

Assessment of Groundwater Quality from Tombia Community in Degema Local Government Area of Rivers State, Nigeria

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Abstract

Groundwater is the primary source of drinking water for rural communities in the Niger Delta, yet its quality is increasingly threatened by natural geochemical processes and anthropogenic activities. This study evaluated the quality of groundwater in Tombia community in Degema Local Government Area, Rivers State, Nigeria, with the aim of assessing its suitability for domestic consumption and identifying potential health risks. Samples were collected from boreholes and hand-dug wells and analysed for physical, chemical, and biological parameters using standard analytical methods. The results revealed that pH (7.27–7.72), temperature (27.5–27.9°C), and TDS (53.2–465.5 mg/L) were within permissible limits in all samples. All major ions (iron and manganese) and total hardness were within WHO and NSDWQ limits, the samples showed significantly higher concentrations of EC, TDS, chloride, sulphate, nitrate, and hardness, suggesting saltwater intrusion and mineral dissolution. Manganese exceeded the aesthetic guideline at ST12 TAP4T (0.119 mg/L). Heavy metals (lead, cadmium, chromium) were below detection limits. Total and faecal coliforms were absent in all samples, indicating no faecal contamination, though THB counts were high (>500 CFU/mL) in 91.7% of samples. The Water Quality Index classified the water samples as Excellent, primarily due to extreme turbidity and iron. Hand-dug wells exhibited higher turbidity and iron than boreholes, highlighting their vulnerability to surface contamination. The study concluded that groundwater in Tombia are generally potable and free from faecal contamination, but aesthetic issues (turbidity, iron, manganese) and early signs of saltwater intrusion require attention. Therefore, regular monitoring of the water in the area advised to enhance water safety and ensure sustainable groundwater management.

Keywords: Groundwater, Water Quality, Tombia Community, Degema, Nigeria

Introduction

Groundwater is a critical source of freshwater globally, supplying nearly half of the world's drinking water and sustaining agricultural and industrial activities (UNESCO, 2022). In sub-Saharan Africa, and particularly in Nigeria, groundwater plays an indispensable role in meeting

domestic water needs due to inadequate surface water infrastructure and unreliable municipal supply systems (Adelana & MacDonald, 2008; Olalekan et al., 2021). The Niger Delta region, where Tombia community is located, is heavily dependent on groundwater accessed through boreholes and hand-dug wells. However, the quality of this resource is increasingly compromised by anthropogenic activities and natural geochemical processes. Several studies have documented the vulnerability of groundwater in the Niger Delta to contamination from oil exploration, industrial effluents, and agricultural runoff. Hydrocarbon pollution, heavy metals, and elevated nitrate levels have been reported in groundwater samples across Rivers State, raising significant public health concerns (Nwankwoala & Udom, 2013; Olalekan et al., 2021). In Tombia, hydrochemical assessments revealed variations in parameters such as pH, total dissolved solids (TDS), chloride, sulphate, and iron, with some values exceeding World Health Organisation (WHO) permissible limits for potable water (Oki & Oboshenure, 2017). Similarly, Otobo and Inengite (2026) characterised the hydrochemical facies of Tombia groundwater and found evidence of contamination linked to both natural sedimentary processes and anthropogenic inputs. Evaluating groundwater quality in Tombia is essential not only for understanding the current state of water resources but also for informing policy interventions, community awareness, and sustainable management practices (Nweke. & Amachere, 2026).. Globally, the importance of monitoring groundwater quality has been emphasised by the United Nations Sustainable Development Goals (SDG 6: Clean Water and Sanitation), which highlight the need for safe and affordable drinking water (UNESCO, 2022). In Nigeria, regulatory frameworks such as those established by the National Environmental Standards and Regulations Enforcement Agency (NESREA) provide guidelines for permissible water quality standards, yet enforcement remains weak in rural communities (NESREA, 2011). This study, therefore, contributes to bridging the gap between policy and practice by providing empirical data on groundwater quality in Tombia benchmarked against WHO and NESREA standards (Nweke, Ihejirika & Deebom, 2018)

The aim of this study is to evaluate the quality of groundwater in Tombia community of Degema LGA, Rivers State. Tombia is a Kalabari community located at the coordinates: 4.7887°N, 6.8943°E in Degema Local Government Area of Rivers State, Nigeria. It lies along the Sombreiro River and its tributary creeks, which form part of the intricate hydrological network of the eastern Niger Delta. The settlement is positioned only a few meters above sea level, making it highly susceptible to tidal fluctuations and seasonal flooding (Oki & Oboshenure, 2017).

The geomorphology that hosts Tombia is the Niger Delta plain: a vast, low-gradient depositional system composed of recent alluvium, mangrove swamps, and estuarine deposits. Contemporary syntheses of the region emphasise its extensive freshwater and mangrove swamps, flat topography, and dense channel network, features that control surface and groundwater interactions and make shallow aquifers highly responsive to tidal and flood influences (Oyegun et al., 2023).

Geologically, the near-surface sediments beneath Tombia and neighbouring communities are dominated by unconsolidated sands, silts and clays deposited in fluvial-estuarine environments. Engineering and geological surveys of the Niger Delta document these lithologies and note their implications for groundwater recharge and contaminant transport: sandy layers permit rapid infiltration while fine-grained horizons limit natural filtration, creating aquifers that are both readily accessible and susceptible to surface-derived pollution (Abam, 2016).



