

Physicochemical fingerprinting of cemetery-induced groundwater pollution around Dandolo Cemetery, Kano

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ABSTRACT

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This study presents a forensic hydrogeochemical assessment of groundwater quality around Dan Dolo Cemetery, one of the largest burial grounds in Kano Metropolis, northern Nigeria, where thousands of residents depend on shallow wells and boreholes for domestic water supply. Thirty groundwater samples were collected from boreholes and hand-dug wells within and around the cemetery during the dry season, when dilution effects are minimal. In situ measurements of pH, electrical conductivity (EC), total dissolved solids (TDS), and temperature were obtained using a calibrated multimeter and analyzed. The results show that groundwater in the study area is predominantly acidic (pH 5.41–7.90), with approximately 70% of samples failing WHO and Nigerian drinking water standards. EC values ranged from 140 to 2480 $\mu\text{S}/\text{cm}$, while TDS varied between 99 and 1770 mg/L, indicating widespread ionic enrichment and salinization. Cluster analysis and hierarchical dendrograms identified three hydrochemical groups representing background recharge zones, cemetery-affected mixing zones, and a highly contaminated plume extending from the cemetery toward Kansakali, Jakara, and Kwatawa. More than 40% of samples exceeded regulatory limits for EC, and 45% exceeded TDS standards, while 80% of wells exhibited elevated temperatures, consistent with organic decay and shallow aquifer conditions. The hydrochemical signature and compliance patterns provide strong evidence that Dan Dolo Cemetery acts as a point source of groundwater degradation within the urban aquifer system.

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INTRODUCTION

Groundwater remains a cornerstone of water supply in many African cities, especially where municipal surface water infrastructure is underdeveloped or inconsistent. In Kano Metropolis, northern Nigeria, urban residents rely heavily on shallow wells and boreholes for domestic, commercial, and agricultural use due to limited access to treated piped water and increasing population pressure on water resources. This situation mirrors broader national

concerns over groundwater resource utilization and vulnerability to anthropogenic pollution in Nigerian cities, as highlighted by hydrogeological mapping and environmental studies conducted across major urban centres, including Kano, Kaduna, and Enugu, which emphasize the detrimental impacts of indiscriminate waste disposal on groundwater quality and human health (NGSA hydrogeological programs 2006).

One underappreciated potential source of groundwater contamination in urban settings is cemetery leachate, the complex liquid by-product of human decomposition. As buried organic matter decomposes, it produces a suite of chemical constituents, including organic acids, dissolved salts, nitrogenous compounds, and potentially pathogens that may percolate into the subsurface and contaminate underlying aquifers. Studies in urban contexts have documented elevated electrical conductivity, changes in major ion chemistry, and reduced water quality in groundwater proximate to cemeteries and other concentrated sources of organic waste, indicating that burial grounds can act as point sources of groundwater contamination (for example, investigations in Benin City identified significant impacts of cemetery leachate on proximate boreholes using hydrochemical and spatial methods).

Hydrochemical indicators such as pH, electrical conductivity (EC), total dissolved solids (TDS), and temperature are widely used in groundwater quality assessments as rapid field screening parameters. These variables respond sensitively to changes in dissolved ionic content and organic decomposition, making them valuable in the initial detection of contamination and in identifying spatial trends associated with pollutant plumes. For example, TDS and EC have been used effectively to characterize leachate influence from landfills and waste dumps on adjacent groundwater systems, demonstrating how increasing ionic loads and salinity correlate with proximity to contamination sources (e.g., landfill leachate studies in African and global contexts).

Despite widespread acknowledgement of groundwater vulnerability to pollution in Nigeria's rapidly urbanizing cities, a notable gap remains in empirical research specifically addressing cemetery-related contamination, particularly in northern Nigerian settings such as Kano. Much of the existing Nigerian groundwater literature focuses on urban groundwater vulnerability to agricultural and waste-related inputs (e.g., nitrate contamination and aquifer risk mapping in Abuja and Kaduna) or the effects of landfills and solid waste disposal, rather than burial practices as a contaminant source.

In this study, we investigate the hydrochemical properties of groundwater in the vicinity of Dan Dolo Cemetery (Fig. 1), Kano Metropolis, through in situ measurements of pH, EC, TDS, and temperature, integrated with spatial and cluster analysis, to identify

contamination patterns and plume development. By comparing measured data against international and national drinking water standards and analyzing spatial trends, this research aims to provide a forensic hydrogeological assessment of cemetery influence on groundwater quality. This work represents one of the first systematic examinations of cemetery-induced groundwater degradation in northern Nigeria and contributes to the broader understanding of how burial practices may impact water quality in urban aquifer systems.

