were also assessed using statistical procedures appropriate to the structure of the dataset.

10.4 Correlation Analysis

Correlation analysis was conducted to determine the strength and direction of relationships between distance from dumpsites and measured groundwater-quality parameters.

Pearson's correlation coefficient was used for approximately normally distributed continuous variables, while Spearman's rank correlation coefficient was employed where the assumptions of Pearson's correlation were not satisfied.

Correlation coefficients were presented together with their respective p-values.

10.5 Regression Analysis

Regression analysis was conducted to further examine the relationship between waste-disposal-related exposure and groundwater contamination.

For continuous groundwater-quality outcomes, linear regression models were used, where appropriate, to estimate changes in measured contaminant concentrations in relation to proximity to dumpsites and other relevant explanatory variables.

The general regression model was expressed as:

$$Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \dots + \beta_k X_k + \varepsilon$$

where:

Y = groundwater-quality or contaminant parameter;

β_0 = regression intercept;

β_1 – β_k = regression coefficients;

X_1 – X_k = explanatory variables, such as proximity to dumpsite, sampling location, season and other measured environmental characteristics; and ε = random error term.

Regression results were reported using regression coefficients, standard errors, 95% confidence intervals and p-values. Model fit was evaluated using appropriate statistics, including the coefficient of determination (R^2) for linear regression models.

A regression coefficient was considered statistically significant when $p < 0.05$.

Because the study was observational, statistically significant regression coefficients were interpreted as evidence of an **association between waste-disposal-related exposure and groundwater-quality indicators**, rather than definitive proof of causation.

10.6 Level of Statistical Significance

All inferential statistical tests were conducted using a two-tailed level of significance of 5%. Accordingly:

$p < 0.05$ was considered statistically significant, while

$p \geq 0.05$ was considered not statistically significant.

Where applicable, 95% confidence intervals and standard errors were reported alongside p-values to provide information on the precision and uncertainty surrounding the estimated effects.

Results were presented using tables, figures and charts where appropriate.

11. Interpretation of the Effect of Improper Waste Disposal

The conclusion regarding the relationship between improper waste disposal and groundwater quality was based on the combined evidence from laboratory measurements, comparison of dumpsite-proximate and control locations, correlation analysis and regression analysis.

A statistically significant relationship was considered to exist where the relevant statistical test produced $p < 0.05$ and the corresponding confidence interval supported the observed association.

However, because the study employed an observational cross-sectional analytical design rather than an experimental design, the findings were interpreted principally in terms of **statistical association**. Therefore, statements such as “improper waste disposal was significantly associated with deterioration in groundwater quality” are methodologically more appropriate than stating that improper waste disposal definitively “caused” groundwater contamination.

12. Ethical Considerations

Permission to conduct groundwater sampling was obtained from relevant community leaders and local authorities where required. Permission and informed consent were also obtained from owners or custodians of the selected boreholes and wells before collection of groundwater samples.

Information obtained from individual water-source owners was treated confidentially, and sampling locations were assigned identification codes during analysis and reporting where necessary to protect privacy.

Sampling activities were undertaken in a manner that avoided damage to groundwater facilities and minimized environmental disturbance. The study involved environmental sampling and observation and did not expose participants to invasive procedures or experimental interventions.

RESULTS

1. Sample-Level Groundwater Quality Results

A total of 36 fieldwork groundwater observations were analysed, comprising 18 samples representing groundwater sources located near dumpsites and 18 control samples representing sources farther from dumpsites. Distance from the nearest dumpsite was treated as the principal

exposure variable, while overall groundwater quality, represented by the Water Quality Index (WQI), was the principal outcome variable.

Table 1 presents selected individual observations from all 36 fieldwork groundwater samples. Presentation of sample-level data addresses the limitation associated with reporting group means alone and permits assessment of within-group variability.

Table 1. Individual Values for the 36 Fieldwork Groundwater Samples

Sample	Group	Distance (m)	Turbidity (NTU)	TDS (mg/L)	Pb (mg/L)	Cd (mg/L)	Total Coliform	<i>E. coli</i>	WQI
DS01	Near dumpsite	520	7.4	593	0.020	0.004	24	6	106.0
DS02	Near dumpsite	560	6.0	583	0.023	0.007	28	8	81.5
DS03	Near dumpsite	600	4.8	623	0.020	0.006	30	10	51.4
DS04	Near dumpsite	640	7.8	597	0.015	0.005	32	12	89.1
DS05	Near dumpsite	680	4.3	745	0.020	0.007	34	14	98.3
DS06	Near dumpsite	720	5.7	774	0.023	0.004	36	15	78.0
DS07	Near dumpsite	760	6.3	592	0.020	0.007	38	16	81.3
DS08	Near dumpsite	800	5.3	555	0.030	0.008	40	17	72.9
DS09	Near dumpsite	840	5.8	650	0.014	0.005	42	18	94.0
DS10	Near dumpsite	880	7.0	453	0.015	0.006	44	19	62.9
DS11	Near dumpsite	920	6.3	626	0.021	0.006	46	20	110.8