Figure 1.1 Map Showing the Sample Locations

Recent hydrochemical work focused specifically on Tombia reinforces the link between the community's creek-side geography and groundwater chemistry: shallow, hydraulically connected aquifers in such settings commonly display signatures of surface influence and rapid geochemical response to land-use and spill events, underscoring the need to interpret water quality in light of local geomorphology and tidal dynamics (Otobo & Inengite, 2026)

Methodology

Sample Collection

The field sampling campaign followed a tightly arranged sequence of actions designed to preserve sample integrity from the moment of collection through delivery to the laboratory. Before mobilisation, the field team (the researcher and assistants) held a briefing to review site assignments, safety measures, and chain-of-custody procedures. Each sampling team carries a pre-packed kit containing sterile microbiological bottles, acid-washed polyethylene bottles for metals, glass or high-density polyethylene bottles for major ions, calibrated field meters (pH, EC, temperature, turbidity), a GPS unit, a camera, permanent markers, sample labels, a cooler with ice packs, personal protective equipment (PPE), and chain-of-custody forms. Community permission was reconfirmed at each site, and the well owner or attendant was informed of the sampling steps to minimise disturbance and ensure cooperation. (Wadi, Prosper, Nweke, Sangtang, Haris, & Rautaray, 2026) At each selected borehole or hand-dug well, the team first recorded site metadata: GPS coordinates, well identification code, well construction details, visible sanitary features, and immediate land use. Field meters were calibrated at the start of each day using standard solutions. During sample collection, a representative groundwater sample was collected: for boreholes, the borehole was allowed to run for 1-2 minutes before sample collection to get a representative sample, in which the field parameters (pH, temperature, electrical conductivity) are stable; for hand-dug wells, water was bailed or pumped until readings stabilise. Samples for in-situ parameters (temperature, pH, electrical conductivity, dissolved oxygen, and turbidity) were measured immediately after stabilisation using calibrated probes and logged. Microbiological samples were collected last to avoid cross-contamination: sterile, single-use bottles were opened at the mouth of the well and filled directly, leaving minimal headspace, then capped immediately. Chemical samples were collected in glass bottles. For trace metal analysis, bottles were acid-washed and pre-labelled, and a portion of the sample was acidified in the field to pH < 2 with nitric acid to preserve dissolved metal species. No preservatives were added to microbiological samples. Each bottle was labelled with a unique sample ID, date, time, sampler initials, and sample type (Wadi, Nweke, Silver, Alagjozovska, Segalerba, & Ibatova, 2026).

Immediately after collection, samples were placed in a cooler with ice packs to maintain a temperature of approximately 4°C. Microbiological samples were kept chilled and delivered to the laboratory for analysis within 24 hours. Chemical samples requiring acidification were stabilised in the field as described; other chemical samples were chilled and analysed within the holding times recommended by standard methods. Bottles were kept upright, cushioned, and segregated by sample type to avoid cross-contamination. A field log records the time of collection, preservation steps taken, cooler temperature, and expected delivery time. Samples were transported under controlled conditions to the laboratory.

Laboratory Analysis

Analytical Methods, the physical parameters, including pH, turbidity, electrical conductivity, and temperature, were measured using electrometric, nephelometric, and conductometric methods with calibrated digital meters and probes. Chemical parameters such as total dissolved solids (TDS), nitrates, sulphates, chlorides, phosphates, and heavy metals were analysed using gravimetric, spectrophotometric, titrimetric, and atomic absorption spectrophotometry (AAS) techniques. Biological parameters, including total coliforms, faecal coliforms, and heterotrophic bacteria, were assessed using the Most Probable Number (MPN), membrane filtration, and plate count methods, employing incubators, filtration units, and colony counters. This methodological framework ensures that each parameter is tested using the most appropriate and reliable technique, with specialised equipment suited to environmental water analysis.

Field measurements were carried out using portable in situ meters, notably the Jenway Model 430 and Hanna HI 9835, which are designed for real-time monitoring of parameters prone to rapid fluctuations. Representative water samples were collected directly from the source and placed in clean 50 mL beakers to minimise external contamination. The probes of the in-situ meters were carefully immersed to record pH, temperature, electrical conductivity (EC), and total suspended solids (TSS).

Chloride (Cl⁻) in Water Samples

The concentration of chloride ions was determined using the Argentometric method (APHA 4500-Cl⁻ B). In this titrimetric procedure, the water sample, adjusted to a neutral or slightly alkaline condition, was treated with potassium chromate indicator. Titration was then performed using a standardised silver nitrate (AgNO₃) solution. Chloride ions precipitated as silver chloride (AgCl), and the endpoint was indicated by the formation of red silver chromate.

The chloride concentration (mg/L) was calculated using the formula:

$$Cl^{-} (mg/L) = \frac{(A-B) \times N \times 35.45}{\text{Sample Volume (mL)}}$$

Where:

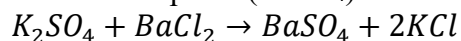
A = volume of AgNO₃ used for sample titration (mL)

B = volume of AgNO₃ used for blank titration (mL)

N = normality of AgNO₃ solution

Sulphate (SO₄²⁻) in Water Samples

Sulphate concentrations were analysed using the Turbidimetric method (APHA 4500-SO₄²⁻ E). In this procedure, sulphate ions were precipitated in an acetic acid medium by adding barium chloride (BaCl₂), forming fine crystals of barium sulphate (BaSO₄):



The resulting suspension was measured photometrically at 420 nm using a UV-Visible spectrophotometer. The degree of turbidity was directly proportional to the sulphate concentration, allowing precise quantification. Sulphate levels are critical for assessing both geogenic influences and anthropogenic inputs such as industrial effluents in Rivers State aquifers.

Cations in Water Samples

Major cations (Na^+ , K^+ , Ca^{2+} , Mg^{2+}) were determined using a GBC Avanta Atomic Absorption Spectrophotometer (AAS), following APHA and ASTM standard procedures (APHA 3111B/D; ASTM D3561). Calibration curves were prepared using standard solutions, and sample concentrations extrapolated accordingly.

The cation concentration was calculated using:

$$\text{Cation (mg/L)} = C \times YX$$

Where:

C = concentration obtained from calibration curve (mg/L)

Y = final volume of solution prepared (mL)

X = volume of water sample analysed (mL)

Heavy Metals in Water Samples

Heavy metals, including Pb, Cd, Zn, Cu, Ni, Fe, and Cr, were quantified using the GBC Avanta AAS, adhering to APHA protocols (APHA 3111B for Pb, Cd, Zn, Cu, Ni, Fe; APHA 3111C for Cr). Calibration was performed with certified standard solutions, and concentrations were derived using the same formula applied for cations:

$$\text{Metal (mg/L)} = C \times YX$$

Microbiological Analysis in Water Samples

The Multiple Tube Fermentation (Most Probable Number, MPN) method was employed following APHA Standard 9221B. Water samples were inoculated into a series of lactose broth tubes and incubated at 35–37°C for 24–48 hours. Gas production and colour change indicated coliform presence. Confirmatory tests for faecal coliforms and *E. coli* were conducted using Eosin Methylene Blue (EMB) agar and incubation at 44.5°C. Colonies with a characteristic metallic sheen were identified as *E. coli*. Results were expressed as MPN/100 mL.

