



Research Article

Impact of Pit Toilets and Dumping Sites on the Quality of Borehole Water in Some Selected Sites in Potiskum Town, Yobe State

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ABSTRACT

Groundwater is the main source of drinking water in Potiskum, Yobe State, Nigeria, but its quality is increasingly compromised by poor waste management. This study evaluated the effects of dumping sites and pit toilets on borehole water quality, with attention to seasonal variation. Eleven boreholes six near dumping sites and five near pit toilets were sampled in wet and dry seasons. Physicochemical parameters, heavy metals, and microbiological indicators were analyzed using standard procedures. Boreholes BH3 (dumping site) and PT2 (pit toilet) consistently exceeded WHO (2011) and NSDWQ (2007) limits for multiple parameters. Pb, Cd, Cr, Mn, and Ni were detected at concerning levels, accompanied by elevated electrical conductivity, total dissolved solids, chloride, and biological oxygen demand. All samples recorded total coliform counts far above permissible limits. Seasonal analysis showed a significant variation in pH ($p = 0.0218$), with greater acidity in the dry season; other parameters, though not statistically significant, tended to be higher during this period, suggesting contaminant concentration under reduced aquifer recharge. Immediate action should deactivate highly contaminated boreholes, provide safe alternative water, and promote household treatment. Short-term measures must enforce sanitary setbacks, require hydrogeological assessments, and improve wellhead protection. Long-term solutions include sanitation upgrades, dumpsite relocation, and routine groundwater monitoring.

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INTRODUCTION

Ensuring access to safe and clean drinking water is critical for safeguarding public health, yet it continues to pose a major challenge globally. Groundwater, relied upon by almost two billion people as a primary source of drinking water, is facing growing risks from human activities, particularly improper waste management and

insufficient sanitation systems (UNESCO, 2022; WHO/UNICEF, 2023). Rapid urbanization and population growth have led to increased generation of municipal solid waste and a proliferation of on-site sanitation systems such as pit latrines particularly in low- and middle-income countries. When poorly managed, these systems often result in groundwater contamination with

pathogens and nitrates, posing serious public health risks (Odewade *et al.*, 2025).

In Nigeria, groundwater is the primary source of drinking water for approximately 60% of the population, especially in rural and peri-urban communities (Nwankwoala, 2021). However, inadequate urban planning, indiscriminate refuse disposal, and unregulated construction of pit toilets have contributed to declining water quality across various regions (Abulude *et al.*, 2023).

Studies in urban and rural areas of Nigeria have shown that contaminants such as nitrate can reach very high concentrations up to 770 mg/L in Maiduguri likely due to combined sources including pit latrines (Abanyie *et al.*, 2023).

Borehole water contamination, especially in northern Nigeria, is further exacerbated by seasonal variability, shallow aquifers, and poor enforcement of environmental regulations (Alhassan *et al.*, 2020).

Yobe State, located in Nigeria's semi-arid northeast, faces pronounced challenges in water supply due to its harsh climate, low rainfall, and rising population (Alhassan *et al.*, 2020). Despite the presence of the Yobe State Environmental Protection Agency (YOSEPA), effective solid waste and excreta management remain deficient, particularly in densely populated districts. An investigation of groundwater pollution in Potiskum found elevated levels of trace metals including chromium, cadmium, nickel, lead, and arsenic in surface and subsurface water, linked to nearby dumpsites (Usman *et al.*, 2025).

Similarly, an electrical resistivity and hydro-chemical study of dumpsites in Potiskum and Nguru revealed that leachate contributes significantly to groundwater contamination, particularly in the shallow, semi-confined aquifer (Bala *et al.*, 2023).

Given the heavy reliance on borehole water in Potiskum and the proximity of wells to contamination sources, especially during the wet season when contaminant transport is accelerated, the risk of waterborne diseases such as diarrhea, typhoid, cholera, and helminthiasis remains high a risk also observed, where wells located only 11.4 m from pit latrines were contaminated with faecal coliforms (Odewade *et al.*, 2025).

Many boreholes across urban and peri-urban Nigeria including areas like Potiskum are situated less than the recommended horizontal separation (often 30 m) from pit latrines or dumpsites. This proximity increases susceptibility to leachate infiltration, especially during wet seasons when subsurface contaminant transport is accelerated (Igelle *et al.*, 2024). Given the high dependence on such water sources for daily needs, the risks of waterborne diseases such as diarrhea, typhoid, cholera, and helminthiasis remain significant (Uguru *et al.*, 2024). While studies on groundwater contamination near waste sites exist in Nigeria, Potiskum's semi-arid climate, shallow aquifers (<45 m), and unregulated waste management practices create unique hydrogeological vulnerabilities (Bala *et al.*, 2021). This study aims to assess the physicochemical, heavy metal, and microbiological quality of borehole water near dumping sites and pit toilets in Potiskum, compare contamination levels between wet and dry seasons, evaluate spatial differences between the two waste sources, and relate the findings to WHO and NSDWQ standards to recommend targeted mitigation strategies

MATERIALS AND METHODS

Study Area

Potiskum Town is located between latitudes 11°42'50"N and longitudes 11°04'52"E in northeastern Nigeria. It serves as the administrative headquarters of Potiskum Local Government Area in Yobe State. The town covers an estimated land area of about 559 km² (216 sq mi) and had a population of 205,876 according to the 2006 National Population Census [NPC]. Potiskum lies within the Sudan savanna ecological zone, characterized by distinct wet and dry seasons, with rainfall occurring mainly between June and September and an average annual precipitation of approximately 500–1000 mm. The climate is generally hot, with mean daily temperatures ranging from 21 °C in the cooler months to over 40 °C during the peak of the dry season.

Hydrogeologically, the town is underlain by the Chad Formation, composed of sands, clays, and silts forming shallow to moderately deep aquifers

(5–20 m). Groundwater, mainly accessed via boreholes and hand-dug wells, is the primary water source. Sandy layers promote recharge, while clayey strata can limit infiltration but may

also allow contamination from surface sources such as pit latrines and dumpsites. Drainage is poor, with seasonal streams and depressions prone to waterlogging.

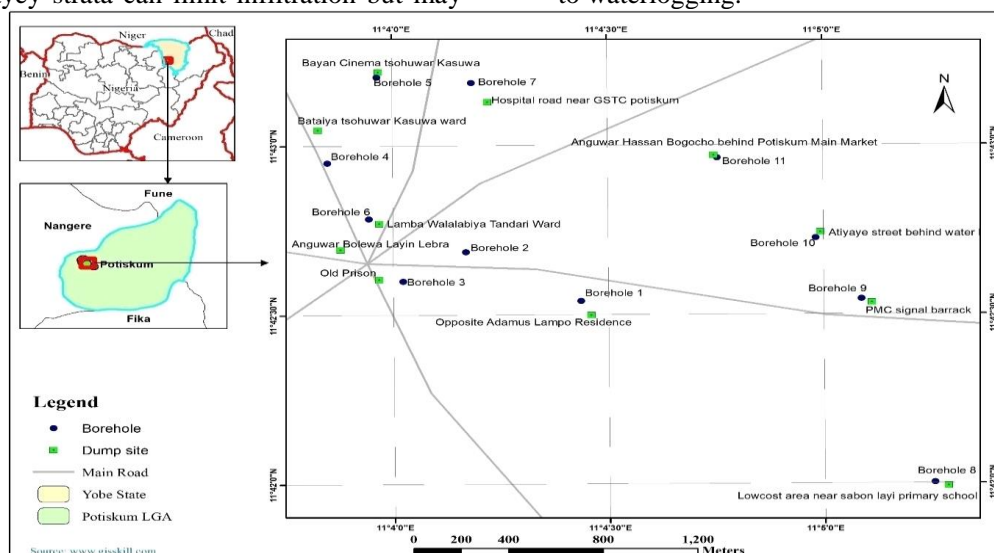


Figure 1: Map of Potiskum town showing the selected dumping sites and nearby borehole **Source:** (Filed Survey, 2021).

Sampling Sites

The table below shows the sampling points, dumping site's location, distance from nearby borehole to dumping site and distance from nearby pit toilets to borehole. The longest distance (m) from nearby dumping site to borehole was recorded on BH 8 (31m) located at Low-cost area near Sabon Layi Pri. Sch. while the shortest distance was recorded on BH 6 (3m) located at Lambawalabiya Tandari. The below table shows the sampling points, Dumping site's location and distance to nearby borehole and pit toilets.

distance was recorded on BH6 (3m) located at Lambawalabiya Tandari. The longest distance (m) from nearby pit toilets to borehole was recorded on BH 1 (10.2 m) located at opposite Adamu Lampo residence while the shortest distance was recorded on BH 4 (5m) located at Bataiya Tsohuwar Kasuwa ward.

Sample points (Dumping sites)	Boreholes Sites	Dist.(m) from dumping site to borehole	Dist.(m)from pit toilets to borehole
Opposite Adamu Lampo Residence	Borehole 1	23	10.2
Anguwar Bolewa Layin Lebra	Borehole 2	15	-
Old Prison	Borehole 3	10	14
Bataiya Tsohuwar Kasuwa ward	Borehole 4	29	5
Bayan Cinema Tsohuwar Kasuwa	Borehole 5	7	8
Lamba walabiya Tandari	Borehole 6	3	18
Hospital road near GSTC Potiskum	Borehole 7	29	-
Lowcost area near Sabon Layi Pri. Sch.	Borehole 8	31	6
PMC Signal Barracks	Borehole 9	11	6
Atiyaye Street behind water board	Borehole10	23	18
Anguwar Hassan Bogocho behind Potiskum main market	Borehole11	5	-

Sampling Strategy and Site Selection

The study was conducted in Potiskum Town, Yobe State, Nigeria, where groundwater from boreholes serves as the primary domestic water source. A purposive sampling strategy was adopted to identify boreholes at elevated risk of contamination from nearby waste dumping sites and pit latrines. Site selection began with a reconnaissance survey to locate and map active waste disposal sites and pit latrines using handheld GPS devices. Boreholes located within a radial distance of 50–100 m from these contamination sources were shortlisted, as this range is within the probable lateral infiltration zone for sandy-loamy soils common in the area. Only boreholes actively in use, with depths between 39–43 m, and in good structural condition were included. Those located beyond 100 m from contamination sources or showing physical defects such as cracked casing or faulty pumps were excluded from the study.