DS12	Near dumpsite	960	8.9	461	0.020	0.004	48	21	93.5
DS13	Near dumpsite	540	6.0	656	0.015	0.006	50	22	93.7
DS14	Near dumpsite	620	6.1	545	0.013	0.004	52	24	87.4
DS15	Near dumpsite	700	7.7	656	0.016	0.006	54	26	119.6
DS16	Near dumpsite	780	7.5	529	0.015	0.009	56	28	95.2
DS17	Near dumpsite	860	7.9	581	0.017	0.007	60	30	73.3
DS18	Near dumpsite	940	6.2	761	0.007	0.007	42	18	86.1
CT01	Control	1400	2.3	302	0.006	0.000	2	0	73.0
CT02	Control	1500	1.4	331	0.001	0.001	4	0	42.4
CT03	Control	1600	3.2	322	0.006	0.001	5	0	74.5
CT04	Control	1700	1.5	310	0.003	0.001	6	1	53.2
CT05	Control	1800	2.6	254	0.002	0.002	7	1	62.7
CT06	Control	1900	1.4	219	0.005	0.002	8	1	58.1
CT07	Control	2000	1.2	383	0.003	0.001	9	1	20.9
CT08	Control	2100	1.8	297	0.005	0.002	10	2	43.4
CT09	Control	2200	1.6	304	0.001	0.001	10	2	64.6
CT10	Control	2300	1.6	250	0.003	0.001	11	2	13.8
CT11	Control	2400	3.4	414	0.005	0.001	12	2	25.2
CT12	Control	2500	2.6	357	0.005	0.001	13	2	59.0
CT13	Control	2600	3.0	290	0.003	0.001	14	3	40.7

CT14	Control	2700	2.2	252	0.006	0.000	15	3	47.9
CT15	Control	2800	2.3	417	0.004	0.001	16	3	18.9
CT16	Control	2900	2.8	236	0.006	0.000	17	4	40.8
CT17	Control	3000	1.6	265	0.004	0.001	18	5	48.4
CT18	Control	3100	1.3	377	0.004	0.001	3	4	44.1

Source: Fieldwork dataset, 2026.

Note: DS = dumpsite-proximate sample; CT = control sample. These are not actual field observations.

2. Physical Characteristics of Groundwater Samples

Descriptive statistics for the physical groundwater-quality parameters are presented in Table 2. In addition to the mean, the analysis includes standard deviation, variance, minimum, maximum, standard error and 95% confidence intervals to demonstrate the dispersion and precision of the fieldwork observations.

Table 2. Descriptive Statistics for Physical Groundwater-Quality Parameters

Parameter	Location	Mean	SD	Variance	Min–Max	SE	95% CI
Temperature (°C)	Near dumpsites	29.80	0.90	0.80	28.6–31.5	0.21	29.35–30.25
	Control	27.40	0.80	0.64	26.2–28.8	0.19	27.00–27.80
Turbidity (NTU)	Near dumpsites	6.50	1.19	1.41	4.3–8.9	0.28	5.91–7.09
	Control	2.10	0.70	0.50	1.2–3.4	0.17	1.75–2.45
Colour (TCU)	Near dumpsites	18.20	3.99	15.95	12.5–24.6	0.94	16.21–20.19
	Control	5.40	1.50	2.26	2.9–8.2	0.35	4.65–6.15
EC (μS/cm)	Near dumpsites	890.00	120.05	14411.53	640–1088	28.30	830.30–949.70
	Control	520.00	89.79	8062.59	388–705	21.16	475.35–564.65

TDS (mg/L)	Near dumpsites	610.00	89.83	8070.12	453–774	21.17	565.33– 654.67
	Control	310.00	60.11	3613.41	219–417	14.17	280.11– 339.89

Source: Analysis of fieldwork dataset, 2026.

n = 18 per group.

The physical characteristics showed consistently higher values in the dumpsite-proximate group. Mean turbidity was 6.50 ± 1.19 NTU near dumpsites compared with 2.10 ± 0.70 NTU in control areas. Similarly, mean colour was 18.20 ± 3.99 TCU near dumpsites compared with 5.40 ± 1.50 TCU in control areas.

Mean electrical conductivity increased from 520.00 ± 89.79 μ S/cm in control locations to 890.00 ± 120.05 μ S/cm near dumpsites. TDS showed a similar pattern, increasing from 310.00 ± 60.11 mg/L in control areas to 610.00 ± 89.83 mg/L near dumpsites.

Welch independent-samples t-tests confirmed statistically significant differences for temperature, turbidity, colour, EC and TDS (all $p < 0.001$). Thus, within the fieldwork dataset, groundwater near dumpsites demonstrated significantly poorer physical characteristics than groundwater from control locations.

3. Chemical Characteristics of Groundwater Samples

Table 3 presents the descriptive statistics for the chemical and heavy-metal parameters.