Water Quality Index (WQI)

A composite WQI examined multiple parameters into a single score for each sampling point to facilitate ranking and communication. For each parameter i , a quality rating Qi was calculated as:

$$Qi = \frac{(Vi - V_{ideal})}{(Si - V_{ideal})} \times 100$$

where Vi is the measured value, V_{ideal} is the ideal value (commonly 0 for many contaminants; 7.0 for pH), and Si is the guideline value (WHO/Nigerian standard). Each parameter was assigned a weight Wi reflecting its relative importance to drinking-water safety. The aggregated WQI was computed as:

$$WQI = \frac{\sum_{i=1}^n W_i \cdot Q_i}{\sum_{i=1}^n W_i}$$

WQI scores were classified into standard categories (for example, excellent, good, poor, very poor, unsuitable) to prioritise sites for intervention.

Results and Discussion

Physical Characteristics of Groundwater

Table 4.1 presents the physical parameters for the six sampling points in Tombia community (ST7T–ST12T), along with the WHO and NSDWQ permissible limits.

Table 4.1: Physical Parameters of Groundwater in Tombia Community

Parameter	ST7	ST8	ST9	ST10	ST11	ST12	WHO Limit	NSDWQ Limit
pH	7.29	7.28	7.41	7.36	7.37	7.27	6.5–8.5	6.5–8.5
Temperature (°C)	27.6	27.6	27.6	27.6	27.5	27.9	-	-
Turbidity (NTU)	0.54	0.49	0.59	1.93	0.93	0.56	5.0	5.0
Conductivity (µS/cm)	76	116	413	107	665	589	-	-
Salinity (%)	0.04	0.06	0.23	0.06	0.38	0.33	-	-
TDS (mg/L)	53.2	81.2	289.1	74.9	465.5	412.3	500	500

In Tombia community, the pH values ranged from 7.27 to 7.41, with a mean of 7.33. The highest pH (7.41) was recorded at ST9 MP1T, while the lowest (7.27) was recorded at ST12 TAP4T. All pH values were within the WHO and NSDWQ permissible limits of 6.5–8.5. The near-neutral pH conditions observed across all Tombia samples are favourable for drinking water quality.

Temperature measurements in Tombia ranged from 27.5°C to 27.9°C, with a mean of 27.6°C. The temperatures were stable across all sampling points, with only a 0.4°C variation. The highest temperature (27.9°C) was recorded at ST12 TAP4T, while the lowest (27.5°C) was recorded at ST11 WELL7T. These values are consistent with the ambient groundwater temperatures typical of the Niger Delta region and are within acceptable limits for drinking water.

Turbidity values in Tombia ranged from 0.49 NTU to 1.93 NTU, with a mean of 0.84 NTU. All samples in Tombia were within the WHO and NSDWQ limit of 5 NTU, indicating that the groundwater is clear and free from excessive suspended solids. The highest turbidity (1.93 NTU) was recorded at ST10 WELL6T, while the lowest (0.49 NTU) was recorded at ST8 TAP3T. The consistently low turbidity across all Tombia samples suggests that the groundwater sources are generally well-protected from surface runoff and sediment intrusion.

Electrical conductivity in Tombia showed considerable variation, ranging from 76 $\mu\text{S}/\text{cm}$ to 665 $\mu\text{S}/\text{cm}$, with a mean of 327.7 $\mu\text{S}/\text{cm}$. The highest EC values were recorded at ST11 WELL7T (665 $\mu\text{S}/\text{cm}$) and ST12 TAP4T (589 $\mu\text{S}/\text{cm}$), both of which are notably higher than the other sampling points in Tombia. These elevated EC values suggest higher dissolved ion concentrations in these specific locations, possibly due to saltwater intrusion or mineral dissolution. The lowest EC was recorded at ST7 WELL TAP2T (76 $\mu\text{S}/\text{cm}$), indicating that the water at this site has a very low ionic content. Salinity in Tombia ranged from 0.04% to 0.38%, with a mean of 0.18%. The highest salinity was recorded at ST11 WELL7T (0.38%), followed by ST12 TAP4T (0.33%) and ST9 MP1T (0.23%). These elevated salinity levels correspond with the high EC values observed at the same locations. The relatively high salinity at ST11 and ST12 may be indicative of saltwater influence, which is plausible given Tombia's proximity to tidal creeks and its location within the deltaic environment. The lowest salinity (0.04%) was recorded at ST7 TAP2T. Total dissolved solids in Tombia ranged from 53.2 mg/L to 465.5 mg/L, with a mean of 229.4 mg/L. All TDS values were below the WHO and NSDWQ limit of 500 mg/L. The highest TDS (465.5 mg/L) was recorded at ST11 WELL7T, which is close to the permissible limit, while the lowest (53.2 mg/L) was recorded at ST7 TAP2T. The elevated TDS at ST11 and ST12, which are the only samples approaching the regulatory limit, suggest that these specific groundwater sources have higher dissolved solids content. This observation is consistent with the high EC and salinity values at these locations, pointing to the influence of saline water or mineral-rich geological formations in these aquifer systems. The remaining samples in Tombia had TDS values well below 300 mg/L, indicating good to excellent water quality.

Chemical Parameters in Tombia Community

Table 4.2 presents the chemical parameters for the six sampling points in Tombia community (ST7T–ST12T), along with the WHO and NSDWQ permissible limits.