Seasonal Sampling Schedule

Sampling was carried out in both the dry and wet seasons to capture seasonal variability in water quality. Each season covered a two-month period, with two sampling events per month (first and third weeks). This schedule was applied in February and April 2021 for the dry season, and in July and September 2021 for the wet season. In each sampling week, 6 borehole and 3 pit latrine-adjacent water samples were collected during the first week, and 5 borehole and 2 pit latrine-adjacent samples during the third week, resulting in a total of 64 samples for the study.

Sample Collection Procedure

At each site, boreholes were pumped for 2–3 minutes before sampling to flush stagnant water and obtain a representative sample. Water was collected directly into 1 L high-density polyethylene bottles that had been pre-cleaned with 10% nitric acid and rinsed with deionized water. All collections were performed aseptically using sterile gloves to prevent cross-contamination. Bottles were immediately sealed, labeled with sample ID, date, and GPS coordinates, and placed in insulated coolers containing ice packs to maintain a temperature of $\leq 4^{\circ}\text{C}$ during transport.

Quality Assurance and Control

Field blanks prepared with deionized water and handled identically to actual samples were used to check for external contamination during collection. Duplicate samples were collected at 10% of sites during each sampling event to evaluate reproducibility. Chain of custody forms were maintained for all samples from the point of collection to arrival at the Microbiology Research Laboratory, Yobe State University, Damaturu, where analyses were conducted within six hours of collection.

Experimentation

Physicochemical Analysis of the Borehole Water Samples

The physicochemical characteristics of water sample such as pH, EC, TDS and temperature were measured *in situ* using a (Hanna HI9813-61) multiparameter meter, calibrated with pH 4.01, 7.00, and 10.01 buffer standards and KCl conductivity standards. Dissolve Oxygen (DO), was determined using a (Hanna HI98198) optical probe after 2-point calibration, and Biological Oxygen Demand (BOD) were analyzed in the laboratory according to the American Public Health Association [APHA], (2012) standard methods for the examination of water and wastewater.

Heavy Metals Analysis

All instruments were calibrated prior to and during analysis to maintain accuracy. Laboratory glassware including volumetric flasks, digestion tubes, and measuring cylinders was washed with detergent and tap water, rinsed with deionized water, and soaked in 10% nitric acid (HNO_3) to eliminate residual metals. Digestion tubes were additionally treated with 1% (w/v) potassium dichromate in 98% (v/v) sulfuric acid, while volumetric flasks were soaked in 10% HNO_3 for 24 hours, oven-dried, and stored dust-free.

Water samples were digested following APHA (2012) protocols: 100 mL of each sample was acidified with concentrated HNO_3 and heated to reduce the volume to 20 mL for complete oxidation of organic matter. The digests were cooled, filtered, and diluted to 50 mL with deionized water. Heavy metals (Pb, Cd, Zn, Mn, Cr, Cu, Ni, and Fe) were quantified using a Buck

Scientific AAS (Model 210 VGP) with an air-acetylene flame at metal-specific wavelengths, applying certified standards and blank corrections. Limits of detection (LOD) and quantification (LOQ) were calculated from reagent blanks as three and ten times the standard deviation of blank measurements, respectively, giving LODs (mg L⁻¹) of Pb (0.001), Cd (0.0005), Zn (0.005), Mn (0.002), Cr (0.002), Cu (0.001), Ni (0.001), and Fe (0.010), with LOQs approximately 3.33 times higher. Quality control procedures included calibration verification, reagent and field blanks, duplicate analyses, spike recoveries, and certified reference material checks to ensure analytical precision and accuracy.

Microbiological Analysis

The Total Aerobic Mesophilic Plate Count (TAMPC) was performed following the *Standard Methods for the Examination of Water and Wastewater* (APHA, 2012). Each water sample (100 mL) was serially diluted in sterile 0.85% physiological saline using ten-fold dilutions. Aliquots (1 mL) from appropriate dilutions were spread-plated in duplicate onto sterile nutrient agar (Oxoid). Plates were incubated at two temperature regimes 22 ± 2 °C and 37 ± 2 °C for 24 ± 2 h to recover a broad spectrum of mesophilic heterotrophic bacteria. Only plates yielding 30–300 colony-forming units (CFU) were counted, and counts were expressed as CFU/mL.

Enumeration and differentiation of *Escherichia coli* and other coliform bacteria were carried out on Chromocult® Coliform Agar (Merck). Plates were incubated at 37 ± 1 °C for 24 ± 2 h, where *E. coli* produced characteristic blue violet colonies, and other coliforms appeared as pink to red colonies due to the chromogenic substrates present in the medium.

Pseudomonas aeruginosa was isolated on cetrimide agar (Oxoid) prepared according to manufacturer's instructions. Plates were inoculated in duplicate and incubated at 42 ± 1 °C for 48 ± 2 h. Presumptive colonies identified by their green pigmentation—were confirmed by examining pyoverdine production under UV illumination at 365 nm, a distinctive trait of *P. aeruginosa*.

Isolation of *Salmonella* spp. followed a selective enrichment procedure. Samples were pre-enriched in buffered peptone water at 37 ± 1 °C for 24 h, followed by selective enrichment in Rappaport–Vassiliadis (RV) broth at 42 ± 1 °C for 24 h. Enriched cultures were streaked onto xylose lysine deoxycholate (XLD) agar (Oxoid) and incubated at 37 ± 1 °C for 24 ± 2 h. Presumptive *Salmonella* colonies (red with black centers) were purified on nutrient agar and subjected to biochemical confirmation using the API 20E identification system (BioMérieux).

Klebsiella spp. were isolated on MacConkey agar (Oxoid) incubated at 37 ± 1 °C for 24 ± 2 h. Lactose-fermenting colonies displaying large, mucoid morphology were purified and biochemically identified with the API 20E system (BioMérieux). Identification was based on characteristic biochemical profiles interpreted using the manufacturer's database.

To ensure microbiological data quality, all media were prepared using deionized water and sterilized at 121 °C for 15 min, with sterility checks performed on randomly selected plates. Positive control strains (*E. coli* ATCC 25922, *P. aeruginosa* ATCC 27853, *Salmonella enterica* serovar Typhimurium ATCC 14028, and *Klebsiella pneumoniae* ATCC 13883) and uninoculated negative controls were included in all analytical runs to verify media performance and confirm identification accuracy.

Most Probable Number (MPN) Assessment

The Most Probable Number (MPN) technique was employed to estimate the concentration of viable microorganisms in water samples. This statistical method involves inoculating replicate tubes of liquid broth with ten-fold serial dilutions of the sample to detect microbial growth. It is particularly suitable for samples with high turbidity or particulate matter that may hinder colony formation on solid media. The MPN values were interpreted using standard probability tables based on the number of positive tubes at each dilution level (APHA, 2012).

Data Analysis

Mean \pm SD was calculated for all parameters. Seasonal (wet vs dry) and spatial (dumping vs pit toilets) differences were tested after checking

assumptions with the Shapiro–Wilk and Levene’s tests. Independent t-tests, Welch’s t-tests, or Mann–Whitney U tests were applied as appropriate; paired comparisons used paired t-tests. For multi-site comparisons, one-way ANOVA with Tukey’s HSD was used. Significance was set at $p < 0.05$, and exceedances were determined against NSDWQ (2007) and WHO (2011) limits.

RESULTS

Physicochemical Parameters

pH

Across all boreholes, pH values demonstrated notable seasonal and spatial variation. In the wet season (Tables 1 and 3), pH ranged from 5.74 to 7.21, with the lowest values consistently observed in BH7 and the highest in BH4. During the dry season (Tables 2 and 4), pH declined slightly, ranging from 5.54 to 7.01, again with BH7 recording the most acidic levels. For boreholes near pit toilets, 40% of samples in both seasons fell below WHO (6.5–8.5) and NSDWQ (6.5–7.5) permissible limits. Overall, acidity was more prevalent in the dry season, likely due to reduced dilution and increased concentration of acidic leachates from nearby waste sites, as summarized in Table 5.

Temperature

Water temperatures remained within WHO standards but were slightly above the SON/NSDWQ recommended minimum of 25 °C in the wet season. Near dumping sites, wet season temperatures ranged from 25.4 °C to 29.5 °C (Table 1), with the highest in BH7, while dry season temperatures were narrower, 24.39–24.70 °C (Table 2). For pit toilet boreholes, wet season values ranged from 26.5 °C to 28.5 °C (Table 3), and dry season readings from 24.39 °C to 24.51 °C (Table 4). Seasonal temperature shifts were minimal, indicating that temperature is not a major limiting factor for groundwater quality in the study area (Table 5).

Total Dissolved Solids (TDS)

TDS concentrations varied widely. In boreholes near dumping sites, wet season values ranged from 2.13 mg/L to 605.72 mg/L (Table 1), while dry season readings extended to 630.40 mg/L (Table 2). In pit toilet boreholes, TDS ranged

from 25.35 mg/L to 605.72 mg/L (wet season, Table 3) and from 49.40 mg/L to 630.40 mg/L (dry season, Table 4). Most sites complied with WHO (600 mg/L) and NSDWQ (500 mg/L) limits, except BH4 and PT2, which exceeded both. Higher dry season values suggest reduced aquifer recharge and greater pollutant concentration (Table 5).

Electrical Conductivity (EC)

EC values reflected TDS trends. Near dumping sites, wet season values ranged from 4.26 µS/cm to 1211.43 µS/cm (Table 1), with dry season peaks reaching 1261.43 µS/cm in BH4 (Table 2). For pit toilet boreholes, EC ranged from 50.69 µS/cm to 1211.43 µS/cm (wet season, Table 3) and 100.69 µS/cm to 1261.43 µS/cm (dry season, Table 4). BH4 and PT2 consistently exceeded the WHO/NSDWQ limit of 1000 µS/cm, indicating substantial ionic contamination, most likely from waste leachate infiltration (Table 5).

Chloride (Cl⁻)

Chloride concentrations showed substantial exceedances across several sites. Near dumping sites, wet season values ranged from 8.57 mg/L to 1001.31 mg/L (Table 1), and dry season values from 28.58 mg/L to 1021.32 mg/L (Table 2). In pit toilet boreholes, chloride ranged from 21.70 mg/L to 1021.32 mg/L across both seasons (Tables 3 and 4). Around 66% of all samples surpassed NSDWQ (250 mg/L) and WHO (400 mg/L) limits, with BH4 and PT2 having the most severe exceedances, suggesting heavy contamination from anthropogenic sources such as sewage and decomposing solid waste (Table 5).