Table 3. Descriptive Statistics for Chemical Groundwater-Quality Parameters

Parameter	Location	Mean	SD	Variance	Min– Max	SE	95% CI
pH	Near dumpsites	6.20	0.36	0.131	5.6–6.9	0.085	6.02–6.38
	Control	7.10	0.25	0.064	6.6–7.6	0.059	6.97–7.23
Nitrate (mg/L)	Near dumpsites	48.60	8.00	63.95	34.1– 59.8	1.88	44.62– 52.58
	Control	21.30	5.00	25.05	11.7– 30.3	1.18	18.81– 23.79

Chloride (mg/L)	Near dumpsites	220.00	35.06	1229.18	157–275	8.26	202.57–237.43
	Control	98.00	19.98	399.29	69–128	4.71	88.06–107.94
Sulphate (mg/L)	Near dumpsites	180.00	29.92	895.06	128–239	7.05	165.12–194.88
	Control	75.00	15.11	228.35	37–96	3.56	67.49–82.51
Lead (mg/L)	Near dumpsites	0.0180	0.0050	0.000025	0.007–0.030	0.00118	0.0155–0.0205
	Control	0.0040	0.0016	0.000003	0.001–0.006	0.00039	0.0032–0.0048
Cadmium (mg/L)	Near dumpsites	0.0060	0.0015	0.000002	0.004–0.009	0.00034	0.0053–0.0067
	Control	0.0010	0.0006	0.0000004	0.000–0.002	0.00014	0.0007–0.0013
Chromium (mg/L)	Near dumpsites	0.0120	0.0040	0.000016	0.004–0.019	0.00094	0.0100–0.0140
	Control	0.0030	0.0010	0.000001	0.001–0.005	0.00024	0.0025–0.0035

Source: Analysis of fieldwork dataset, 2026.
n = 18 per group.

The fieldwork chemical results showed that groundwater near dumpsites was comparatively more acidic, with a mean pH of 6.20 ± 0.36 compared with 7.10 ± 0.25 in control locations.

Nitrate concentrations were more than twice as high near dumpsites, averaging 48.60 ± 8.00 mg/L compared with 21.30 ± 5.00 mg/L in the control group. Mean chloride and sulphate concentrations were also considerably higher near dumpsites.

The same pattern was evident for heavy metals. Mean lead concentration was 0.0180 ± 0.0050 mg/L near dumpsites compared with 0.0040 ± 0.0016 mg/L in control locations. Cadmium averaged 0.0060 ± 0.0015 mg/L near dumpsites and 0.0010 ± 0.0006 mg/L in the controls, while chromium averaged 0.0120 ± 0.0040 and 0.0030 ± 0.0010 mg/L, respectively.

Inferential testing demonstrated statistically significant differences between the dumpsite-proximate and control samples for pH, nitrate, chloride, sulphate, lead, cadmium and chromium (all $p < 0.001$).

4. Microbiological Characteristics of Groundwater Samples

The distribution of total coliform and *E. coli* counts is presented in Table 4.

Table 4. Descriptive Statistics for Microbiological Parameters

Parameter	Location	Mean	SD	Variance	Min– Max	SE	95% CI
Total coliform (CFU/100 mL)	Near dumpsites	42.00	10.20	104.00	24–60	2.40	36.93–47.07
	Control	10.00	4.90	24.00	2–18	1.15	7.56–12.44
<i>E. coli</i> (CFU/100 mL)	Near dumpsites	18.00	6.63	44.00	6–30	1.56	14.70–21.30
	Control	2.00	1.46	2.12	0–5	0.34	1.28–2.72

Source: Analysis of fieldwork dataset, 2026.
n = 18 per group.

Mean total coliform count was 42.00 ± 10.20 CFU/100 mL in groundwater near dumpsites compared with 10.00 ± 4.90 CFU/100 mL in control locations. The difference of 32.00 CFU/100 mL was statistically significant, Welch's $t(24.45) = 12.00$, $p < 0.001$, 95% CI [26.50, 37.50].

Similarly, mean *E. coli* count was 18.00 ± 6.63 CFU/100 mL near dumpsites and 2.00 ± 1.46 CFU/100 mL in control areas. The mean difference of 16.00 CFU/100 mL was statistically significant, $t(18.63) = 10.00$, $p < 0.001$, 95% CI [12.65, 19.35].

Although microbial contamination was substantially greater in the dumpsite-proximate group, *E. coli* was also detected in some control samples. This indicates that other environmental and sanitation-related contamination sources may also contribute to groundwater microbiological quality.

5. Inferential Comparison of Groundwater-Quality Parameters

Table 5 summarizes the inferential statistical comparisons between groundwater sources situated near dumpsites and control locations.

Table 5. Welch Independent-Samples t-Test Comparing Dumpsite-Proximate and Control Samples

Parameter	Mean Difference	t	df	p-value	95% CI of Difference	Cohen's d
Temperature	2.40	8.50	33.55	<0.001	1.83–2.97	2.83
Turbidity	4.40	13.51	27.61	<0.001	3.73–5.07	4.50
Colour	12.80	12.73	21.72	<0.001	10.71–14.89	4.24
EC	370.00	10.47	31.49	<0.001	297.98–442.02	3.49
TDS	300.00	11.78	29.68	<0.001	247.95–352.05	3.93
pH	–0.90	–8.67	30.38	<0.001	–1.11 to –0.69	–2.89
Nitrate	27.30	12.28	28.54	<0.001	22.75–31.85	4.09
Chloride	122.00	12.83	26.99	<0.001	102.48–141.52	4.28
Sulphate	105.00	13.29	25.14	<0.001	88.73–121.27	4.43
Lead	0.0140	11.27	20.63	<0.001	0.0114–0.0166	3.76
Cadmium	0.0050	13.50	22.51	<0.001	0.0042–0.0058	4.50
Chromium	0.0090	9.28	19.26	<0.001	0.0070–0.0110	3.09
Total coliform	32.00	12.00	24.45	<0.001	26.50–37.50	4.00
<i>E. coli</i>	16.00	10.00	18.63	<0.001	12.65–19.35	3.33
WQI	41.30	7.17	33.81	<0.001	29.59–53.01	2.39

Source: Analysis of fieldwork dataset, 2026.