Table 4.2: Chemical Parameters of Groundwater in Tombia Community

Parameter	ST7	ST8	ST9	ST10	ST11	ST12	WHO Limit	NSDWQ Limit
Chloride as Cl^- (mg/L)	9.8	15.8	54.3	14.8	79.0	64.2	250	250
Total Hardness (mg/L as CaCO_3)	20.6	21.9	71.0	40.0	113.2	96.7	500	150
Magnesium as Mg^{2+} (mg/L)	0.372	0.667	3.324	0.412	4.251	4.893	-	0.20
Manganese as Mn^{2+} (mg/L)	0.041	0.078	0.011	0.007	0.011	0.119	0.08	0.05
Iron as $\text{Fe}^{2+}/^{3+}$ (mg/L)	0.070	0.073	0.070	0.067	0.067	0.075	0.30	0.30
T.Alk (mg/L as CaCO_3)	2	4	8	6	8	8	-	-

Nitrate as NO₃⁻ (mg/L)	1.40	1.86	3.46	0.66	4.02	6.20	50	10
Sulphate as SO₄²⁻ (mg/L)	5.02	5.74	12.59	7.49	11.96	20.71	250	100
Phosphate as PO₄³⁻ (mg/L)	<0.05	<0.05	<0.5	<0.05	<0.05	<0.05	-	-
Calcium as Ca²⁺ (mg/L)	7.68	7.68	23.04	15.36	38.40	30.72	-	-
Bicarbonate (mg/L)	63.0	59.9	61.0	108.5	60.0	30.0	-	-
Potassium (mg/L)	1.411	6.259	2.973	1.090	0.527	0.466	-	-

Chloride concentrations in Tombia ranged from 9.8 mg/L to 79.0 mg/L, with a mean of 39.7 mg/L. The highest chloride level was recorded at ST11 WELL7T (79.0 mg/L), followed by ST12 TAP4T (64.2 mg/L) and ST9 MP1T (54.3 mg/L). The lowest chloride concentration was observed at ST7 WELL TAP2T (9.8 mg/L). All chloride values were within the WHO and NSDWQ limit of 250 mg/L. Sulphate concentrations in Tombia ranged from 5.02 mg/L to 20.71 mg/L, with a mean of 10.59 mg/L. The highest sulphate level was recorded at ST12 TAP4T (20.71 mg/L), followed by ST9 MP1T (12.59 mg/L) and ST11 WELL7T (11.96 mg/L). All values were far below the WHO limit of 250 mg/L and NSDWQ limit of 100 mg/L. The elevated sulphate at ST12, combined with the high chloride and TDS at this location, suggests the possible influence of groundwater recharge from sulphate-bearing minerals or tidal influence.

Nitrate concentrations in Tombia ranged from 0.66 mg/L to 6.20 mg/L, with a mean of 2.93 mg/L. The highest nitrate level was recorded at ST12 TAP4T (6.20 mg/L), followed by ST11 WELL7T (4.02 mg/L) and ST9 MP1T (3.46 mg/L). All values were well below the WHO and NSDWQ limits of 50 mg/L and 10 mg/L, respectively. Phosphate concentrations were consistently below the detection limit (<0.05 mg/L) across all Tombia samples, except ST9 (mono pump), which recorded <0.5 mg/L. The absence of detectable phosphate indicates minimal fertiliser or detergent contamination in Tombia groundwater. Bicarbonate concentrations in Tombia ranged from 30.0 mg/L to 108.5 mg/L, with a mean of 63.7 mg/L. The highest bicarbonate level was recorded at ST10 WELL6T (108.5 mg/L), while the lowest was at ST12 TAP4T (30.0 mg/L). Carbonate was <1 mg/L in all samples. The moderate to high bicarbonate levels indicate that carbonate mineral dissolution is an important geochemical process influencing Tombia groundwater chemistry. The elevated bicarbonate at ST10 may reflect the dissolution of calcite or dolomite in the aquifer materials. Calcium concentrations in Tombia ranged from 7.68 mg/L to 38.40 mg/L. The calcium levels contribute significantly to the total hardness observed in Tombia groundwater. Magnesium concentrations ranged from 0.372 mg/L to 4.893 mg/L, with a mean of 2.320 mg/L. The highest magnesium level was recorded at ST12 TAP4T (4.893 mg/L), followed by ST11 WELL7T (4.251 mg/L) and ST9 MP1T (3.324 mg/L). All six Tombia samples exceeded the NSDWQ guideline of 0.20 mg/L for magnesium. However, the WHO does not set a health-based guideline for magnesium, and these elevated levels reflect the natural geochemistry of the aquifer

rather than anthropogenic pollution. Potassium concentrations ranged from 0.466 mg/L to 6.259 mg/L, with a mean of 2.121 mg/L. The highest potassium level was recorded at ST8 TAP3T (6.259 mg/L), followed by ST9 MP1T (2.973 mg/L). Potassium is an essential nutrient and is not regulated in drinking water. Iron concentrations in Tombia ranged from 0.067 mg/L to 0.075 mg/L, with a mean of 0.070 mg/L. All Tombia samples were within the WHO and NSDWQ limits of 0.30 mg/L. The uniform and low iron levels across Tombia samples indicate that iron-bearing minerals are not readily dissolving into the groundwater at these locations. Manganese concentrations in Tombia ranged from 0.007 mg/L to 0.119 mg/L, with a mean of 0.044 mg/L. The WHO aesthetic guideline for manganese is 0.08 mg/L, while the NSDWQ sets a limit of 0.05 mg/L. One sample (ST12 TAP4T) exceeded both the WHO aesthetic guideline (0.119 mg/L) and the NSDWQ limit (0.119 mg/L). Two other samples approached the limits: ST8 TAP3T (0.078 mg/L) exceeded the NSDWQ limit of 0.05 mg/L but was slightly below the WHO aesthetic guideline of 0.08 mg/L; ST7 TAP2T (0.041 mg/L) was below both limits. The elevated manganese at ST12 TAP4T is a concern, as high manganese concentrations can cause aesthetic problems such as black staining of plumbing fixtures, unpleasant taste, and black discolouration of laundry. While manganese is not typically a health hazard at these concentrations, the aesthetic issues can reduce consumer acceptability of the water.

Total hardness (as CaCO_3) in Tombia ranged from 20.6 mg/L to 113.2 mg/L, with a mean of 60.6 mg/L. Based on water hardness classification:

- ST11 WELL7T (113.2 mg/L) and ST12 TAP4T (96.7 mg/L) fall into the moderately hard category.
- ST9 MP1T (71.0 mg/L) is on the boundary between moderately soft and moderately hard.
- ST10 WELL6T (40.0 mg/L) is classified as soft.
- ST7 WELL TAP2T (20.6 mg/L) and ST8 TAP3T (21.9 mg/L) are classified as very soft.

All hardness values were well below the WHO limit of 500 mg/L and the NSDWQ limit of 150 mg/L.