Biological Oxygen Demand (BOD)

BOD values, while within the NSDWQ limit of 30 mg/L, indicated localized organic pollution. Near dumping sites, wet season BOD ranged from 2.32 mg/L to 11.91 mg/L (Table 1), increasing to 4.65 mg/L–23.83 mg/L in the dry season (Table 2). In pit toilet boreholes, the lowest BOD occurred in PT3 and the highest in PT2 across both seasons (Tables 3 and 4). Elevated BOD at BH4 and PT2 indicates significant biodegradable organic matter loading, which could promote microbial growth and oxygen depletion if not controlled (Table 5).

Overall Assessment

The combined analysis confirms that BH4 (dumping site) and PT2 (pit toilet) are persistent contamination hotspots, with multiple parameters particularly EC, TDS, chloride, and BOD showing critical exceedances. Seasonal effects were evident, with most parameters peaking in the

dry season due to reduced dilution. The data suggest that both waste dumping and pit toilet proximity significantly degrade groundwater quality, with implications for public health and the need for improved waste management and groundwater protection measures

Table 1: Mean \pm SD levels of Physical Characteristics of the Borehole Water Analyzed (Wet season)

Site	Temp (WHO — / NSDWQ —)	pH (WHO 6.5–8.5 / NSDWQ 6.5– 8.5)	EC (WHO 1000 / NSDWQ 1000)	TDS (WHO 600 / NSDWQ 500)	Cl (WHO 400 / NSDWQ 250)	BOD (WHO — / NSDWQ 30)
BH1	27.50 (27.56 \pm 1.12)	6.33* (6.45 \pm 0.49)	169.07 (249.86 \pm 355.36)	84.53 (124.94 \pm 177.68)	172.41 (230.63 \pm 296.98)	4.11 (5.61 \pm 3.32)
BH2	25.40 (27.56 \pm 1.12)	6.57 (6.45 \pm 0.49)	13.35 (249.86 \pm 355.36)	6.68 (124.94 \pm 177.68)	33.98 (230.63 \pm 296.98)	2.32 (5.61 \pm 3.32)
BH3	27.50 (27.56 \pm 1.12)	6.66 (6.45 \pm 0.49)	478.88 (249.86 \pm 355.36)	239.44 (124.94 \pm 177.68)	465.00* (230.63 \pm 296.98)	7.30 (5.61 \pm 3.32)
BH4	28.00 (27.56 \pm 1.12)	7.21 (6.45 \pm 0.49)	1211.43* (249.86 \pm 355.36)	605.72* (124.94 \pm 177.68)	1001.31* (230.63 \pm 296.98)	11.91 (5.61 \pm 3.32)
BH5	28.50 (27.56 \pm 1.12)	6.76 (6.45 \pm 0.49)	50.69 (249.86 \pm 355.36)	25.35 (124.94 \pm 177.68)	21.70 (230.63 \pm 296.98)	3.15 (5.61 \pm 3.32)
BH6	27.00 (27.56 \pm 1.12)	5.82* (6.45 \pm 0.49)	373.81 (249.86 \pm 355.36)	186.91 (124.94 \pm 177.68)	363.53* (230.63 \pm 296.98)	8.96 (5.61 \pm 3.32)
BH7	29.50 (27.56 \pm 1.12)	5.74* (6.45 \pm 0.49)	244.85 (249.86 \pm 355.36)	122.43 (124.94 \pm 177.68)	244.64 (230.63 \pm 296.98)	5.78 (5.61 \pm 3.32)
BH8	28.50 (27.56 \pm 1.12)	6.10* (6.45 \pm 0.49)	64.52 (249.86 \pm 355.36)	32.26 (124.94 \pm 177.68)	78.08 (230.63 \pm 296.98)	3.81 (5.61 \pm 3.32)
BH9	26.50 (27.56 \pm 1.12)	7.05 (6.45 \pm 0.49)	132.11 (249.86 \pm 355.36)	66.15 (124.94 \pm 177.68)	136.20 (230.63 \pm 296.98)	9.42 (5.61 \pm 3.32)
BH10	28.00 (27.56 \pm 1.12)	6.00* (6.45 \pm 0.49)	5.52 (249.86 \pm 355.36)	2.76 (124.94 \pm 177.68)	11.53 (230.63 \pm 296.98)	2.39 (5.61 \pm 3.32)
BH11	26.80 (27.56 \pm 1.12)	6.68 (6.45 \pm 0.49)	4.26 (249.86 \pm 355.36)	2.13 (124.94 \pm 177.68)	8.57 (230.63 \pm 296.98)	2.55 (5.61 \pm 3.32)

Keys: BH-Borehole E.C-Electrical Conductivity, TDS-Total Dissolved Solids, BOD-Biological Oxygen Demand;

Note: Values marked with an asterisk (*) indicate exceedances of WHO (2011) or NSDWQ (2007) permissible limits.

Table 2: Mean \pm SD levels of Physical Parameters of borehole water near dumping sites (Dry season)

Site	Temp (WHO — / NSDWQ —)	pH (WHO 6.5–8.5 / NSDWQ 6.5–8.5)	EC (WHO 1000 / NSDWQ 1000)	TDS (WHO 600 / NSDWQ 500)	Cl (WHO 400 / NSDWQ 250)	BOD (WHO — / NSDWQ 30)
BH1	24.50 (24.49 \pm 0.08)	6.13* (6.22 \pm 0.46)	219.07 (298.04 \pm 356.76)	107.65 (148.53 \pm 178.52)	192.42 (250.64 \pm 296.98)	8.22 (11.21 \pm 6.65)
BH2	24.50 (24.49 \pm 0.08)	6.37* (6.22 \pm 0.46)	63.35 (298.04 \pm 356.76)	31.55 (148.53 \pm 178.52)	53.98 (250.64 \pm 296.98)	4.65 (11.21 \pm 6.65)
BH3	24.70 (24.49 \pm 0.08)	6.46* (6.22 \pm 0.46)	528.88 (298.04 \pm 356.76)	263.85 (148.53 \pm 178.52)	485.00* (250.64 \pm 296.98)	14.60 (11.21 \pm 6.65)
BH4	24.50 (24.49 \pm 0.08)	7.01 (6.22 \pm 0.46)	1261.43* (298.04 \pm 356.76)	630.40* (148.53 \pm 178.52)	1021.32* (250.64 \pm 296.98)	23.83 (11.21 \pm 6.65)
BH5	24.40 (24.49 \pm 0.08)	6.56 (6.22 \pm 0.46)	100.69 (298.04 \pm 356.76)	49.40 (148.53 \pm 178.52)	41.70 (250.64 \pm 296.98)	6.17 (11.21 \pm 6.65)

BH6	24.50 (24.49 ± 0.08)	5.62* (6.22 ± 0.46)	423.81 (298.04 ± 356.76)	212.80 (148.53 ± 178.52)	383.54* (250.64 ± 296.98)	17.91 (11.21 ± 6.65)
BH7	24.50 (24.49 ± 0.08)	5.54* (6.22 ± 0.46)	294.85 (298.04 ± 356.76)	147.20 (148.53 ± 178.52)	264.65* (250.64 ± 296.98)	11.56 (11.21 ± 6.65)
BH8	24.39 (24.49 ± 0.08)	5.90* (6.22 ± 0.46)	114.52 (298.04 ± 356.76)	56.85 (148.53 ± 178.52)	98.08 (250.64 ± 296.98)	7.61 (11.21 ± 6.65)
BH9	24.40 (24.49 ± 0.08)	6.59 (6.22 ± 0.46)	182.11 (298.04 ± 356.76)	90.45 (148.53 ± 178.52)	156.21 (250.64 ± 296.98)	18.83 (11.21 ± 6.65)
BH10	24.50 (24.49 ± 0.08)	5.80* (6.22 ± 0.46)	45.52 (298.04 ± 356.76)	22.20 (148.53 ± 178.52)	31.54 (250.64 ± 296.98)	4.78 (11.21 ± 6.65)
BH11	24.50 (24.49 ± 0.08)	6.48* (6.22 ± 0.46)	44.26 (298.04 ± 356.76)	21.50 (148.53 ± 178.52)	28.58 (250.64 ± 296.98)	5.10 (11.21 ± 6.65)

Keys: BH-Borehole E.C-Electrical Conductivity, TDS-Total Dissolved Solids, BOD-Biological Oxygen Demand;
Note: Values marked with an asterisk (*) indicate exceedances of WHO (2011) or NSDWQ (2007) permissible limits.