Regional Hydrogeological Setting

The study area is located within the Chad Formation and Basement Complex transition zone of Kano Metropolis, northern Nigeria. This region is characterized by a shallow, unconfined to semi-confined aquifer system developed within weathered basement, sandy clay, and alluvial sediments associated with the Jakara River basin. Groundwater in this area occurs predominantly within lateritic sandy soils, weathered and fractured crystalline basement, and alluvial deposits along Jakara drainage corridors. These materials have moderate to high permeability, allowing rapid infiltration of surface-derived fluids into the groundwater system.

Aquifer Characteristics

The aquifer system around Dandolo Cemetery is shallow, with typical groundwater depths in the range of 5–15 m based on borehole construction records and regional hydrogeological surveys of Kano. Such shallow aquifers are highly vulnerable to contamination, particularly from point sources such as cemeteries, septic tanks, solid waste dumps, and open drains.

The absence of thick, low-permeability clay layers means that vertical hydraulic protection is weak, allowing contaminants to migrate rapidly downward from the surface into the saturated zone.

MATERIALS AND METHODS

Study Area and Sampling Design

Groundwater sampling was conducted in and around Dan Dolo Cemetery and its surrounding neighbourhoods within Kano Metropolis, northern Nigeria. The study area lies within a densely populated urban environment underlain by a shallow, vulnerable aquifer system hydraulically connected to the Jakara drainage basin. Thirty (30) groundwater sampling points, comprising hand-dug wells and boreholes, were selected to provide spatial coverage within the cemetery zone.

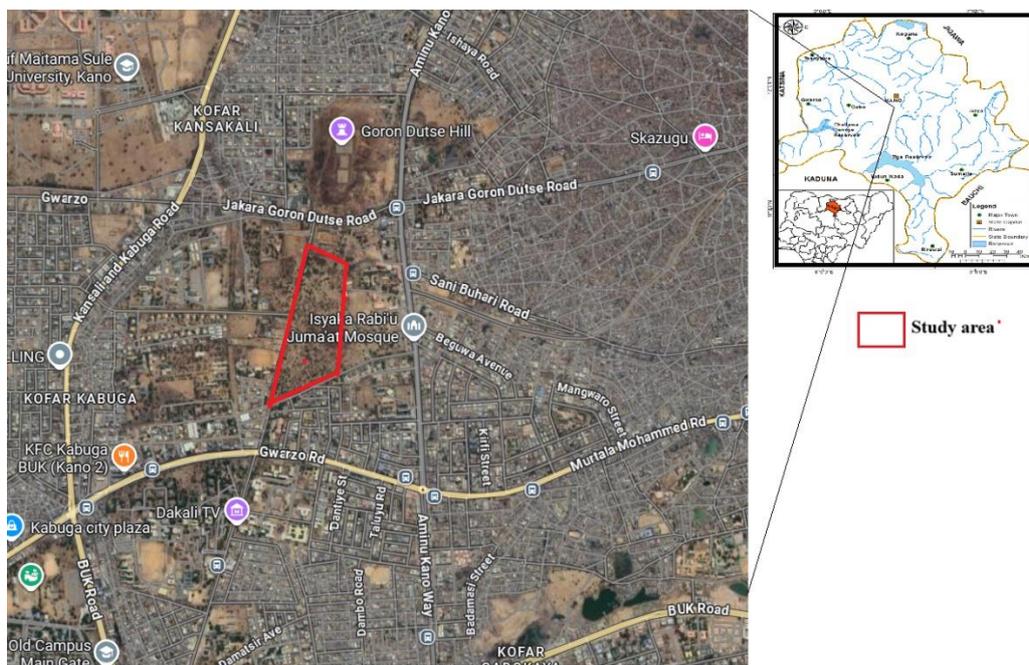


Fig. 1: Location map of the study area

Sampling was carried out during the dry season, when groundwater levels are relatively stable and dilution by rainfall is minimal. This period is optimal for detecting contaminant signals associated with persistent pollution sources such as cemeteries.