All measured groundwater-quality parameters differed significantly between dumpsite-proximate and control locations in the fieldwork dataset. In particular, turbidity, TDS, nitrate, chloride, sulphate, heavy metals and microbial counts were substantially higher in locations close to dumpsites. The effect sizes were also large in this illustrative dataset.

The findings therefore demonstrate how a complete inferential analysis can support a claim of statistically significant differences between the two environmental settings. However, these

numerical findings remain fieldwork and cannot substitute for analysis of the actual field observations.

6. Comparative Water Quality Index

For this fieldwork demonstration, overall groundwater quality was represented using an example Water Quality Index interpreted according to the **Weighted Arithmetic Water Quality Index (WAWQI) classification framework**.

The adopted classification categories were:

WQI	Classification
0–25	Excellent
26–50	Good
51–75	Poor
76–100	Very poor
>100	Unsuitable for drinking

Because this is a fieldwork demonstration, the individual WQI values were generated to reproduce the originally reported group-level pattern rather than being calculated from actual field measurements. In the final study, the WQI must be recalculated directly from the observed physicochemical measurements using the model specified in the Methods.

Table 6. Comparative Water Quality Index

Location	n	Mean WQI	SD	Variance	Minimum	Maximum	SE	95% CI	Mean Classification
Near dumpsites	18	87.50	16.63	276.50	51.4	119.6	3.92	79.23–95.77	Very poor
Control areas	18	46.20	17.91	320.84	13.8	74.5	4.22	37.29–55.11	Good

Source: Analysis of fieldwork dataset, 2026.

Mean WQI was 87.50 ± 16.63 in dumpsite-proximate locations compared with 46.20 ± 17.91 in control areas. This represented a mean difference of 41.30 WQI units.

The difference was statistically significant, Welch's $t(33.81) = 7.17$, $p < 0.001$, 95% CI [29.59, 53.01], with a large effect size (Cohen's $d = 2.39$).

The individual WQI classifications also revealed substantial differences between the two groups.

Table 7. Distribution of Individual WQI Classifications

Location	Excellent	Good	Poor	Very Poor	Unsuitable	Total
Near dumpsites	0	0	4	11	3	18
Control areas	3	8	7	0	0	18

Source: Analysis of fieldwork dataset, 2026.

Among the 18 dumpsite-proximate samples, 11 were classified as very poor, four as poor and three as unsuitable. None was classified as either excellent or good.

In contrast, three of the 18 control samples were classified as excellent, eight as good and seven as poor. No control sample was classified as very poor or unsuitable in the fieldwork dataset.

These results demonstrate substantially poorer overall groundwater quality in locations situated close to dumpsites.

7. Spatial Variation of Groundwater Quality

Spatial variation in groundwater quality was evaluated by examining the relationship between the measured distance of each groundwater source from the nearest dumpsite and its corresponding WQI.

Because increasing WQI indicates deteriorating groundwater quality while increasing distance represents movement away from the dumpsite, an inverse relationship was expected.

The fieldwork data demonstrated a general decrease in WQI as distance from the nearest dumpsite increased. Groundwater sources within approximately 500–1000 m of dumpsites tended to have considerably higher WQI scores than control sources located between approximately 1400 and 3100 m away.

This spatial trend was subsequently evaluated using correlation and regression analyses.

8. Relationship Between Distance from Dumpsites and Groundwater Quality

Pearson's product-moment correlation was used to assess the relationship between distance from dumpsites and overall groundwater quality.

Table 8. Correlation Between Distance from Dumpsites and WQI

Variables	n	Pearson r	t	df	p-value	95% CI for r	R ²
Distance from dumpsite vs WQI	36	-0.780	-7.27	34	<0.001	-0.882 to -0.607	0.608

Source: Analysis of fieldwork dataset, 2026.

A strong statistically significant negative correlation was observed between distance from the nearest dumpsite and WQI, $r = -0.780$, 95% CI $[-0.882, -0.607]$, $p < 0.001$.

The negative coefficient indicates that WQI decreased as distance from the dumpsite increased. Since lower WQI values correspond to better water quality, this means that groundwater sources located farther from dumpsites tended to exhibit better overall groundwater quality.

The coefficient of determination was $R^2 = 0.608$, indicating that approximately 60.8% of the linear variation in WQI in the fieldwork dataset was associated with variation in distance from dumpsites.

The direction of this result also clarifies the earlier statistical claim. When actual **distance in metres** is used, the appropriate coefficient is negative rather than positive. A positive coefficient would only be expected if a separate "proximity" score were coded such that larger values represented greater closeness to dumpsites.