Table 3: Mean ± SD levels of Physical Parameters of borehole water near Pit toilet (Wet season)

Site	Temp (WHO — / NSDWQ —)	pH (WHO 6.5–8.5 / NSDWQ 6.5–8.5)	EC (WHO 1000 / NSDWQ 1000)	TDS (WHO 600 / NSDWQ 500)	Cl (WHO 400 / NSDWQ 250)	BOD (WHO — / NSDWQ 30)
PT 1	27.50 (27.78 ± 0.82)	6.33* (6.69 ± 0.47)	169.07 (325.56 ± 497.59)	84.53 (162.80 ± 248.79)	172.41 (281.94 ± 406.21)	4.11 (6.48 ± 3.94)
PT 2	28.00 (27.78 ± 0.82)	7.21 (6.69 ± 0.47)	1211.43* (325.56 ± 497.59)	605.72* (162.80 ± 248.79)	1001.31* (281.94 ± 406.21)	11.91 (6.48 ± 3.94)
PT 3	28.40 (27.78 ± 0.82)	6.76 (6.69 ± 0.47)	50.69 (325.56 ± 497.59)	25.35 (162.80 ± 248.79)	21.70 (281.94 ± 406.21)	3.15 (6.48 ± 3.94)
PT 4	28.50 (27.78 ± 0.82)	6.10* (6.69 ± 0.47)	64.52 (325.56 ± 497.59)	32.26 (162.80 ± 248.79)	78.08 (281.94 ± 406.21)	3.81 (6.48 ± 3.94)
PT 5	26.50 (27.78 ± 0.82)	7.05 (6.69 ± 0.47)	132.11 (325.56 ± 497.59)	66.15 (162.80 ± 248.79)	136.20 (281.94 ± 406.21)	9.42 (6.48 ± 3.94)

Keys: BH-Borehole E.C-Electrical Conductivity, TDS-Total Dissolved Solids, BOD-Biological Oxygen Demand;
Note: Values marked with an asterisk (*) indicate exceedances of WHO (2011) or NSDWQ (2007) permissible limits

Table 4: Mean ± SD levels of Physical Parameters of borehole water near Pit toilet (Dry season)

Site	Temp (WHO — / NSDWQ —)	pH (WHO 6.5–8.5 / NSDWQ 6.5–8.5)	EC (WHO 1000 / NSDWQ 1000)	TDS (WHO 600 / NSDWQ 500)	Cl (WHO 400 / NSDWQ 250)	BOD (WHO — / NSDWQ 30)
PT 1	24.50 (24.44 ± 0.06)	6.13* (6.44 ± 0.43)	219.07 (375.56 ± 497.59)	107.65 (186.95 ± 249.05)	192.42 (301.95 ± 406.21)	8.22 (12.93 ± 7.90)
PT 2	24.51 (24.44 ± 0.06)	7.01 (6.44 ± 0.43)	1261.43* (375.56 ± 497.59)	630.40* (186.95 ± 249.05)	1021.32* (301.95 ± 406.21)	23.83 (12.93 ± 7.90)

PT 3	24.39 (24.44 ± 0.06)	6.56 (6.44 ± 0.43)	100.69 (375.56 ± 497.59)	49.40 (186.95 ± 249.05)	41.70 (301.95 ± 406.21)	6.17 (12.93 ± 7.90)
PT 4	24.40 (24.44 ± 0.06)	5.90* (6.44 ± 0.43)	114.52 (375.56 ± 497.59)	56.85 (186.95 ± 249.05)	98.08 (301.95 ± 406.21)	7.61 (12.93 ± 7.90)
PT 5	24.40 (24.44 ± 0.06)	6.59 (6.44 ± 0.43)	182.11 (375.56 ± 497.59)	90.45 (186.95 ± 249.05)	156.21 (301.95 ± 406.21)	18.83 (12.93 ± 7.90)

Keys: BH-Borehole E.C-Electrical Conductivity, TDS-Total Dissolved Solids, BOD-Biological Oxygen Demand;

Note: Values marked with an asterisk (*) indicate exceedances of WHO (2011) or NSDWQ (2007) permissible limits.

Table 5: Mean ± SD levels of Physicochemical Parameters in Boreholes near Dumpsites

Site	pH (WHO 6.5–8.5 / NSDWQ 6.5–7.5)	EC (WHO 1000 / NSDWQ 1000)	TDS (WHO 600 / NSDWQ 500)	Cl ⁻ (WHO 400 / NSDWQ 250)	BOD (WHO — / NSDWQ 30)
BH1	6.13 ± 1.52*	219.07 ± 780.9	107.65 ± 392.4	192.42 ± 57.58	8.22 ± 21.78
BH2	6.37 ± 1.28*	63.35 ± 936.7	31.55 ± 468.5	53.98 ± 196.00	4.65 ± 25.35
BH3	6.46 ± 1.19*	528.88 ± 471.1	263.85 ± 236.2	485.00 ± -235.00*	14.60 ± 15.40
BH4	7.01 ± 0.64	1261.43 ± 261.4*	630.40 ± -130.4*	1021.32 ± -771.3*	23.83 ± 6.17
BH5	6.56 ± 1.09	100.69 ± 899.3	49.40 ± 450.6	41.70 ± 208.3	6.17 ± 23.83
BH6	5.62 ± 2.03*	423.81 ± 576.2	212.80 ± 287.2	383.54 ± -133.5*	17.91 ± 12.09
BH7	5.54 ± 2.11*	294.85 ± 705.2	147.20 ± 352.8	264.65 ± -14.65*	11.56 ± 18.44
BH8	5.90 ± 1.75*	114.52 ± 885.5	56.85 ± 443.2	98.08 ± 151.9	7.61 ± 22.39
BH9	6.59 ± 1.06	182.11 ± 817.9	90.45 ± 409.6	156.21 ± 93.79	18.83 ± 11.17
BH10	5.80 ± 1.85*	45.52 ± 954.5	22.20 ± 477.8	31.54 ± 218.5	4.78 ± 25.22
BH11	6.48 ± 1.17*	44.26 ± 955.7	21.50 ± 478.5	28.58 ± 221.4	5.10 ± 24.9

Keys: BH-Borehole E.C-Electrical Conductivity, TDS-Total Dissolved Solids, BOD-Biological Oxygen Demand;

Note: Values marked with an asterisk (*) indicate exceedances of WHO (2011) or NSDWQ (2007) permissible limits.

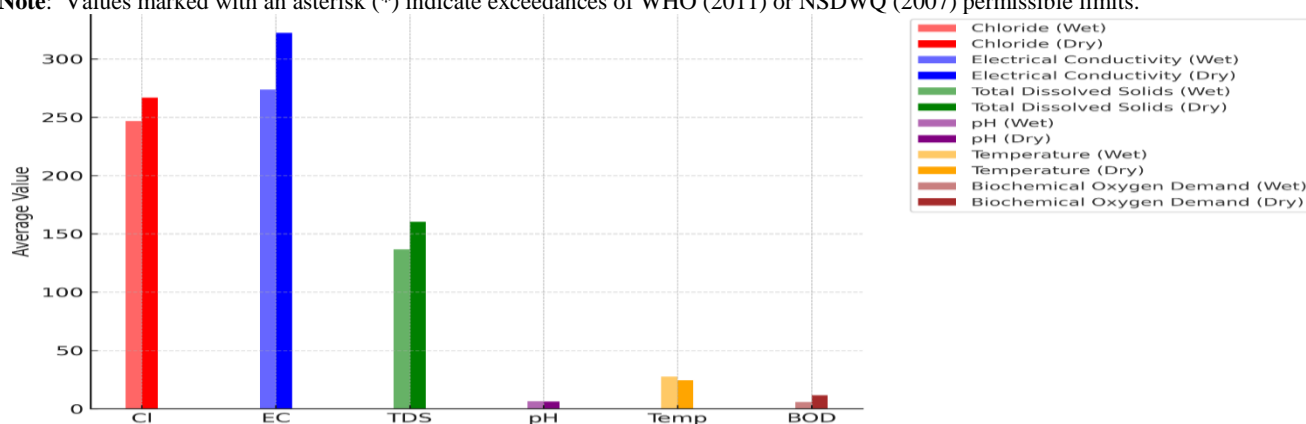


Figure 2: Showing Seasonal Variation of the Physicochemical Parameters

Chloride concentrations showed a slight seasonal increase, with a wet season mean of approximately 246.7 mg/L rising to 266.7 mg/L in the dry season, reflecting reduced dilution from rainfall and continued pollutant loading. Electrical conductivity (EC) followed a similar pattern, averaging 273.5 µS/cm during the wet season and increasing to 322.3 µS/cm in the dry season, indicating higher ionic concentrations when

aquifer recharge is low. Total dissolved solids (TDS) also increased slightly in the dry season, with a mean of 160.5 mg/L compared to 136.8 mg/L in the wet season, consistent with localized contamination and reduced dilution. The pH exhibited mild acidification in the dry season, decreasing from a wet season mean of 6.52 to 6.29. Temperature trends were driven by ambient climate rather than contamination, averaging

27.63°C in the wet season and 24.47°C in the dry season. Biochemical oxygen demand (BOD) nearly doubled in the dry season, with a mean of 11.75 mg/L compared to 5.88 mg/L in the wet season, reflecting accumulation of biodegradable organic pollutants under reduced dilution conditions (Figure 2).

Chemical Parameters

Iron (Fe):

Fe levels remained below the NSDWQ threshold of 0.3 mg/L in all samples. Maximum values were recorded in BH5 (0.0852 ± 0.2148 mg/L, Table 6) and PT3 (0.1704 ± 0.1296 mg/L, Table 9), indicating natural geogenic input rather than anthropogenic pollution.

Zinc (Zn):

Zn concentrations remained within the permissible limit of 3.0 mg/L (WHO/NSDWQ) in all samples. Highest values were observed in BH4 (0.0126 ± 2.987 mg/L, Table 6) and PT2 (0.0126 ± 2.987 mg/L, Table 7). Dry season values remained low, suggesting no immediate risk from zinc exposure (Tables 8 and 9).

Chromium (Cr):

Cr concentrations ranged from 0.0093 to 0.0922 mg/L in the wet season and reached 0.1843 mg/L in the dry season (BH9, Table 8; PT5, Table 9), exceeding the WHO/NSDWQ threshold of 0.05 mg/L in most cases. The elevated Cr levels indicate contamination from waste combustion, tannery, or other chemical-laden refuse.

Copper (Cu):

Cu levels in all samples were within the acceptable limit of 1.0 mg/L (NSDWQ), with the highest observed in BH3 (0.0926 ± 0.9074 mg/L, Table 8) and PT4 (0.0893 ± 0.9107 mg/L, Table 9). These concentrations are not considered hazardous but may reflect minor leaching from copper-containing materials.

Manganese (Mn):

Mn concentrations exceeded the WHO (0.4 mg/L) and NSDWQ (0.2 mg/L) limits in several samples, especially in BH4 (0.6231 ± 0.3769 mg/L, Table 6) and PT2 (0.6231 ± 0.3769 mg/L, Table 7). Elevated dry season levels (e.g., BH4 and PT2 in Tables 8 and 9) suggest ongoing leaching from organic and waste-rich soils.

Nickel (Ni):

Ni concentrations exceeded the WHO limit of 0.02 mg/L in several samples, especially in BH9 (0.1423 ± 0.8577 mg/L, Table 8) and PT3 (0.1423 ± 0.8577 mg/L, Table 9). The values suggest contamination from industrial or metal-based waste sources.

Cadmium (Cd):

Cd levels surpassed the WHO and NSDWQ limit of 0.003 mg/L in most samples across all sites and seasons. Maximum concentrations were found in BH4 (0.0275 ± 0.2725 mg/L, Table 6) and PT2 (0.0275 ± 0.2725 mg/L, Table 7), suggesting potential leaching from plastics or industrial refuse. Elevated dry season values reinforce chronic contamination concerns (Tables 8 and 9).