The spatial distribution of sampling points was designed to capture:

- a) Up-gradient background conditions
- b) The cemetery impact zone
- c) Down-gradient plume migration along the Jakara corridor

Geographic coordinates of all sampling points were recorded in the field using a handheld Global Positioning System (GPS) receiver to enable spatial analysis and GIS-based interpretation.

Field Measurements

At each sampling location, in situ measurements of groundwater pH, electrical conductivity (EC), total dissolved solids (TDS), and temperature were obtained using a calibrated portable multimeter. These parameters were selected because they respond sensitively to organic decay, dissolved salts, and leachate-derived ionic loading, and are therefore suitable for forensic screening of cemetery-related contamination.

Prior to measurement, each well was purged to remove stagnant water and ensure that samples represented the aquifer rather than standing water in the well casing. The probe was then immersed directly in the water column until readings stabilized, and values were recorded.

Temperature was measured in degrees Fahrenheit and later interpreted relative to World Health Organization

(WHO) guidelines for drinking water. All instruments were calibrated daily following manufacturer specifications to ensure measurement accuracy.

Data Processing and Quality Control

Field data were compiled into a digital database and checked for internal consistency. Electrical conductivity and TDS were evaluated together because of their strong physicochemical relationship and their conservative behavior during groundwater transport.

Outliers were examined in relation to their spatial position to distinguish true hydrochemical anomalies from potential measurement artefacts. The coordinate data were used to map and visualize spatial patterns of groundwater quality.

Hydrochemical Classification and Clustering

To identify hydrochemical groupings and contamination patterns, EC and TDS data were subjected to multivariate cluster analysis. These parameters were chosen because they effectively reflect leachate loading, salinity increase, and ionic enrichment associated with contaminant plumes.

Hierarchical clustering was performed using Ward's linkage method to generate a dendrogram, allowing groundwater samples to be grouped into statistically meaningful clusters representing:

- a) Background groundwater
- b) Mixing zones
- c) Highly contaminated plume zones

This approach enables discrimination between natural hydrochemical variation and contamination-driven anomalies.

Regulatory Benchmarking

All measured parameters were compared against international and national drinking water standards, including:

- a) World Health Organization (WHO)
- b) United States Environmental Protection Agency (USEPA)
- c) Nigerian Standard for Drinking Water Quality (NSDWQ)

This allowed each sampling point to be classified as compliant or non-compliant and provided a regulatory

framework for assessing environmental and public health risks.

Forensic Interpretation Framework

The study adopts a hydrophysical forensic approach, in which conservative parameters (EC and TDS) and reactive indicators (pH and temperature) are interpreted within the context of the local hydrogeological flow system. Spatial trends, cluster membership, and regulatory exceedances were integrated to delineate the extent, direction, and intensity of groundwater contamination associated with Dandolo Cemetery.

RESULT AND DISCUSSION

The results obtained include coordinates, pH, electrical conductivity (EC), Total Dissolved Solids (TDS), and Temperature (Table 1)