Alkalinity in Tombia ranged from 2 mg/L to 8 mg/L (as CaCO_3), with a mean of 6.0 mg/L. ST9 MP1T, ST11 WELL7T, and ST12 TAP4T recorded the highest alkalinity values (8 mg/L), which correspond with the higher hardness values at these locations, suggesting that carbonate minerals are a common source of both alkalinity and hardness in Tombia groundwater.

Biological Parameters in Tombia Community

Table 4.3 presents the biological parameters for the six sampling points in Tombia community (ST7T–ST12T), along with the WHO and NSDWQ permissible limits.

Table 4.3: Biological Parameters of Groundwater in Tombia Community

Parameter	ST7	ST8	ST9	ST10	ST11	ST12	WHO Limit	NSDWQ Limit
Total Coliform Bacteria (TCB)	Nil	Nil	Nil	Nil	Nil	Nil	0 per 100 mL	0 per 100 mL
Faecal Coliform Bacteria (FCB)	Nil	Nil	Nil	Nil	Nil	Nil	0 per 100 mL	0 per 100 mL
Total Bacteria (CFU/mL)	5.4	0.2	1.4	5.6	1.0	7.0	No specific guideline	No specific guideline
Heterotrophic (THB) ($\times 10^3$)								

Total coliform bacteria were absent (Nil) in all six samples collected from Tombia community. The absence of total coliforms across all Tombia samples indicates that the groundwater sources are not contaminated by faecal matter or surface runoff. This finding is particularly noteworthy given the elevated turbidity and chemical parameters observed at some Tombia sites (ST11, ST12), which might have been expected to correlate with microbial contamination. However, the absence of coliforms suggests that despite higher ionic content and possible saltwater influence, the well construction and protection measures in Tombia are effective in preventing the ingress of microbial pathogens. The zero-detection rate across all Tombia samples indicates that the community is not exposed to acute waterborne disease risks from microbial contamination.

Faecal coliform bacteria were also absent (Nil) in all six Tombia samples. The absence of *E. coli* confirms that the groundwater is free from recent faecal contamination and is microbiologically safe according to WHO and NSDWQ zero-tolerance standards. This result is consistent with the absence of total coliforms and indicates that the sanitation and wellhead protection practices in Tombia are effective in preventing microbial contamination. The high THB counts observed at some Tombia sites (ST7, ST10, ST12) are not associated with faecal contamination, as evidenced by the absence of coliforms, and likely reflect the presence of non-pathogenic environmental bacteria. Total heterotrophic bacteria counts in Tombia ranged from 0.2×10^3 CFU/mL to 7.0×10^3 CFU/mL, with a mean of 3.43×10^3 CFU/mL. The highest THB count was recorded at ST12 TAP4T (7.0×10^3 CFU/mL), followed by ST10 WELL6T (5.6×10^3 CFU/mL) and ST7 TAP2T (5.4×10^3 CFU/mL). The lowest count was observed at ST8 TAP3T (0.2×10^3 CFU/mL).

All Tombia samples exceeded 500 CFU/mL, except ST8 TAP3T, which recorded 0.2×10^3 CFU/mL (i.e., 200 CFU/mL), which is below the 500 CFU/mL threshold. Therefore, five out of six samples (83.3%) showed elevated THB counts. The highest THB count at ST12 TAP4T (7,000 CFU/mL) is noteworthy, as this sample also exhibited elevated chemical parameters (high EC, TDS, chloride, nitrate, sulphate, and manganese). The concurrence of high THB with high ionic content may indicate that the groundwater at this site contains more organic matter or nutrients, possibly from surface recharge or interaction with organic-rich sediments. However, the absence of coliforms confirms that the bacterial population is non-faecal in origin.

Comparison of Water Source Types

To further understand spatial variations, groundwater quality was compared between the two principal water source types: hand-dug wells and boreholes/taps. This comparison is important because hand-dug wells are generally shallower and more vulnerable to surface contamination, while boreholes are deeper and typically better protected. Table 4.4 presents the mean values for selected parameters across the two source types.

Parameters Higher in Hand-dug Wells

Hand-dug wells exhibited higher turbidity, EC, TDS, salinity, total hardness, and iron compared to boreholes and taps.

Turbidity was notably higher in hand-dug wells (mean: 4.47 NTU) compared to boreholes (mean: 1.16 NTU). This substantial difference (more than three times higher) is consistent with the shallower depth and less protective lining of hand-dug wells, which makes them more vulnerable to surface runoff, sediment intrusion, and the infiltration of suspended particles. The exceptionally high turbidity at ST3 WELL 3B (24.4 NTU) in Bukuma is a key contributor to this trend. The elevated turbidity in hand-dug wells is a concern, as it not only affects the aesthetic quality of water but can also shield pathogenic microorganisms from disinfection and may indicate poor well construction or inadequate wellhead protection.

Table 4.4: Comparison of Parameters by Water Source Type

Parameter (Unit)	Hand-dug Wells (n=7) Mean $\pm$ SD	Boreholes/Taps (n=5) Mean $\pm$ SD	Difference
pH	7.40 $\pm$ 0.16	7.35 $\pm$ 0.06	+0.05 (similar)
Temperature (°C)	27.64 $\pm$ 0.09	27.66 $\pm$ 0.15	-0.02 (similar)
Turbidity (NTU)	4.47 $\pm$ 8.56	1.16 $\pm$ 0.81	+3.31 (higher in wells)
EC (μS/cm)	285.0 $\pm$ 194.0	228.6 $\pm$ 221.5	+56.4 (higher in wells)
Salinity (%)	0.17 $\pm$ 0.12	0.14 $\pm$ 0.14	+0.03 (higher in wells)
TDS (mg/L)	199.5 $\pm$ 135.8	160.0 $\pm$ 155.1	+39.5 (higher in wells)
Chloride (mg/L)	32.1 $\pm$ 24.3	31.0 $\pm$ 23.4	+1.1 (similar)
Total Hardness (mg/L)	55.2 $\pm$ 28.4	49.1 $\pm$ 33.1	+6.1 (higher in wells)