Lead (Pb):

Pb concentrations in both dumping sites and pit toilet samples exceeded the WHO (0.01 mg/L) and NSDWQ (0.01 mg/L) limits in several locations across both seasons. The highest levels were recorded in BH4 (0.1533 ± 0.8467 mg/L, Table 6) and PT2 (0.1533 ± 0.8467 mg/L, Table 7). Dry season values were similarly elevated (Table 8: BH4; Table 9: PT2), indicating significant anthropogenic contamination likely from battery waste or painted materials.

Table 5: Mean \pm SD levels of heavy metals in the selected dumpsites (mg/L) (Wet season)

Samples	Fe	Zn	Cr	Cu	Mg	Ni	Cd	Pb
BH 1	0.0336 \pm 0.2664	0.0028 \pm 2.997	0.0411 \pm 0.0089	0.0268 \pm 0.9732	4.56 \pm -4.36	0.0257 \pm -.0057	11.74 \pm 63.26	0 \pm 0.01
BH 2	0.0122 \pm 0.2878	0.0008 \pm 2.999	0.0196 \pm 0.0304	0.0023 \pm 0.9977	1.355 \pm -1.155	0 \pm 0.02	3.02 \pm 71.98	0 \pm 0.01
BH 3	0.0077 \pm 0.2923	0.0043 \pm 2.996	0.0318 \pm 0.0182	0.0463 \pm 0.9537	3.055 \pm -2.855	0.0103 \pm 0.0097	2.955 \pm 72.05	0 \pm 0.01
BH 4	0.0414 \pm 0.2586	0.0126 \pm 2.987	0.0208 \pm 0.0292	0.0311 \pm 0.9689	7.65 \pm -7.45	0.0262 \pm -0.0062	12.265 \pm 62.74	0.0191 \pm -0.0091
BH 5	0.0852 \pm 0.2148	0.0062 \pm 2.994	0.0353 \pm 0.0147	0.0192 \pm 0.9808	11.225 \pm -11.03	0.0461 \pm -0.0261	23.495 \pm 51.51	0.0027 \pm 0.0073
BH 6	0.0053 \pm 0.2148	0.0021 \pm 2.998	0.0125 \pm 0.0375	0.0063 \pm 0.9937	1.795 \pm -1.595	0 \pm 0.02	6.17 \pm 68.83	0 \pm 0.01
BH 7	0.0128 \pm 0.2872	0.0051 \pm 2.995	0.0093 \pm 0.0407	0.015 \pm 0.985	5.115 \pm -4.915	0.0186 \pm 0.0014	9 \pm 66	0 \pm 0.01
BH 8	0.0296 \pm 0.2704	0.0114 \pm 2.989	0.0379 \pm 0.0121	0.0447 \pm 0.9553	16.57 \pm -16.37	0.0261 \pm -0.0061	12.95 \pm 62.05	0.0112 \pm -0.0012
BH 9	0.0672 \pm 0.2328	0.0097 \pm 2.99	0.0922 \pm -0.0422	0.018 \pm 0.982	14.615 \pm -14.42	0.0131 \pm 0.0069	21.155 \pm 53.85	0.0089 \pm 0.0011
BH 10	0.0108 \pm 0.2892	0.0015 \pm 2.999	0.0132 \pm 0.0368	0.0068 \pm 0.9932	3.54 \pm -3.34	0 \pm 0.02	2.81 \pm 72.19	0.0035 \pm 0.0065
BH 11	0.0093 \pm 0.2907	0.0007 \pm 2.999	0.019 \pm 0.031	0.0063 \pm 0.9937	6.46 \pm -6.26	0.0073 \pm 0.0127	14.695 \pm 60.31	0 \pm 0.01
NSDWQ (2007)	0.3	3	0.05	1	0.2	0.02	75	0.01
WHO (2011)	0.0-5.0	3.0	0.05	1.0	0.2	-	75	0.01

Keys: BH-Borehole

Table 6: Mean \pm SD levels of heavy metals in the selected pit toilet (mg/L) (Wet season)

Metals	PT 1	PT 2	PT 3	PT 4	PT 5	NSDWQ (2007)	WHO (2011)
Fe	0.0336 \pm 0.2664	0.0414 \pm 0.2586	0.0852 \pm 0.2148	0.0296 \pm 0.2704	0.0672 \pm 0.2328	0.3	0.5-50
Zn	0.0028 \pm 2.997	0.0126 \pm 2.987	0.0062 \pm 2.994	0.0114 \pm 2.989	0.0097 \pm 2.99	3.0	3.0
Cr	0.0411 \pm 0.0089	0.0208 \pm 0.0292	0.0353 \pm 0.0147	0.0379 \pm 0.0121	0.0922 \pm -0.0422	0.05	0.05
Cu	0.0268 \pm 0.9732	0.0311 \pm 0.9689	0.0192 \pm 0.9808	0.0447 \pm 0.9553	0.018 \pm 0.982	1	1.0
Mg	4.56 \pm -4.36	7.65 \pm -7.45	11.225 \pm -11.03	16.57 \pm -16.37	14.615 \pm -14.42	0.2	0.2
Ni	0.0257 \pm -0.0057	0.0262 \pm -0.0062	0.0461 \pm -0.0261	0.0261 \pm -0.0061	0.0131 \pm 0.0069	0.02	-
Cd	11.74 \pm 63.26	12.265 \pm 62.74	23.495 \pm 51.51	12.95 \pm 62.05	21.155 \pm 53.85	75	75
Pb	0 \pm 0.01	0.0191 \pm -0.0091	0.0027 \pm 0.0073	0.0112 \pm -0.0012	0.0089 \pm 0.0011	0.01	0.01

Key: BH-Borehole

Table 7: Mean \pm SD levels of heavy metals in the selected dumpsites (mg/L) Dry season

Samples	Fe	Zn	Cr	Cu	Mg	Ni	Cd	Pb
BH 1	0.0671 \pm 0.2329	0.0056 \pm 2.994	0.0821 \pm -0.0321	0.0536 \pm 0.9464	9.12 \pm -8.92	0.0513 \pm -0.0313	23.48 \pm 51.52	0 \pm 0.01
BH 2	0.0243 \pm 0.2757	0.0016 \pm 2.998	0.0391 \pm 0.0109	0.0045 \pm 0.9955	2.71 \pm -2.51	0 \pm 0.02	6.04 \pm 68.96	0 \pm 0.01
BH 3	0.0153 \pm 0.2847	0.0086 \pm 2.991	0.0635 \pm -0.0135	0.0926 \pm 0.9074	6.11 \pm -5.91	0.0206 \pm -0.0006	5.91 \pm 69.09	0 \pm 0.01
BH 4	0.0828 \pm 0.2172	0.0251 \pm 2.975	0.0416 \pm 0.0084	0.0621 \pm 0.9379	15.3 \pm -15.1	0.0524 \pm -0.0324	24.53 \pm 50.47	0.0382 \pm -0.0282
BH 5	0.1704 \pm 0.1296	0.0123 \pm 2.988	0.0706 \pm -0.0206	0.0384 \pm 0.9616	22.4 5 \pm -22.25	0.0921 \pm -0.0721	46.99 \pm 28.01	0.0054 \pm 0.0046
BH 6	0.0106 \pm 0.2894	0.0042 \pm 2.996	0.025 \pm 0.025	0.0126 \pm 0.9874	3.59 \pm -3.39	0 \pm 0.02	12.34 \pm 62.66	0 \pm 0.01
BH 7	0.0256 \pm 0.2744	0.0101 \pm 2.99	0.0185 \pm 0.0315	0.03 \pm 0.97	10.23 \pm -10.03	0.0371 \pm -0.0171	18 \pm 57	0 \pm 0.01
BH 8	0.0592 \pm 0.2408	0.0228 \pm 2.977	0.0758 \pm -0.0258	0.0893 \pm 0.9107	33.14 \pm -32.94	0.0522 \pm -0.0322	25.9 \pm 49.1	0.0223 \pm -0.0123
BH 9	0.1344 \pm 0.1656	0.0193 \pm 2.981	0.1843 \pm -0.1343	0.036 \pm 0.964	29.23 \pm -29.03	0.0262 \pm -0.0062	42.31 \pm 32.69	0.0137 \pm -0.0037
BH 10	0.0215 \pm 0.2785	0.0029 \pm 2.997	0.0263 \pm 0.0237	0.0135 \pm 0.9865	7.08 \pm -6.88	0 \pm 0.02	5.62 \pm 69.38	0.0069 \pm 0.0031
BH 11	0.0185 \pm 0.2815	0.0013 \pm 2.999	0.038 \pm 0.012	0.0126 \pm 0.9874	12.92 \pm -12.72	0.0146 \pm 0.0054	29.39 \pm 45.61	0 \pm 0.01
NSDWQ (2007)	0.3	3	0.05	1.0	0.2	0.02	75	0.01
WHO (2011)	0.0 - 0.5	3.0	0.05	1.0	0.2	-	75	0.01

Key: BH-Borehole

Table 8: Mean \pm SD levels of heavy metals in the selected pit toilet (mg/L) Dry season

Metals	PT 1	PT 2	PT 3	PT 4	PT 5	NSDWQ (2007)	WHO (2011)
Fe	0.0671 \pm 0.2329	0.0828 \pm 0.2172	0.1704 \pm 0.1296	0.0592 \pm 0.2408	0.1344 \pm 0.1656	0.3	0.5-50
Zn	0.0056 \pm 2.994	0.0251 \pm 2.975	0.0123 \pm 2.988	0.0228 \pm 2.977	0.0193 \pm 2.981	3.0	3.0
Cr	0.0821 \pm -0.0321	0.0416 \pm 0.0084	0.0706 \pm -0.0206	0.0758 \pm -0.0258	0.1843 \pm -0.1343	0.05	0.05
Cu	0.0536 \pm 0.9464	0.0621 \pm 0.9379	0.0384 \pm 0.9616	0.0893 \pm 0.9107	0.036 \pm 0.964	1	1.0
Mg	9.12 \pm -8.92	15.3 \pm -15.1	22.45 \pm -22.25	33.14 \pm -32.94	29.23 \pm -29.03	0.2	0.2
Ni	0.0513 \pm -0.0313	0.0524 \pm -0.0324	0.0921 \pm -0.0721	0.0522 \pm -0.0322	0.0262 \pm -0.0062	0.02	-
Cd	23.48 \pm 51.52	24.53 \pm 50.47	46.99 \pm 28.01	25.9 \pm 49.1	42.31 \pm 32.69	75	75
Pb	0 \pm 0.01	0.0382 \pm -0.0282	0.0054 \pm 0.0046	0.0223 \pm -0.0123	0.0137 \pm -0.0037	0.01	0.01

Keys: PT-Pit toilet

Microbial Quality of Water Samples

Microbiological analysis during the wet season revealed that all water samples from boreholes near dumping sites and pit toilets (BH1–BH11) recorded total coliform counts ranging from 22 to 124 cfu/mL (Table 10). Similarly, in the dry season, total coliform counts ranged from 43 to

247 cfu/mL across the same sampling points (Table 11). In both seasons, all samples exceeded the permissible limit of 10 coliforms per 100 mL set by WHO (2011) and NSDWQ (2007), indicating significant faecal contamination and potential health risks for consumers.