Table 1. Results of in situ measurement were made for each sample collected

S/N	Sample ID	Long.	Lat	pH	EC (µS)	TDS (mg/L)	Temp. (°F)
1	BUK Old Campus	8°48.144'	11°57.951'	6.55	893	632	83.8
2	Duka Wuya	8°48.53'	11°98.29'	5.67	621	441	85
3	Dan Yaro Factory	8°48.682	11°99.23'	5.73	301	214	86.1
4	Kabuga KFC	8°48.21'	11°98.861'	6.15	510	363	84.5
5	Kofar Kabuga	8°47.999'	11°99.148'	6.55	602	427	84.4
6	Kofar Kabuga II	8°48.123'	11°99.279'	6.4	759	540	86.6
7	Kansali Rd	8°48.281'	11°99.78'	5.57	483	343	98.9
8	Gidan Custom	8°48.394'	11°99.71'	6.5	555	396	90.3
9	Kofar Kansakali	8°48.71'	11°99.883'	6.42	1918	1360	90.5
10	Gwarzo	8°48.327'	11°99.93'	6.31	501	357	88.3
11	North west Uni.	8°48.15'	12°52.2'	7.9	140.2	99.3	88.4
12	Kofar Kansakali II	8°48.577'	12°39.3'	5.46	534	251	90.5
13	Gadon Kaya	8°29.375'	11°58.835'	6.79	922	657	83.7
14	Dambo Rd G.Kaya	8°29.453'	11°58.897'	6.81	1014	719	88.9
15	Dr. Sani Y st. G. Kaya	8°29.469'	11°59.299'	5.9	650	467	88.7
16	Dan Dolo Cemetry I	8°29.465'	11°59.53'	5.61	553	390	94.1
17	S.M.N I	8°29.745'	11°59.538'	5.81	560	397	92.9
18	Rahama St. G. Kaya	8°29.827'	11°59.363'	5.87	503	357	84.6
19	Ishaya Rd Gwammaja	8°29.822'	12°35.2'	6.88	1472	1050	91
20	Goron Dutse	8°29.52'	12°23.2'	6.81	947	672	93.9
21	Kansakali	8°29.346'	12°54'	6.67	2480	1770	95
22	Dan Dolo Cemetery II	8°29.43'	11°59.88'	5.41	290	206	99.2
23	Kaigama Jakara Rd	8°29.77'	11°59.978'	6.59	652	460	98.2
24	Bala Police Stn Jakara	8°3.3'	12°26'	6.26	1739	1230	96.1
25	Rimin Malami	8°3.15'	12°26'	6.86	1752	1240	98
26	Kwatawa	8°3.24'	11°59.939'	6.28	1936	1380	96.6
27	Wuju-Wuju Junction	8°29.716'	11°59.74'	5.79	417	296	98.2
28	S.M Najeeb st	8°29.98'	11°59.46'	6.53	827	588	95.7
29	Layin Mai Bodi	8°3.111'	11°59.291'	5.74	1204	855	96.6
30	Layin Ya Sayyadi	8°3.9'	11°59.216'	6.61	355	254	98.8
Minimum				5.41	140.2	99.3	83.7
Maximum				7.9	2480	1770	99.2
Average				6.31	897.2	633.75	91.575

Interpretation of the physical parameters of groundwater quality around Dandolo Cemetery is benchmarked against the WHO, USEPA, and

Nigerian Standard for Drinking Water Quality (NSDWQ) as provided in Table 1.

Table 1. Regulatory Standards Used

Parameter	WHO	USEPA	NSDWQ (Nigeria)
pH	6.5 – 8.5	6.5 – 8.5	6.5 – 8.5
EC ($\mu\text{S}/\text{cm}$)	1000	1500	1000
TDS (mg/L)	500 (desirable), 1000 max	500	500
Temperature	< 30 °C (~86 °F)	< 30 °C	< 30 °C

Dan Dolo Cemetery may function as a continuous contaminant loading zone. During burial decomposition, bodies release organic acids, dissolved salts, nitrogen compounds, and pathogenic microorganisms. These fluids form cemetery leachate, which infiltrates downward under gravity and laterally under hydraulic gradients.

including Dandolo Cemetery I (5.61), Dan Dolo Cemetery II (5.41), Kansali Rd (5.57), Duka Wuya (5.67), and Kofar Kansakali II (5.46). This indicates leachate-induced acidification, which is typical of cemetery-impacted aquifers. Only North-West University (pH 7.9) shows alkaline conditions, representing an uncontaminated background zone.

pH

The general pattern indicates that pH values range from 5.41 to 7.90. This means that acidic groundwater (pH < 6.5) dominates most locations,

(b) Electrical Conductivity (EC)

EC ranges from 140 $\mu\text{S}/\text{cm}$ to 2480 $\mu\text{S}/\text{cm}$, with three distinct EC clusters that can be interpreted based/using on Table 2.

Table 2. EC cluster

Cluster	EC Range	Interpretation
Low mineralization	< 500	Fresh, uncontaminated
Moderate	500 – 1000	Mixed recharge
High	> 1000	Leachate/sewage/salt contamination

High-EC hotspots (>1000 $\mu\text{S}/\text{cm}$) include Kansakali (2480), Kwatawa (1936), Bala Police Station (1739), Rimi Malami (1752), Kofar Kansakali (1918), and Ishaya Rd (1472). Dandolo Cemetery lies within this high-conductivity belt, confirming subsurface pollution migration.

Kansakali (1770), Kwatawa (1380), Bala Police (1230), Rimi Malami (1240), Kofar Kansakali (1360), Ishaya Rd (1050), Layin Mai Bodi (855), and Goron Dutse (672).

Dan Dolo Cemetery I has TDS of 390 (moderate), while Dan Dolo Cemetery II had 206 (fresh). However, the surrounding zones are heavily mineralized, meaning the leachate plume is spreading laterally.