Magnesium (mg/L)	1.32 ± 1.31	2.24 ± 2.35	-0.92 (higher in boreholes)
Iron (mg/L)	0.202 ± 0.378	0.050 ± 0.017	+0.152 (higher in wells)
Manganese (mg/L)	0.015 ± 0.012	0.047 ± 0.052	-0.032 (higher in boreholes)
Nitrate (mg/L)	1.56 ± 1.26	2.25 ± 2.27	-0.69 (higher in boreholes)
Sulphate (mg/L)	6.67 ± 2.72	10.25 ± 6.70	-3.58 (higher in boreholes)
Calcium (mg/L)	17.88 ± 8.78	18.20 ± 12.14	-0.32 (similar)
THB (×10³ CFU/mL)	2.26 ± 1.35	3.58 ± 2.89	-1.32 (higher in boreholes)

Iron was also higher in hand-dug wells (mean: 0.202 mg/L) compared to boreholes (mean: 0.050 mg/L). The elevated iron in hand-dug wells may be attributed to the dissolution of iron-bearing minerals under reducing conditions in shallow aquifers. Elevated iron is undesirable for aesthetic reasons, causing a metallic taste and staining of laundry and plumbing fixtures. EC, TDS, and total hardness were also moderately higher in hand-dug wells. The higher EC and TDS suggest that hand-dug wells may be more influenced by mineral dissolution and the concentration of dissolved ions, possibly due to their shallower depth and greater interaction with near-surface sediments. The higher hardness reflects the elevated calcium and magnesium concentrations typically found in hand-dug wells, which are more influenced by carbonate mineral dissolution from near-surface geological formations.

Parameters Higher in Boreholes/Taps

Boreholes and taps exhibited higher magnesium, manganese, nitrate, sulphate, and THB compared to hand-dug wells. Nitrate was higher in boreholes (mean: 2.25 mg/L) compared to hand-dug wells (mean: 1.56 mg/L). This difference may reflect the fact that boreholes tap deeper aquifers that may be more influenced by regional groundwater flow patterns, which can transport nitrate from agricultural activities or domestic waste over longer distances. Alternatively, the lower nitrate in hand-dug wells may be attributed to denitrification processes occurring in the shallow, reducing environment of the near-surface aquifer. Despite the difference, nitrate levels in both source types are well below WHO and NSDWQ limits. Sulphate was notably higher in boreholes (mean: 10.25 mg/L) compared to hand-dug wells (mean: 6.67 mg/L). The elevated sulphate in boreholes may reflect the dissolution of sulphate-bearing minerals (such as gypsum) present in deeper geological formations, or the influence of groundwater recharge from sulphate-rich surface waters. The higher sulphate at ST12 TAP4T (20.71 mg/L) in Tombia contributes significantly to this trend.

Magnesium and manganese were also higher in boreholes. The higher magnesium (2.24 mg/L in boreholes versus 1.32 mg/L in hand-dug wells) may reflect the dissolution of magnesium-bearing

minerals (such as dolomite) at greater depths. The higher manganese in boreholes (0.047 mg/L versus 0.015 mg/L in hand-dug wells) is driven by the elevated manganese at ST12 TAP4T (0.119 mg/L), which is a borehole/tap in Tombia. Manganese dissolution is influenced by redox conditions, and deeper aquifers may have conditions favourable for the mobilisation of manganese from the aquifer matrix.

Total heterotrophic bacteria were higher in boreholes (mean: 3.58×10^3 CFU/mL) compared to hand-dug wells (mean: 2.26×10^3 CFU/mL). This difference may reflect the presence of more stable nutrient conditions in deeper aquifers, where bacterial populations can establish more consistent communities. However, both source types exhibited elevated THB counts, and the difference is not substantial.

WQI Values and Classification

Table 4.5 presents the computed WQI values and their corresponding classifications for all twelve sampling points, categorised by community. The results reveal a broad range of water quality, from excellent to unsuitable, with the majority of samples falling into the excellent category.

Table 4.5: WQI Values and Classification by Sampling Point

Community	Sample ID	WQI Value	Classification
Tombia	ST8 TAP3T	21.10	Excellent
	ST9 MP1T	19.05	Excellent
	ST10 WELL6T	15.16	Excellent
	ST11 WELL7T	24.49	Excellent
	ST12 TAP4T	38.01	Good

No sample fell into the Poor or Very Poor categories, indicating that groundwater quality in the community is generally good to excellent.

Physical Characteristics of Groundwater

The physical parameters of groundwater provide fundamental insights into its overall quality, aesthetic acceptability, and potential contamination pathways. In this study, the physical parameters assessed included pH, temperature, turbidity, electrical conductivity (EC), salinity, and total dissolved solids (TDS). The results obtained revealed significant spatial variations, with several parameters showing notable deviations from WHO and NSDWQ permissible limits.

The pH values recorded ranged from 7.27 to 7.72, with a mean of 7.37. All samples fell within the WHO (6.5–8.5) and NSDWQ (6.5–8.5) permissible limits, indicating that groundwater is neither acidic nor excessively alkaline. This near-neutral to slightly alkaline condition is favourable for drinking water, as it minimises the risk of corrosion in plumbing systems and does not pose immediate health concerns.

The findings are consistent with those of Ejechi et al. (2007), who reported slightly acidic pH values (mean 6.04 during dry season and 6.43 during wet season) in hand-dug wells from oil-producing areas of the Niger Delta, attributing the acidity to emissions from gas flaring and