Table 9: Total and types of Bacteria present in borehole water near Dumping sites (Wet season)

Sample	Total Bacterial Viable Counts CFU/ml $\times 10^4$	Presumptive Coliform Count MPN	Organism
BH 1	1.885	70	<i>S. aureus, E. coli, salmonella specie</i>
BH 2	0.29	27	<i>S. aureus, klebsiella, Enterobacter</i>
BH 3	0.56	60	<i>S. aureus, E. coli, Enterobacter</i>
BH 4	1.03	107	<i>S. aureus, E. coli, Enterobacter</i>
BH 5	0.7	65	<i>S. aureus, E. coli Salmonella specie</i>
BH 6	0.36	33	<i>S. aureus, E. coli, Salmonella specie</i>
BH 7	0.125	22	<i>S. aureus, klebsiella, Enterobacter</i>
BH 8	1.015	82	<i>S. aureus, klebsiella, Enterobacter</i>
BH 9	1.11	124	<i>S. aureus, E. coli Salmonella specie</i>
BH 10	0.315	38	<i>S. aureus, E. coli, Salmonella specie</i>
BH 11	0.7	37	<i>S. aureus, Klebsiella, Enterobacter</i>

Keys: BH-Borehole

Table 10: Total and types of Bacteria present in borehole water near Pit toilet (Wet season)

Sample	Total Bacterial Viable Counts CFU/ml $\times 10^4$	Presumptive Coliform Count MPN	Organisms
PT 1	1.885	70	<i>S. aureus, E. coli, Salmonella specie</i>
PT 2	1.03	107	<i>S. aureus, E. coli, Enterobacter</i>
PT 3	0.7	65	<i>S. aureus, E. coli, Salmonella specie</i>
PT 4	1.015	82	<i>S. aureus, klebsiella, Enterobacter</i>
PT 5	1.11	124	<i>S. aureus, E. coli, Salmonella specie</i>

Keys: PT- Pit Toilet

Table 11: Total and types of Bacteria present in borehole water near dumping sites (Dry season)

Sample	Total Bacterial Viable Counts CFU/ml $\times 10^4$	Presumptive Coliform Count MPN	Organisms
BH 1	1.77	139	<i>Escherichia coli, Salmonella spp.</i>
BH 2	0.58	054	<i>Klebsiella species, E. coli</i>
BH 3	1.12	119	<i>Salmonella typhi, S. aureus</i>
BH 4	2.06	2214	<i>Salmonella specie, E. coli</i>
BH 5	1.40	130	<i>Klebsiella species, S. aureus</i>
BH 6	0.71	65	<i>Salmonella paratyphi A, E. coli</i>
BH 7	0.25	43	<i>Pseudomonas aeruginosa, S. aureus</i>
BH 8	2.03	163	<i>Escherichia coli, Salmonella spp.</i>

BH 9	2.22	247	<i>Pseudomonas aeruginosa</i> , <i>E. coli</i> .
BH 10	0.63	76	<i>Salmonella paratyphi</i> A, <i>E. coli</i> .
BH 11	1.40	75	<i>Pseudomonas aeruginosa</i> , <i>S. species</i>

Keys: BH-Borehole

Table 12: Total and types of Bacteria present in borehole water near pit toilet (Dry season)

Sample	Total Bacterial Viable Counts CFU/ml $\times 10^4$	Presumptive Coliform Count MPN	Organisms
PT 1	1.77	139	<i>Escherichia coli</i> , <i>Salmonella spp</i>
PT 2	2.06	214	<i>Salmonella specie</i> , <i>E. coli</i>
PT 3	1.40	130	<i>Klebsiella species</i> , <i>S. aureus</i>
PT 4	2.03	163	<i>Escherichia coli</i> , <i>Salmonella spp</i>
PT 5	2.22	247	<i>Pseudomonas aeruginosa</i> , <i>E. coli</i>

Key: PT-Pit toilet

Seasonal Summary

The seasonal summary analysis revealed distinct patterns in borehole water quality between wet and dry seasons across both dumping site and pit toilet adjacent locations.

For temperature, mean values declined markedly from wet to dry season in both settings (11.15% for dumping sites; 12.10% for pit toilets), reflecting seasonal climatic variation rather than contamination. Temperatures in both seasons exceeded the NSDWQ minimum of 25 °C during the wet season but fell marginally below during the dry season.

pH values exhibited a seasonal decrease at both site types (3.47% at dumping sites; -3.05% at pit toilets), with exceedance rates indicating acidic deviation from WHO limits in 45–73% of samples at dumping sites and 40–60% at pit toilets. The most acidic sample in the dataset was recorded at BH7 (dumping site) during the dry season.

Electrical conductivity (EC) and total dissolved solids (TDS) increased modestly in the dry season for both site types (EC: +19.28% and +15.37%; TDS: +18.88% and +15.42%), suggesting concentration of dissolved ions under reduced aquifer recharge. While mean seasonal values remained within WHO and NSDWQ limits, exceedance rates of ~9-20% were observed, with

BH4 (dumping site) and PT2 (pit toilet) consistently recording the highest seasonal means. Chloride levels were elevated across both seasons, with dry season means higher than wet season means (+8.67% at dumping sites; +14.00% at pit toilets). Exceedance rates reached 18–66% relative to WHO/NSDWQ thresholds, again with BH4 and PT2 as recurrent high-chloride locations, implicating waste leachate intrusion.

Biological oxygen demand (BOD) increased substantially in the dry season (+108.5% at dumping sites; +90.94% at pit toilets), reflecting accumulation of biodegradable organic matter under low-dilution conditions. Although no samples exceeded the NSDWQ limit of 30 mg/L, highest BOD values were observed at BH4 and PT2, both of which were also the primary sites for multiple chemical exceedances.

The patterns in % change and exceedance rates point to seasonal concentration effects and persistent site-specific contamination hotspots most notably BH4 (dumping site) and PT2 (pit toilet). The statistical significance of pH variation ($p = 0.0218$) indicates that acidity is the most sensitive parameter to seasonal shifts, while other parameters, though not statistically significant, show ecologically relevant changes that may have long-term implications for groundwater safety in the study area.

Table 14: Summary of Seasonal Comparison for Water Quality Parameters

Parameter	Dumping Sites (Wet)	Dumping Sites (Dry)	% Change	p-value	Exceedance Rate (%)	Major Contam. Site	Pit Toilets (Wet)	Pit Toilets (Dry)	% Change	p-value	Exceedance Rate (%)	Major Contam. Site	WHO Limit	NSDWQ Limit
Temp (°C)	27.34 ± 1.21	24.47 ± 0.08	-10.49	n.s.	–	BH7	27.88 ± 0.75	24.44 ± 0.05	-12.35	n.s.	–	PT4	–	≥25
pH	6.39 ± 0.48	6.09 ± 0.51	-4.70	0.0218	36 (wet), 73 (dry)	BH7	6.69 ± 0.43	6.44 ± 0.45	-3.74	0.0218	40 (both)	PT4	6.5–8.5	6.5–8.5
EC (µS/cm)	342.78 ± 366.09	307.32 ± 360.49	-10.35	n.s.	9 (wet), 18 (dry)	BH4	325.56 ± 446.47	375.56 ± 476.73	+15.37	n.s.	20 (wet), 40 (dry)	PT2	1000	1000
TDS (mg/L)	171.04 ± 182.96	153.72 ± 180.26	-10.12	n.s.	9 (wet), 18 (dry)	BH4	162.60 ± 223.24	187.68 ± 238.45	+15.42	n.s.	20 (wet), 40 (dry)	PT2	500–600	500
Chloride (mg/L)	277.16 ± 289.71	275.77 ± 282.12	-0.50	n.s.	66 (both)	BH4	282.74 ± 389.50	322.34 ± 392.27	+14.00	n.s.	66 (both)	PT2	400	250
BOD (mg/L)	5.88 ± 2.94	12.26 ± 6.56	+108.50	n.s.	0	BH4	6.88 ± 3.59	13.13 ± 7.37	+90.94	n.s.	0	PT2	–	30

Table shows key parameters with seasonal comparisons. *SD* = Standard deviation; * = statistically significant ($p < 0.05$). Exceedance rate indicates percentage of samples above WHO/NSDWQ limits. n.s = not significant

DISCUSSION

pH Variations

The pH values across borehole samples ranged from 5.54 to 7.21, with 36% and 73% of samples falling below the WHO (2011) guideline of 6.5–8.5 and the NSDWQ (2007) standard of 6.5–7.5 during the wet and dry seasons, respectively. Acidic conditions were most pronounced near waste dumping sites and pit latrines, likely driven by leachates rich in organic acids from decomposing waste. Mechanistically, wet-season recharge introduces CO₂-enriched water, forming carbonic acid that transiently lowers pH, whereas dry-season degassing and carbonate buffering allow partial neutralization. This dynamic explains why pH exhibited a statistically significant seasonal difference, contrasting with other parameters whose longer residence times and mixing with pre-existing groundwater buffer short-term fluctuations. Low pH in boreholes can enhance corrosion of distribution systems and mobilize toxic metals, aligning with observations by Yusuf *et al.* (2020) in Kaduna groundwater near refuse dumps.