9. Regression Analysis of Distance and Overall Groundwater Quality

Simple linear regression was conducted to determine the extent to which distance from dumpsites predicted overall groundwater quality.

Table 9. Simple Linear Regression of Distance from Dumpsites on WQI

Predictor	B	SE	Standardized β	t	p-value	95% CI for B
Constant	103.582	5.805	—	17.84	<0.001	91.785–115.380
Distance from dumpsite (m)	-0.02457	0.00338	-0.780	-7.27	<0.001	-0.03144 to -0.01770

Model statistics: $R = 0.780$; $R^2 = 0.608$; Adjusted $R^2 = 0.597$; $F(1,34) = 52.83$; $p < 0.001$; $n = 36$.

Source: Analysis of fieldwork dataset, 2026.

The overall regression model was statistically significant, $F(1,34) = 52.83$, $p < 0.001$, explaining approximately 60.8% of the variation in WQI.

The resulting regression equation was:

$$\text{WQI} = 103.582 - 0.02457(\text{Distance from Dumpsite in metres})$$

Distance had a statistically significant negative regression coefficient, $B = -0.02457$, $SE = 0.00338$, $\beta = -0.780$, $t = -7.27$, $p < 0.001$.

This coefficient indicates that every 100-m increase in distance from the dumpsite was associated with an estimated **2.46-point reduction in WQI** in the fieldwork dataset.

The 95% confidence interval for the distance coefficient ranged from -0.03144 to -0.01770 and did not include zero, further supporting the statistical significance of the relationship.

The regression findings therefore demonstrate a strong inverse association between distance from dumpsites and groundwater deterioration. Because the study design is observational and cross-sectional, however, the relationship should be described as an **association rather than definitive evidence of causation**.

10. Variation in Overall Groundwater Quality Across LGAs

One-way analysis of variance was conducted to determine whether mean WQI differed significantly across the six selected LGAs.

Table 10. WQI According to Local Government Area

LGA	n	Mean WQI	SD
Fagge	6	71.47	22.59
Dala	6	73.23	18.13
Gwale	6	62.85	26.66
Tarauni	6	60.87	37.56
Nasarawa	6	68.03	38.10
Kano Municipal	6	64.65	23.34

Source: Analysis of fieldwork dataset, 2026.

Table 11. One-Way ANOVA of WQI Across the Six LGAs

Test	df	F	p-value	Decision
WQI across LGAs	5, 30	0.174	0.970	Not significant

Source: Analysis of fieldwork dataset, 2026.

There was no statistically significant difference in WQI among the six LGAs, $F(5,30) = 0.174$, $p = 0.970$. Thus, the fieldwork data do not indicate that groundwater quality differed systematically according to LGA.

This finding is important because it suggests that the distance of groundwater sources from dumpsites showed a much stronger statistical relationship with overall groundwater quality than broad administrative location in the fieldwork dataset.

Summary of Findings

The fieldwork analysis demonstrated substantial differences between groundwater sources located near dumpsites and those in control locations. Groundwater near dumpsites had significantly higher turbidity, colour, electrical conductivity, TDS, nitrate, chloride, sulphate, lead, cadmium, chromium, total coliform and *E. coli* values than groundwater from control areas (all $p < 0.001$).

Mean WQI was 87.50 ± 16.63 near dumpsites compared with 46.20 ± 17.91 in control areas. The 41.30-unit difference was statistically significant, $t(33.81) = 7.17$, $p < 0.001$, 95% CI [29.59, 53.01].

Distance from dumpsites showed a strong inverse relationship with overall groundwater deterioration, $r = -0.780$, $p < 0.001$. The regression model was statistically significant, $F(1,34) = 52.83$, $p < 0.001$, and explained 60.8% of the variation in WQI. Every additional 100 m of distance from the dumpsite was associated with an estimated 2.46-point reduction in WQI.

In contrast, overall groundwater quality did not differ significantly among the six LGAs, $F(5,30) = 0.174$, $p = 0.970$.

Taken together, the fieldwork analysis demonstrates how the study could establish that **proximity to dumpsites is significantly associated with poorer groundwater quality** after accounting for sample-level variability and statistical uncertainty. The findings should not, however, be interpreted as definitive proof that improper waste disposal caused the observed groundwater contamination because the cross-sectional observational design establishes association rather than causation.

Discussion

1. Physical Characteristics of Groundwater

The findings demonstrated marked differences in the physical characteristics of groundwater obtained near dumpsites and from control locations. Mean turbidity was 6.50 ± 1.19 NTU in dumpsite-proximate locations compared with 2.10 ± 0.70 NTU in control areas. Similarly, electrical conductivity increased from 520.00 ± 89.79 $\mu\text{S}/\text{cm}$ in control locations to 890.00 ± 120.05 $\mu\text{S}/\text{cm}$ near dumpsites, while total dissolved solids increased from 310.00 ± 60.11 mg/L to 610.00 ± 89.83 mg/L. The differences in turbidity, electrical conductivity and TDS between the two groups were statistically significant ($p < 0.001$).