petroleum refining activities. The higher pH values observed in the present study suggest that the aquifers in Tombia may be better buffered against acidification, possibly due to the dissolution of carbonate minerals in the aquifer materials. Rim-Rukeh et al. (2007) reported pH ranges of 5.7 to 6.8 in hand-dug well water from the Niger Delta, which are lower than the values recorded in this study, further highlighting the variability in groundwater pH across different locations within the region. Temperature measurements ranged from 27.5°C to 27.9°C, with a mean of 27.6°C. These temperatures are consistent with the tropical climate of the Niger Delta and fall within the ranges reported by Rim-Rukeh et al. (2007), who documented temperatures of 26–30°C in hand-dug wells and 26.9–28.6°C in river water samples from the region. The stability of groundwater temperatures across all sampling points reflects the consistent thermal conditions of shallow aquifers, which are influenced by the ambient air temperature and the insulating properties of the overlying soil layers. The narrow temperature range observed (0.4°C difference) suggests that the sampled groundwater sources are of similar depth and are not significantly affected by surface heat exchange or geothermal anomalies. Turbidity in Tombia samples were within the permissible limit, with turbidity values ranging from 0.49 to 1.93 NTU. A regional study in the Cross-River Basin and Niger Delta reported mean turbidity values of 21.02 NTU for hand-dug wells and 15.97 NTU for boreholes, confirming that elevated turbidity is a common issue in shallow groundwater sources across the delta (Edet, 2014). Electrical conductivity values ranged from 76 $\mu\text{S}/\text{cm}$ to 665 $\mu\text{S}/\text{cm}$, with significantly higher mean values in Tombia (327.7 $\mu\text{S}/\text{cm}$). The highest EC values were recorded at ST11 WELL7T (665 $\mu\text{S}/\text{cm}$) and ST12 TAP4T (589 $\mu\text{S}/\text{cm}$) in Tombia, indicating higher concentrations of dissolved ions at these locations. These values are comparable to those reported by Oki and Akana (2016), who found EC values ranging from 201 to 950 $\mu\text{S}/\text{cm}$ for shallow well water and 670 to 1650 $\mu\text{S}/\text{cm}$ for borehole water in Yenagoa, Niger Delta. The elevated EC in Tombia suggests greater mineral dissolution or the influence of saltwater intrusion, which is consistent with the community's proximity to tidal creeks and its location within the deltaic environment. Studies have shown that saltwater intrusion affects approximately 30% of coastal aquifers in the Niger Delta, driven by factors such as overexploitation of groundwater, unregulated borehole drilling, and climatic impacts, including rising sea levels and increased tidal fluctuations (Eyankware et al., 2025). The elevated EC at ST11 and ST12 may therefore be an early indicator of saline influence in these specific locations.

Total dissolved solids followed a similar spatial pattern to EC, ranging from 53.2 mg/L to 465.5 mg/L. All samples were within the WHO and NSDWQ limit of 500 mg/L, indicating that the groundwater is generally fresh and suitable for drinking. These values are consistent with those reported in other Niger Delta studies. For instance, a study in the Somebreiro-Warri plain sand of Ughelli reported TDS values of 120 mg/L (Akpoborie & Atakpo, 2023), while research in Obomkpa, western Niger Delta, found a mean TDS of 28.62 mg/L in surface water. The high TDS in Tombia, particularly at ST11 and ST12, suggests that these aquifers are more influenced by mineral dissolution or saline water mixing, which warrants continued monitoring to prevent future deterioration of water quality.

The highest salinity was recorded at ST11 WELL7T (0.38%) and ST12 TAP4T (0.33%) in Tombia, which corresponds with the elevated EC and chloride at these locations. While these salinity values are relatively low, they indicate the presence of dissolved salts in the groundwater, which may be attributed to the proximity of these communities to tidal creeks and estuarine environments. Eyankware et al. (2025) documented that saline intrusion in Niger Delta coastal aquifers is a critical environmental challenge, significantly jeopardising freshwater resources

essential for drinking, agriculture, and industrial use. The slightly elevated salinity at ST11 and ST12 may therefore be an early warning sign of saltwater encroachment, which could escalate if groundwater abstraction rates increase or if sea-level rise continues.

Chemical Composition of Groundwater

The chemical composition of groundwater provides critical insights into the underlying hydrogeochemical processes, the influence of aquifer geology, and the potential sources of contamination affecting water quality. In this study, the chemical parameters assessed included major ions (chloride, sulphate, nitrate, phosphate, bicarbonate, calcium, magnesium, and potassium), total hardness, alkalinity, and heavy metals (iron and manganese). The results revealed notable spatial variations with several parameters showing distinct patterns that reflect both natural geogenic influences and anthropogenic activities. Chloride concentrations in all samples were well within the WHO and NSDWQ permissible limit of 250 mg/L. The elevated chloride levels in Tombia, particularly at ST11 WELL7T (79.0 mg/L) and ST12 TAP4T (64.2 mg/L), suggest the influence of saltwater intrusion or tidal activity. These findings are consistent with studies conducted across the Niger Delta, where chloride concentrations have been documented to vary widely. Ngah (2020) reported chloride values ranging from 5.6 to 710 mg/L in deep aquifer systems of the Niger Delta, with 18% of samples exceeding 250 mg/L, particularly in coastal areas and parts of Port Harcourt bordering saltwater creeks and tidal channels. Similarly, a hydrochemical assessment of borehole water in Effurun, Delta State, found that chloride levels varied widely, indicating potential contamination from seawater intrusion or industrial discharge (Tope et al., 2025). The chloride levels in Tombia are therefore consistent with the community's proximity to tidal creeks and its location within the deltaic environment, where saltwater intrusion is a recognised threat to freshwater aquifers. The sulphate at ST12 TAP4T (20.71 mg/L) and ST11 WELL7T (11.96 mg/L) in Tombia may reflect the dissolution of sulphate-bearing minerals such as gypsum, or the influence of surface water recharge carrying dissolved sulphates. Ojo et al. (2025) reported elevated sulphate concentrations in borehole water from Effurun, Delta State, pointing to agricultural runoff as a potential source. The relatively low sulphate levels observed suggest that sulphate minerals are not significantly contributing to groundwater chemistry, and there is minimal industrial or agricultural sulphate pollution in the study areas.