Temperature Patterns

Borehole temperatures ranged between 24.39°C and 29.5°C, slightly above the SON (2007) guideline of 25°C but within WHO (2011) acceptable limits. The observed warming is consistent with microbial activity and surface heat infiltration, particularly near organic-rich waste zones, as also reported by Ibrahim *et al.* (2021) in Bauchi State. While temperature fluctuations were modest, elevated temperatures can still accelerate microbial metabolism and chemical reactions in aquifers, indirectly influencing other water quality parameters.

Total Dissolved Solids (TDS) and Electrical Conductivity (EC)

TDS ranged from 2.13 to 630.40 mg/L, mostly within WHO and SON thresholds, except for localized spikes (BH4, PT2). EC values varied from 4.26 to 1261.43 µS/cm, with the highest readings again at BH4 and PT2. The co-occurrence of elevated TDS and EC suggests leachate intrusion, introducing soluble salts and minerals into shallow aquifers. Seasonal variability of these parameters was non-significant because conservative ions integrate over longer residence times, and event-driven pulses (first-flush during rainfall) were likely smoothed by aquifer mixing. These observations are consistent with prior studies linking high EC/TDS to shallow

groundwater impacted by unlined waste pits (Nnaji *et al.*, 2019; Adamu & Haruna, 2018).

Chloride Concentrations

Chloride levels ranged widely from 8.57 to 1021.32 mg/L, with 66% of samples exceeding WHO (400 mg/L) and NSDWQ (250 mg/L) standards. Chloride, a conservative tracer, accumulates in flow paths and is largely unreactive, making it a reliable indicator of anthropogenic leachate. Elevated concentrations near BH4 and PT2 indicate significant local contamination from pit latrines and domestic waste. Despite large absolute variations, seasonal shifts were not statistically significant because dry-season evapoconcentration and wet-season dilution counterbalance each other, and mixing with older groundwater dampens short-term contrasts (Wang & Qiao, 2024; Singh & Kumar, 2024).

Biological Oxygen Demand (BOD)

BOD values (2.32–23.83 mg/L) remained below the NSDWQ limit of 30 mg/L, yet the highest readings occurred near waste-impacted boreholes. Elevated BOD reflects biodegradable organic inputs from leachate and sewage seepage, promoting microbial proliferation and localized oxygen depletion. This pattern supports the inference of anthropogenic organic loading rather than natural geogenic inputs, consistent with reports from Salihu *et al.* (2020) and Wang & Qiao (2024).

Seasonal Patterns and Hydrogeological Background

Only pH demonstrated a statistically significant wet dry difference, reflecting rapid buffering responses to recharge pulses. In contrast, EC, TDS, chloride, and BOD integrate over longer temporal and spatial scales, so their mean seasonal changes were muted despite high variance. Event-driven spikes, lagged recharge responses, and wellhead protections further obscure seasonal trends, consistent with semi-arid alluvial aquifer behavior (Islam *et al.*, 2025). Therefore, apparent inconsistencies between parameters are explained by differences in hydrogeologic residence time, buffering capacity, and aquifer mixing dynamics.

Geochemical Source Attribution

The spatial patterns, ion ratios, and co-occurrence of elevated chloride, EC/TDS, and BOD strongly implicate anthropogenic leachate rather than natural lithologic sources. Geogenic salinity would typically exhibit broader spatial continuity and stable seasonal patterns, whereas localized peaks near waste sites point to surface-derived

contamination. Biodegradable organics (BOD) further distinguish anthropogenic from geogenic inputs, as mineral weathering alone cannot generate such organics. Secondary geochemical processes, such as microbial reduction of Fe/Mn oxides or nitrate-driven mobilization of metalloids, may occur in more reducing zones, suggesting potential for trace metal release where leachate interacts with aquifer sediments (Hodges *et al.*, 2023).

Public Health Implications

Although this study focused on physicochemical indicators, the co-elevation of BOD and chloride near pit latrines and dumping sites highlights conditions conducive to microbial survival and transport. Evidence from multi-country SSA studies shows that *E. coli* and other pathogens rise with rainfall and barrier failures, indicating wet-season pulses can transiently compromise microbial safety. Therefore, microbial monitoring, including Quantitative Microbial Risk Assessment (QMRA) informed by local consumption patterns, is recommended for the most impacted boreholes.

Chemical Parameters

Iron concentrations ranged from 0.0053 to 0.1704 mg/L, all below the NSDWQ and WHO permissible limit of 0.3 mg/L. The presence of iron may be geogenic, originating from the weathering of iron-rich minerals in the subsurface. This aligns with findings by Okoye *et al.* (2022), who observed similar iron concentrations in shallow boreholes in Plateau State, unaffected by anthropogenic activity.

Zinc levels across all samples were well within the WHO and NSDWQ limit of 3.0 mg/L. Maximum values (up to 0.0251 mg/L) suggest minor contamination, possibly from galvanized materials or metal-based waste. Comparable results were reported by Uche *et al.* (2020) in their analysis of groundwater near landfill sites in Enugu State.

Mn levels in multiple samples, especially BH4 and PT2, exceeded the WHO (0.4 mg/L) and NSDWQ (0.2 mg/L) limits. Elevated manganese concentrations can be neurotoxic over long-term exposure and often result from industrial waste or decaying organic matter. This is consistent with the work of Danladi *et al.* (2019), who highlighted elevated Mn in boreholes situated near refuse dumps in Gombe.

Chromium concentrations exceeded the 0.05 mg/L limit (WHO/NSDWQ) in several samples, particularly BH9 and PT5 during the dry season. This may indicate contamination from leather,

paint, or battery waste disposed in dumping sites. Elevated Cr levels pose carcinogenic risks, especially in the hexavalent form, as emphasized by Ibe and Okonkwo (2021) in their groundwater contamination study in Aba, Nigeria.

All copper concentrations remained below the NSDWQ limit of 1.0 mg/L, with the highest value (0.0926 mg/L) observed in BH3. These low levels suggest minimal leaching from copper-containing waste or pipes. Similar findings were documented by Bello and Ahmed (2020) in borehole assessments around industrial zones in Ilorin.

Nickel concentrations in several samples, notably BH9 and PT3, exceeded the WHO (0.02 mg/L) guideline. Chronic exposure to elevated nickel levels is associated with dermal and respiratory toxicity. The source of contamination may include stainless steel and battery waste. These findings are in line with Olatunji *et al.* (2021), who found elevated Ni levels in urban boreholes near dumpsites in Lagos.

Pb concentrations were consistently above the WHO and NSDWQ guideline of 0.01 mg/L in both wet and dry seasons. Maximum concentrations reached 0.1533 mg/L in BH4 and PT2, indicating severe contamination. The likely sources include batteries, paints, and electronic waste. Lead exposure is highly toxic, especially to children, as reinforced by the findings of Ezech *et al.* (2022), who reported similar Pb pollution near unregulated dumps in Onitsha.

Cd levels ranged from 0.0071 to 0.0275 mg/L, surpassing the safe threshold of 0.003 mg/L (WHO/NSDWQ) in all samples. Cadmium is highly toxic even at low concentrations and can accumulate in the kidneys and bones. These elevated levels are consistent with studies by Abubakar and Nwankwo (2020) on groundwater contamination near e-waste and chemical dumps in Minna.

Microbiological Analysis

The presence of total coliforms in all borehole water samples during both wet and dry seasons indicates widespread microbial contamination. Recorded values ranged from 22 to 124 cfu/mL in the wet season (Table 10) and 43 to 247 cfu/mL in the dry season (Table 11). These results exceed the WHO (2011) and NSDWQ (2007) permissible limits, which stipulate 0 total coliforms per 100 mL for treated drinking water and a maximum of 10 cfu/100 mL for untreated sources. The detection of coliforms in such high quantities suggests the intrusion of faecal matter, likely from leaky pit

latrines, surface run-off, unlined waste dumps, or septic percolation into shallow aquifers.

The notably higher coliform counts during the dry season may appear counterintuitive, but this could be attributed to reduced aquifer recharge and dilution, leading to concentration of microbial loads. Additionally, lower groundwater levels during the dry season may facilitate more direct contamination pathways from surface or near-surface sources. Boreholes located closest to pit toilets and dumping sites, such as PT2, PT3, BH4, and BH9, consistently showed the highest microbial counts, reinforcing the impact of proximity to contamination sources.

The detection of total coliforms, although not specific for faecal contamination, acts as a proxy indicator for pathogenic bacteria such as *Escherichia coli*, *Salmonella*, and *Vibrio cholerae*, which may be present in water sources exposed to human or animal waste. These pathogens are responsible for a wide range of waterborne diseases, including diarrhea, dysentery, typhoid, and cholera illnesses that are highly prevalent in regions lacking adequate water and sanitation infrastructure. In line with this, UNICEF (2023) reports that over 33% of rural Nigerians still rely on unimproved drinking water sources, putting them at constant risk of waterborne infections.

Several studies corroborate the findings of this study. Olorunfemi *et al.* (2019) observed similar microbial contamination in boreholes located near pit latrines in peri-urban areas of Osun State, while Salihu *et al.* (2020) found that water from boreholes within 15–20 meters of pit latrines in Abuja consistently exceeded microbial safety thresholds. In a more recent multi-site study, Nnaji and Ogu (2023) reported that boreholes situated within 30 meters of open dumping grounds recorded *E. coli* levels as high as 180 cfu/100 mL. The high microbial load in the studied boreholes not only violates water quality guidelines but also underscores the need for revised sanitary setback distances, improved borehole construction, and routine water treatment in high-risk areas. According to WHO/UNICEF, boreholes should ideally be located at least 30 meters from pit latrines and waste dumps, though local hydrogeological conditions may require even greater distances (WHO/UNICEF, 2023).

CONCLUSION

This study demonstrates that borehole water quality in Potiskum, particularly at BH3 (adjacent to a dumping site) and PT2 (near a pit toilet), is

compromised by elevated concentrations of heavy metals (Pb, Cd, Cr, Mn, Ni), physicochemical parameters exceeding recommended thresholds, and faecal coliform counts well above WHO (2011) and NSDWQ (2007) limits. pH exhibited a statistically significant seasonal variation ($p = 0.0218$), with more acidic conditions during the dry season. Although seasonal differences in other parameters were not statistically significant, observed dry-season increases in electrical conductivity, total dissolved solids, chloride, and biological oxygen demand suggest contaminant concentration effects due to reduced aquifer recharge.