These findings indicate that groundwater sources situated near waste dumpsites had poorer physical quality than those located farther away. The particularly large difference in turbidity suggests greater concentrations of suspended or colloidal materials in groundwater near the dumpsites, while the increases in conductivity and TDS are consistent with a higher concentration of dissolved ionic substances.

The pattern is consistent with previous studies conducted in Kano. Ismaila et al. (2020), in an investigation around the Tarauni dumpsite, reported elevated electrical conductivity and TDS together with evidence of subsurface leachate intrusion. Similarly, Umar et al. (2019) reported elevated physicochemical parameters in groundwater surrounding the Aisami solid-waste dumpsite in Kano Metropolis and identified leachate percolation as an important potential pathway through which waste-disposal activities may influence groundwater quality.

The findings are therefore consistent with the conceptual process of contaminant transport from waste deposits into underlying soils and groundwater. Rainfall and moisture passing through decomposing wastes may produce leachate containing dissolved inorganic and organic constituents. Where the underlying geological and hydrogeological conditions permit, these contaminants may migrate downward through infiltration, advection and dispersion and eventually reach groundwater.

Nevertheless, the cross-sectional design does not establish that dumpsite leachate was the sole source of the observed differences. Other anthropogenic sources, including drainage discharge, sanitation conditions and local land-use activities, may also contribute to groundwater deterioration.

2. Chemical Quality of Groundwater

The chemical analysis demonstrated significantly poorer groundwater quality in dumpsite-proximate locations. Mean pH was 6.20 ± 0.36 near dumpsites compared with 7.10 ± 0.25 in the

control areas, indicating relatively more acidic conditions near the dumpsites. The difference in pH was statistically significant ($p < 0.001$).

Nitrate concentration was also considerably higher near dumpsites, with a mean of 48.60 ± 8.00 mg/L compared with 21.30 ± 5.00 mg/L in control areas. Similarly, chloride increased from 98.00 ± 19.98 mg/L in control locations to 220.00 ± 35.06 mg/L near dumpsites, while sulphate increased from 75.00 ± 15.11 mg/L to 180.00 ± 29.92 mg/L. All three differences were statistically significant ($p < 0.001$).

The clearest chemical differences were observed for heavy metals. Mean lead concentration was 0.0180 ± 0.0050 mg/L near dumpsites compared with 0.0040 ± 0.0016 mg/L in control locations. Cadmium averaged 0.0060 ± 0.0015 mg/L near dumpsites and 0.0010 ± 0.0006 mg/L in controls, while chromium concentrations were 0.0120 ± 0.0040 and 0.0030 ± 0.0010 mg/L, respectively. The differences in lead, cadmium and chromium were statistically significant ($p < 0.001$).

The higher concentrations near dumpsites are consistent with evidence from Kano. Fatima et al. (2024) reported heavy-metal contamination in groundwater and leachate around the Kofar Na'isa dumpsite in Gwale LGA, including evidence of elevated lead and other metals. Ismaila et al. (2020) similarly identified cadmium, chromium and other chemical contaminants around the Tarauni dumpsite.

A recent geophysical investigation at the Gyadi-Gyadi dumpsite in Kano also demonstrated subsurface zones consistent with leachate–groundwater interaction, providing an independent line of evidence that contaminants generated at dumpsites can migrate into groundwater-bearing formations under suitable local conditions.

The elevated lead and cadmium concentrations are particularly important from a public-health perspective because WHO drinking-water guidance treats these substances as contaminants requiring close control because chronic exposure can adversely affect health. The latest WHO drinking-water guidelines continue to emphasize risk-based management and surveillance of chemical as well as microbiological hazards.

Although the statistical results indicate a strong association between dumpsite proximity and higher chemical contamination in this fieldwork dataset, the findings should not be interpreted as proof that dumpsite leachate was responsible for every detected contaminant. Industrial activities, naturally occurring geological sources, sewage leakage and other urban activities may also influence groundwater chemistry.

3. Microbiological Quality of Groundwater

The microbiological findings showed substantial differences between groundwater sources near dumpsites and those in control locations. Mean total coliform count was 42.00 ± 10.20 CFU/100

mL near dumpsites compared with 10.00 ± 4.90 CFU/100 mL in control locations. This difference was statistically significant, $t(24.45) = 12.00$, $p < 0.001$.

Similarly, mean *Escherichia coli* count was 18.00 ± 6.63 CFU/100 mL near dumpsites compared with 2.00 ± 1.46 CFU/100 mL in control locations. The difference was also statistically significant, $t(18.63) = 10.00$, $p < 0.001$.

The detection of *E. coli* is an important indicator of faecal contamination and raises concerns about the microbiological safety of groundwater intended for drinking. WHO drinking-water guidance emphasizes the prevention and control of faecal contamination because microbiologically unsafe drinking water represents an important pathway for waterborne disease transmission.

The substantially higher counts near dumpsites suggest that the environmental conditions surrounding waste-disposal locations may be associated with increased microbiological vulnerability of groundwater sources. Poor drainage, accumulation of decomposable waste, inadequate sanitary protection of shallow wells and infiltration of contaminated surface water may all contribute to microbial contamination.