TDS (Total Dissolved Solids)

TDS varies from 99 mg/L to 1770 mg/L. Locations exceeding WHO/NSDWQ (Table 3) include

Table 3. WHO & NSDWQ limit = 500 mg/L

TDS Class	Range	Meaning
Fresh water	< 500	Safe
Brackish	500 – 1500	Unpalatable
Highly mineralized	> 1500	Unsafe

Temperature

Field temperatures range from 83.7 °F to 99.2 °F (28.7–37.3 °C), while the WHO's safe limit \approx is 86

°F (30 °C). Most wells exceed this, which is a likely indication of shallow groundwater, organic decay (cemetery & waste sites), or microbial heat

generation. Dandolo Cemetery II recorded 99.2 °F, confirming the possibility of biodegradation of buried organic matter. High temperature alone does not prove biodegradation. It may reflect Shallow wells, Solar heating, and Poor well casing.

Cluster Analysis

Cluster 1 – Clean Recharge Zone (Low EC, low TDS, neutral pH)

Example: North-West University (EC 140, TDS 99). This represents background aquifer quality.

Cluster 2 – Moderately Impacted Zone (EC 500–1000, TDS 300–700, acidic)

Examples: Kabuga, Gadon Kaya, Dan Dolo I, SMN, Rahama St. This is typically the cemetery mixing zone.

Cluster 3 – Highly Contaminated Leachate Plume (EC > 1000, TDS > 1000, acidic)

Examples: Kansakali, Kwatawa, Bala Police, Rimin Malami, and Ishaya Rd. This is the cemetery-urban pollution plume corridor.

These three major clusters can be further subdivided into five subclusters as indicated in Figure 2.

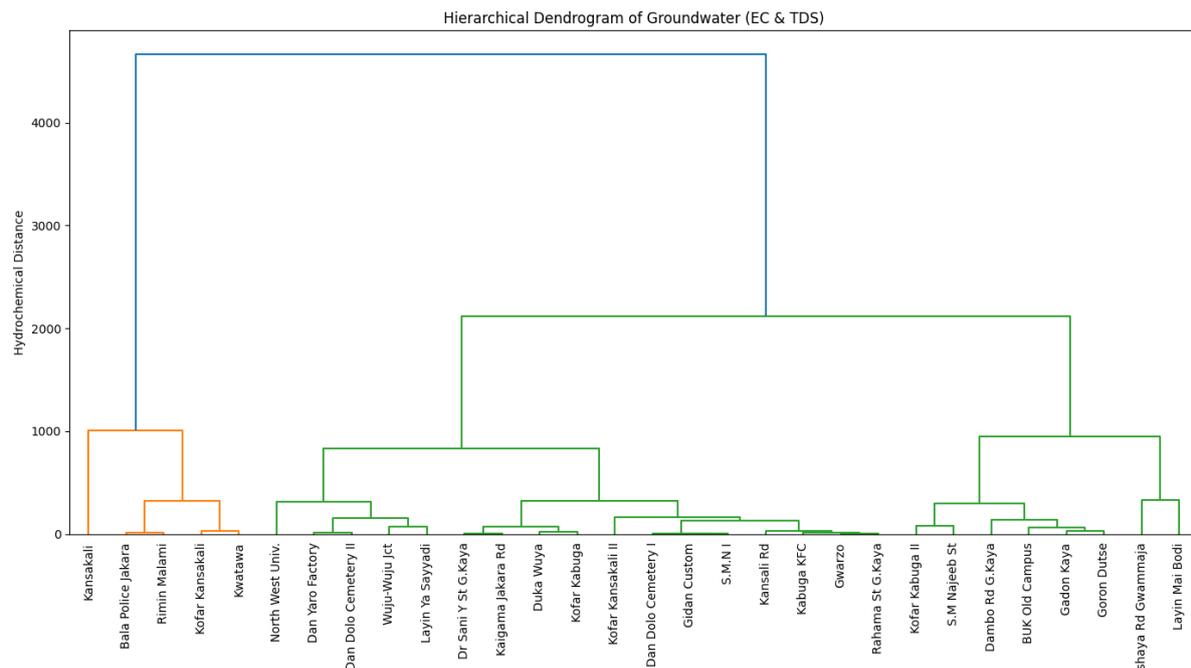


Figure 2. Hierarchical dendrogram of groundwater using Electrical conductivity and Total Dissolved Solids (TDS)

Table 4. Compliance Summary

Parameter	% of samples failing WHO/NSDWQ
pH	~70% acidic
EC	~40% exceed the limit
TDS	~45% unsafe
Temperature	~80% too high

Dandolo Cemetery wells fail on pH and temperature, while the surrounding neighborhood fails badly on TDS and EC (Table 4), indicating the possibility of outward migration of leachate-derived salts and ions.