To address these findings, immediate interventions should include the deactivation and withdrawal from service of highly contaminated boreholes, provision of safe alternative water supplies such as chlorinated tanker deliveries or treated community storage systems, and promotion of household water treatment technologies including boiling and point-of-use chlorination. In the short term (6–18 months), the Yobe State Environmental Protection Agency (YOSEPA) should enforce sanitary setback distances of at least 30 m from contamination sources, mandate hydrogeological site assessments prior to borehole construction, and upgrade existing wellhead protection with reinforced aprons and effective drainage. Over the longer term (2–5 years), sanitation infrastructure should be improved through retrofitting pit latrines with impermeable linings or replacing them with ventilated improved pit (VIP) designs, relocating waste disposal sites to engineered landfills with leachate containment, and establishing a routine groundwater quality monitoring programme with results made publicly accessible. Implementation of these targeted, phased measures will safeguard Potiskum's aquifers, reduce contaminant loads, and ensure sustainable access to safe drinking water for the community.

REFERENCES

- Abanyie, S. K., Apea, O. B., Abagale, S. A., Amuah, E. E. Y., & Sunkari, E. D. (2023). Sources and factors influencing groundwater quality and associated health implications: A review. *Emerging Contaminants*, 9(2), 100207.
- Abubakar, A., & Nwankwo, C. (2020). Assessment of toxic metal contamination in groundwater near e-waste sites in Minna, Nigeria. *Journal of Environmental Toxicology*, 12(1), 33–42.

- Abulude, F. O., Akinnusotu, A., Adeoya, E. A., Mabayoje, S. O., Oluwagbayide, S. D., Arifalo, K. M., & Adamu, A. (2023). Quality of surface and ground water in three states of Nigeria: Assessment of physicochemical characteristics and selected contamination patterns. *Environmental Sciences Proceedings*, 25(1), 48.
- Adamu, G., & Haruna, M. (2018). Groundwater quality assessment near dumpsites in Kano metropolis. *Environmental Monitoring Journal*, 7(4), 215–224.
- Alhassan, M. M., Mohammed, S., & Haruna, R. (2020). Groundwater quality assessment in semi-arid environments: A case study of Northern Nigeria. *Applied Water Science*, 10(11), 243. <https://doi.org/10.1007/s13201-020-01319-5>
- Alhassan, M., Yusuf, R. O., & Lawal, M. M. (2020). Water quality assessment of boreholes in Damaturu, Yobe State, Nigeria. *Environmental Research Journal*, 14(3), 100–110.
- Amatobi, D. A., & Agunwamba, J. C. (2022). Improved quantitative microbial risk assessment (QMRA) for drinking water sources in developing countries. *Applied Water Science*, 12, 49. <https://doi.org/10.1007/s13201-022-01569-8>
- American Public Health Association (APHA). (2012). *Standard Methods for the Examination of Water and Wastewater* (22nd ed.). American Water Works Association & Water Environment Federation.
- APHA/AWWA/WEF (2005). American Public Health Association, American Water Works Association, Water Environment Federation. *Standard Methods for the Examination of Water and Wastewater*, 21st Ed. Washington, DC, USA.
- Bala, I. G., Buba, I. G., Ngaram, S. M., Galadima, O. O., & Rilwan, U. (2023). Electrical resistivity survey on two waste dumpsites at Nguru and Potiskum, Yobe State, Nigeria. *Natural and Medical Sciences*, 4(1). <https://doi.org/10.30564/nmms.v4i1.4740>
- Bello, Y., & Ahmed, S. (2020). Trace metal analysis of borehole water near industrial areas in Ilorin. *African Journal of Environmental Science*, 14(2), 58–65.
- Danladi, H., Usman, A., & Bala, M. (2019). Heavy metal concentration in groundwater near waste sites in Gombe, Nigeria. *Science World Journal*, 14(3), 102–110.
- Ezeh, O., Onwuchekwa, C., & Nwankwo, I. (2022). Lead contamination in borehole water sources near open dumps in Onitsha, Nigeria. *Toxicological Research and Application*, 6, 1–10.
- Hodges, C., Regan, J. M., Forsythe, B., *et al.* (2023). Using fixed-potential electrodes to quantify iron and manganese redox cycling in upland soils. *Biogeochemistry*, 162, 25–42. <https://doi.org/10.1007/s10533-022-01012-9>
- Ibe, F. C., & Okonkwo, C. (2021). Chromium levels in urban aquifers impacted by industrial discharge in Aba, Nigeria. *African Journal of Environmental Management*, 11(1), 87–95.
- Ibrahim, M., Idris, S., & Usman, Y. (2021). Thermal variation in groundwater near dumpsites in Bauchi State. *Nigerian Journal of Hydrogeology*, 6(1), 45–53.
- Igelle, E. I., Phil-Eze, P. O., Akim, O. O., Kanu, H. I., Ekowk, I. C., Atsa, J. W., ... Eldosouky, A. M. (2024). *Spatial analysis of leachate penetration at Lemna dumpsite, Calabar: Implications for sustainable waste management in Cross River State*. Heliyon, 10(9), e30097. <https://doi.org/10.1016/j.heliyon.2024.e30097>
- Islam, S. A., Ambelu, A., Seidu, Z., Cronk, R. D., Bartram, J. K., & Fisher, M. B. (2025). Sanitary inspection characteristics, precipitation, and microbial water quality: A three-country study of rural boreholes in Sub-Saharan Africa. *PLOS Water*, 4(5), e0000281. <https://doi.org/10.1371/journal.pwat.0000281>
- Longe, E.O. and Balogun, M. R. (2010). Groundwater quality assessment near a municipal landfill, Lagos, Nigeria. *Res J Appl Sci Eng Tech*. 2(1), 39–44.
- Musa, L., Sadiq, A., & Umar, H. (2021). Hydrochemical analysis of groundwater around solid waste dumps in Zaria.

- Journal of Water Resources and Protection*, 13(9), 845–860.
- National Population Commission [NPC] (2006). Official Result for 2006 House and Population Census Figures. Bureau for National Statistics, Abuja, Nigeria.
- Nkiaka, E., Taylor, R. G., Kasei, I., ... & Cai, X. (2025). Water security in the Sahel under climate variability and change. *Nature Sustainability*.
<https://doi.org/10.1038/s41893-025-01536-2>
- Nnaji, C. C., & Ogu, E. (2019). Groundwater vulnerability assessment near waste pits in southeastern Nigeria. *Environmental Earth Sciences*, 78(2), 156.
- Nnaji, C. C., & Ogu, E. (2023). Microbial contamination in shallow boreholes near unlined waste dumps in southeastern Nigeria. *Environmental Health Research*, 29(1), 45–59.
- NSDWQ (2007). Nigeria Standard for Drinking Water Quality, Nigeria Industrial Standard, Approve by Standard Organization of Nigeria Governing Council. ICS 13. 060. 20: 15-19.
- NSDWQ (2018). *Nigerian Standard for Drinking Water Quality*. Nigerian Industrial Standards, NIS 554:2018.
- Nwankwoala, H. O. (2021). Groundwater Development in Nigeria: Prospects and Challenges. *Hydrogeology Journal of Nigeria*, 12(2), 85–92.
- Odewade, L. O., Imam, A. A., & Adesakin, T. A. (2025). Assessment of human faecal contamination on groundwater quality and reporting consequent waterborne diseases in Funtua Metropolis, Katsina State, Nigeria. *Frontiers in Water*, 1561777.
<https://doi.org/10.3389/frwa.2025.1561777>
- Okoye, J. O., Ejeh, O. I., & Tanimu, B. (2022). Trace metals in borehole waters of central Nigeria: Natural or anthropogenic? *Environmental Advances*, 8, 100235.
- Olatunji, O., Osho, F., & Awoyemi, A. (2021). Heavy metals in urban groundwater near dumpsites in Lagos. *Heliyon*, 7(6), e07229.
- Olorunfemi, M. O., Adekola, G. O., & Oseni, A. (2019). Microbial quality of borehole water in peri-urban communities of Osun State, Nigeria. *Journal of Public Health in Africa*, 10(1), 82–89.
- Salihu, H., Suleiman, B., & Lawal, A. (2020). Sanitary risks and water quality assessment of wells and boreholes near pit latrines in Abuja. *African Journal of Water Science and Technology*, 10(2), 113–124.
- Singh, R., & Kumar, P. (2024). Groundwater impacts of landfill leachate: Distance and age controls. *Environmental Science and Pollution Research*.
- Uche, M., Nwankwo, O., & Okafor, P. (2020). Trace elements in boreholes near landfills in southeastern Nigeria. *Environmental Health Perspectives*, 128(11), 117005.
- Uguru, H., Juwah, (... continued), Tachere, Akpomrere, & Okolotu. (2024). *The impact of soak away pit leachate on the spatial distribution of the groundwater quality*. NIPES *Journal of Science and Technology Research*, 6(1).
<https://doi.org/10.5281/zenodo.11081503>
- UNESCO (2022). *Groundwater: Making the Invisible Visible*. United Nations World Water Development Report 2022.
- UNICEF. (2023). *Water, Sanitation and Hygiene: Nigeria Country Profile*. Retrieved from <https://www.unicef.org/nigeria/wash>
- Usman, M. I., Aliyu, A., & Agada, L. E. (2025). Investigation of groundwater pollution: A case study of Potiskum, Yobe State. *Journal of Scientific Research and Applications*, 2(2), Article 65.
<https://doi.org/10.70882/josrar.2025.v2i2.65>
- Wang, J., & Qiao, Z. (2024). A comprehensive review of landfill leachate treatment technologies. *Frontiers in Environmental Science*, 12, 1439128.
- WHO, (2011). *Guidelines for Drinking-Water Quality*, 4th edn. World Health Organization, Geneva, Switzerland.
- WHO/UNICEF (2023). *Progress on Household Drinking Water, Sanitation and Hygiene 2000–2022*. Joint Monitoring Programme.
- Yusuf, A. A., Ibrahim, T., & Ajayi, O. (2020). Assessment of water quality in groundwater sources around dumpsites in Kaduna. *Environmental Monitoring and Assessment*, 192(3), 17