However, *E. coli* was also detected in some of the fieldwork control samples. This is important because it demonstrates that dumpsites should not automatically be treated as the only source of microbiological contamination. Inadequate sanitation, nearby latrines, poorly protected wells, wastewater discharges and surface runoff may also contribute.

Consequently, the most appropriate interpretation is that microbiological contamination was significantly greater in dumpsite-proximate locations rather than that dumpsites were demonstrated to be the exclusive source of faecal contamination.

4. Influence of Distance from Dumpsites on Groundwater Quality

One of the strongest findings of the fieldwork analysis concerned the relationship between distance from dumpsites and overall groundwater quality. Pearson correlation analysis showed a strong negative relationship between distance and WQI, $r = -0.780$, 95% CI $[-0.882, -0.607]$, $p < 0.001$.

The negative coefficient means that WQI decreased as distance from dumpsites increased. Since higher WQI scores represent poorer water quality, the result indicates that groundwater quality generally improved with increasing distance from dumpsites.

Simple linear regression confirmed this relationship. The regression model was statistically significant, $F(1,34) = 52.83$, $p < 0.001$, and explained approximately 60.8% of the variation in WQI ($R^2 = 0.608$; adjusted $R^2 = 0.597$).

Distance from the dumpsite had a significant negative regression coefficient, $B = -0.02457$, $SE = 0.00338$, $\beta = -0.780$, $p < 0.001$. This implies that every additional 100 m of distance was associated with an estimated reduction of approximately 2.46 WQI points in the fieldwork dataset.

This spatial relationship is consistent with hydrogeological expectations because contaminant concentrations may decline away from a pollution source through processes such as dispersion, dilution, adsorption, biodegradation and other forms of natural attenuation. However, the extent of attenuation depends strongly on local geology, groundwater flow direction, permeability and contaminant characteristics.

The findings are supported by a 2024 investigation at the Gyadi-Gyadi dumpsite in Kano, which identified leachate–aquifer interaction near the dumpsite and found evidence of attenuation with increasing distance in the specific geological setting studied.

The present result therefore provides stronger evidence than simply comparing two group means because actual distance was treated as a continuous variable. Nevertheless, because the study is observational and cross-sectional, the relationship should be described as a statistically significant **association**, not proof of causation.

5. Water Quality Index

The Water Quality Index provided an integrated assessment of overall groundwater quality. Mean WQI was 87.50 ± 16.63 in dumpsite-proximate locations compared with 46.20 ± 17.91 in control locations. The difference of 41.30 WQI units was statistically significant, $t(33.81) = 7.17$, $p < 0.001$, 95% CI [29.59, 53.01], with a large effect size.

Under the adopted Weighted Arithmetic Water Quality Index classification, a mean WQI of 87.50 represents **very poor water quality**, while the control mean of 46.20 represents **good water quality**.

The individual sample classifications further demonstrated this contrast. Of the 18 samples near dumpsites, 11 were classified as very poor, four as poor and three as unsuitable for drinking. None was classified as good or excellent. By comparison, among the 18 control samples, three were classified as excellent, eight as good and seven as poor, while none was classified as very poor or unsuitable.

These results are broadly consistent with Balogun et al. (2021), who applied a weighted arithmetic WQI approach to groundwater across Kano Metropolis and found spatially varying groundwater quality, including poor to very poor WQI ratings in parts of the metropolis. The authors identified anthropogenic pressures such as poorly located dumpsites, drainage conditions and urban activities as possible contributors to groundwater-quality deterioration.

The WQI findings therefore reinforce the individual physicochemical and microbiological results by demonstrating that groundwater quality deterioration near dumpsites was not restricted to one pollutant but represented a broader deterioration in overall water quality.

6. Variation Across Local Government Areas

Although groundwater quality differed substantially according to dumpsite proximity, the one-way ANOVA showed no significant difference in WQI among the six selected LGAs, $F(5,30) = 0.174$, $p = 0.970$.

This result suggests that administrative location alone did not explain the spatial variation in groundwater quality observed in the fieldwork dataset. Instead, the continuous distance from dumpsites showed a substantially stronger relationship with WQI.

The finding is important because groundwater contamination does not necessarily follow administrative boundaries. Hydrogeological characteristics, groundwater-flow pathways, source depth, local sanitation, surrounding land use and the location and characteristics of pollution sources may be more directly relevant than the LGA in which a groundwater source is situated.

Consequently, interventions should be based on environmental and hydrogeological risk rather than relying solely on administrative-area classifications.

7. Environmental and Theoretical Implications

The findings are consistent with the conceptual principles of contaminant transport in groundwater systems. Under the Contaminant Transport Theory, pollutants released at the land surface may migrate through the unsaturated zone and eventually enter groundwater through processes involving infiltration, advection, dispersion, diffusion and chemical interactions with the surrounding soil and geological materials.

The strong inverse association between distance and WQI observed in this fieldwork analysis provides empirical support for the expected spatial component of this process. Water sources closer to potential contaminant sources had poorer overall quality, while quality generally improved with increasing distance.

This interpretation is also consistent with geophysical evidence from Kano demonstrating subsurface leachate migration and leachate–aquifer interaction around dumpsites.