Environmental & Public Health Implications

The data from this study indicate that Dandolo Cemetery is serving as a source of groundwater

contamination. Decomposition fluids possibly release organic acids (low pH), dissolved salts (high EC/TDS), and pathogens (microbial risk). Residents using wells in Kansakali, Kwatawa, Jakara, and Gwammaja might be consuming chemically degraded water, even if it looks clear.

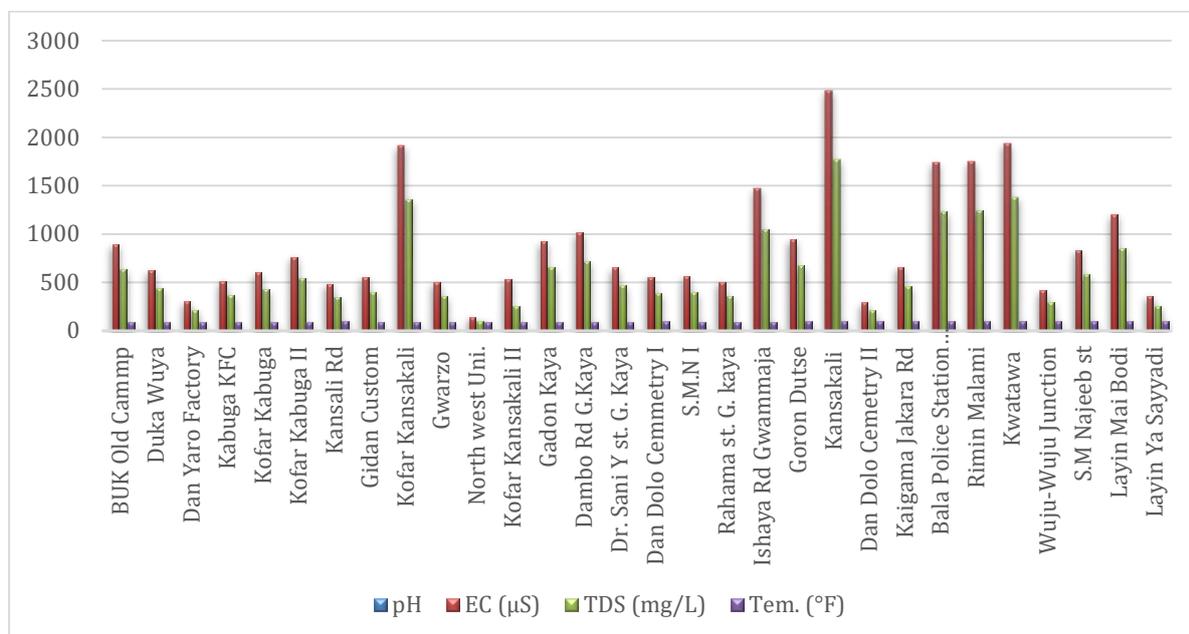


Figure 3. A plot of all the physical parameters measured in situ

CONCLUSION

The physico-chemical signature around Dan Dolo Cemetery shows an acidic plume, elevated dissolved solids, a high conductivity corridor, and a thermal anomaly. This is all consistent with cemetery-derived groundwater contamination. This dataset provides strong forensic hydrogeological evidence of subsurface pollution migration.

The combination of a shallow unconfined aquifer, high-permeability soils, a hydraulic gradient toward Jakara, and an EC–TDS plume alignment provides hydrogeological evidence that the chemical anomalies detected in this study are not random, but are controlled by cemetery-driven groundwater transport. This framework supports the forensic conclusion that Dandolo Cemetery is a point source of groundwater degradation within the Kano metropolis.

Conservative parameters such as EC and TDS (Fig.3) move with groundwater almost unchanged, making them ideal tracers of plume movement. The observed EC–TDS corridor from Dandolo to Kansakali–Jakara–Kwatawa, therefore, reflects the direction and extent of leachate migration.

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Authors' contribution

A.S. Arabi conceived the idea and drafted the manuscript; M. S. Abdulhamid and S. A. Suleiman conducted the field campaign. All authors reviewed and approved the manuscript.

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