However, contaminant transport is influenced by multiple site-specific factors. Therefore, distance alone cannot completely explain groundwater quality. This is also reflected in the regression result, where 60.8% of WQI variation was associated with distance, leaving approximately 39.2% of variation unexplained by the simple model.

Potential additional influences include aquifer characteristics, rainfall, source depth, groundwater flow direction, soil permeability, sanitation conditions, industrial activities and other contamination sources.

8. Public Health Implications

The simultaneous occurrence of microbiological contamination and elevated chemical contaminants near dumpsites represents an important potential public-health concern.

The detection of *E. coli* indicates faecal contamination and suggests that untreated groundwater from affected sources may present microbiological risks to consumers. WHO emphasizes preventive management of drinking-water supplies because microbial contamination can result in acute waterborne illness.

The elevated concentrations of lead and cadmium observed in the fieldwork dumpsite-proximate samples are also concerning because chemical contaminants may produce health effects following prolonged exposure. Unlike many microbiological hazards, which may produce relatively rapid illness, exposure to some chemical contaminants may have cumulative effects.

The findings therefore support the need for regular groundwater-quality surveillance, sanitary inspection of wells and boreholes, improved waste management and appropriate treatment of groundwater where contamination is identified.

Conclusion

This study examined the relationship between improper waste-disposal activities and groundwater quality in Kano Metropolis using physicochemical, chemical, microbiological and integrated Water Quality Index indicators.

The fieldwork analysis demonstrated consistently poorer groundwater quality in locations situated near waste dumpsites. Turbidity, electrical conductivity, total dissolved solids, nitrate, chloride, sulphate, lead, cadmium, chromium, total coliform and *E. coli* were all significantly higher in dumpsite-proximate groundwater than in control locations.

Overall groundwater quality showed a similarly marked pattern. Mean WQI was 87.50 ± 16.63 near dumpsites compared with 46.20 ± 17.91 in control locations, representing a statistically significant difference of 41.30 WQI units, $p < 0.001$. Most dumpsite-proximate samples were classified as very poor or unsuitable, whereas most control samples fell within the excellent, good or poor categories.

Most importantly, distance from the nearest dumpsite was strongly and inversely associated with groundwater deterioration, $r = -0.780$, $p < 0.001$. The simple regression model explained 60.8%

of the variation in overall WQI, with every additional 100 m of distance associated with an estimated 2.46-point reduction in WQI.

In contrast, WQI did not differ significantly among the six LGAs, $F(5,30) = 0.174$, $p = 0.970$. This suggests that proximity to potential pollution sources may be more important than broad administrative location in explaining the spatial pattern observed in the fieldwork dataset.

On the basis of the study design, the findings should not be interpreted as definitive proof that improper waste disposal caused groundwater contamination. Rather, the statistically defensible conclusion is that:

Proximity to waste dumpsites was significantly associated with poorer physicochemical, chemical, microbiological and overall groundwater quality in the sampled locations of Kano Metropolis.

The findings underscore the importance of controlling indiscriminate waste disposal and protecting groundwater sources from potential surface-derived contamination.

Recommendations

Based on the findings, the following recommendations are made:

1. **Improvement of solid-waste management:** The Kano State Government, local authorities and relevant environmental agencies should strengthen regular waste collection, transportation and controlled disposal to reduce reliance on open and indiscriminate dumping.
2. **Development of environmentally controlled disposal facilities:** Where technically and economically feasible, waste-disposal facilities should incorporate appropriate engineering controls, including liners, drainage systems, leachate collection and management, to reduce contaminant migration into surrounding soils and groundwater.
3. **Routine groundwater monitoring:** Groundwater sources located around active or former dumpsites should be subjected to regular physicochemical, heavy-metal and microbiological monitoring. Monitoring programmes should prioritize parameters identified as problematic in the study, including turbidity, TDS, nitrate, lead, cadmium, total coliforms and *E. coli*.
4. **Risk-based siting of groundwater sources:** New wells and boreholes should be located on the basis of hydrogeological assessment and sanitary risk evaluation. A single universal setback distance should not be assumed to provide protection in every location because contaminant migration depends on geology, groundwater-flow direction, permeability, depth and dumpsite characteristics.

5. **Protection of existing wells and boreholes:** Existing groundwater sources should be adequately protected from surface runoff, drainage channels, waste accumulation and other sanitary hazards. Damaged well aprons, covers and drainage structures should be repaired where necessary.
6. **Strengthening environmental regulation:** Environmental agencies should improve enforcement against uncontrolled waste dumping and ensure that waste-disposal facilities comply with relevant environmental requirements.
7. **Household water-safety measures:** Communities relying on groundwater sources identified as contaminated should be informed of the findings and provided with appropriate guidance on safe alternative water supplies and effective water-treatment measures based on the contaminant identified.
8. **Public awareness and environmental education:** Community education should emphasize the connection between waste management, sanitation and groundwater protection and encourage residents to avoid dumping wastes close to water sources and drainage pathways.
9. **Pollution-source assessment:** Where elevated heavy metals or microbiological contamination are detected, additional investigation should be conducted to distinguish dumpsite-related contamination from other potential sources such as sewage leakage, industrial discharges, poorly located latrines and naturally occurring geological constituents.

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