Nitrate concentrations in all samples were well below the WHO limit of 50 mg/L and the NSDWQ limit of 10 mg/L. The elevated nitrate at ST12 TAP4T (6.20 mg/L) and ST11 WELL7T (4.02 mg/L) in Tombia suggests slightly greater anthropogenic influence, possibly from agricultural runoff, pit latrines, or domestic waste infiltration. Research in the eastern Niger Delta has shown that the region is a hotspot for reactive nitrogen pollution due to extensive animal husbandry, pit latrine usage, and agricultural practices, with groundwater nitrate concentrations highly variable and some areas recording values well above the safe drinking water threshold of 50 mg/L (Aleku et al., 2024). Willabo (2026) similarly found that nitrate levels in Yenagoa approached the permissible threshold of 50 mg/L, linking elevated nitrate to land use practices such as soak pits, dumpsites, and runoff. The relatively low nitrate levels in the present study indicate that while there is some anthropogenic influence, particularly in Tombia, the risk of methemoglobinemia ("blue baby syndrome") is minimal. The absence of detectable phosphate across all samples further supports the conclusion that agricultural fertiliser runoff and detergent contamination are not significant issues in these communities. The moderate to high bicarbonate levels suggest that carbonate mineral dissolution (calcite and dolomite) is an important geochemical process influencing groundwater chemistry in both communities. Hydrogeochemical assessments of

groundwater in the Niger Delta have identified (Ca-Mg-HCO₃) dominance from carbonate weathering via rock-water interaction as a primary hydrochemical process (Gbadebo et al., 2026). Total hardness (as CaCO₃) in all samples were well below the WHO limit of 500 mg/L and the NSDWQ limit of 150 mg/L. Based on water hardness classification, the groundwater ranges from very soft to moderately hard, with ST11 WELL7T (113.2 mg/L) and ST12 TAP4T (96.7 mg/L) in Tombia falling into the moderately hard category. These hardness values are consistent with those reported in other Niger Delta studies. A study on groundwater in gas flare environments in Rivers State reported a mean total hardness of 44.51 mg/L while research in Egi clan, Rivers State, found similar ranges of total hardness in hand-dug wells (Elemile et al., 2025). The higher hardness in Tombia reflects the elevated calcium and magnesium concentrations in that community, which are derived from carbonate mineral dissolution in the aquifer.

Calcium concentrations exceeded the NSDWQ guideline of 0.20 mg/L for magnesium. However, the WHO does not set a health-based guideline for magnesium, as it is an essential nutrient, and these elevated levels reflect the geogenic nature of the aquifer materials (likely dolomitic or magnesium-rich sediments). Ojo et al. (2025) reported calcium levels ranging from 29.95 mg/L to 64.50 mg/L and magnesium levels ranging from 9.50 mg/L to 14.20 mg/L in borehole water from Effurun, Delta State, which are higher than the values observed in the present study. The lower calcium and magnesium concentrations suggest that the aquifers in these communities are less influenced by carbonate mineral dissolution compared to other parts of the Niger Delta.

Biological Quality of Groundwater

The biological quality of groundwater is a critical determinant of its safety for human consumption, as microbial contamination constitutes one of the most immediate and severe public health risks associated with drinking water. In this study, the biological parameters assessed included total coliform bacteria, faecal coliform bacteria (indicative of *Escherichia coli*), and total heterotrophic bacteria. The results revealed a remarkable finding: total coliform and faecal coliform bacteria were completely absent (Nil) in all samples. This absence of indicator organisms signifies that the groundwater sources in both communities are free from faecal contamination and meet the WHO and NSDWQ zero-tolerance standards for coliform bacteria in drinking water.

The absence of coliforms in this study contrasts with widespread groundwater contamination reported across Nigeria, particularly in the Niger Delta. For instance, Amadi et al. (2024) found that groundwater in Rumuigbo, Obio-Akpor, contained *Proteus*, *Bacillus*, *Micrococcus*, *Pseudomonas*, *Salmonella*, *Erythrobacter*, and *Klebsiella*, failing potable standards. Similarly, Ojukwu and Udom (2022) identified *Escherichia coli*, *Vibrio*, and *Salmonella* in Okrika, with *Bacillus* being the most frequently isolated genus, raising risks of waterborne diseases. In Imiringi Town, Seiyaboh et al. (2020) reported prevalence rates of *Staphylococcus* (40.75%), *E. coli* (20.75%), *Pseudomonas* (12.00%), and *Salmonella* (2.25%). Elemile et al. (2023) found total coliform counts of 0.78–75 CFU/100 mL in southern Nigeria, exceeding WHO limits. In Offa, Oyewale et al. (2025) revealed that wells were more contaminated than boreholes, with total coliforms in 4 of 5 wells versus 1 of 5 boreholes.

The absence of coliform bacteria in the present study suggests that the boreholes and hand-dug wells are adequately constructed, properly sited, and sufficiently protected from surface contamination sources such as pit latrines, refuse dumps, and surface runoff. The absence of coliforms despite elevated turbidity indicates that the turbidity at these sites is primarily caused by inorganic suspended solids (sediment) rather than microbial contaminants. This observation is consistent with the findings of Oyewale et al. (2025) in Offa, Kwara State, who reported that

boreholes showed better compliance with bacteriological standards compared to hand-dug wells, largely due to better construction and protection. The effectiveness of wellhead protection measures in the study communities is further supported by the fact that even hand-dug wells, which are generally more vulnerable to contamination than boreholes, tested negative for coliforms.

While there is no specific WHO or NSDWQ guideline for total heterotrophic bacteria in drinking water, counts above 500 CFU/mL are generally considered indicative of elevated bacterial populations that may affect the aesthetic quality of water and suggest the presence of nutrients and organic matter that can support bacterial growth. The THB ranges observed in this study are comparable to those reported in other Nigerian studies. Amadi et al. (2024) reported THB populations ranging from 1.8×10^2 to 3.4×10^2 CFU/mL in groundwater from Rumuigbo, Rivers State, which are lower than the values recorded in the present study. However, a study in Amawom Ikwuano, Abia State, reported total heterotrophic bacteria counts ranging from 2.5×10^3 to 8.1×10^3 CFU/mL, which are consistent with the upper ranges observed in Tombia. Research in Imiringi Town, Bayelsa State, documented even higher THB densities ranging from 2.97×10^4 to 6.03×10^4 CFU/mL, indicating that the THB levels in the present study are moderate by regional standards. The presence of elevated heterotrophic bacteria in the absence of coliforms indicates that the bacterial populations are non-faecal in origin and consist of naturally occurring environmental bacteria that are ubiquitous in soil and groundwater. These bacteria are not typically pathogenic but can affect the taste and odour of water and may contribute to biofilm formation in storage containers and plumbing systems. The higher THB counts at some sites, particularly ST12 TAP4T (7.0×10^3 CFU/mL) and ST10 WELL6T (5.6×10^3 CFU/mL) in Tombia, may be associated with higher organic content or nutrient availability in those aquifers, which is consistent with the elevated chemical parameters (EC, TDS, chloride, nitrate) observed at these same locations. While the current results provide a robust baseline, regular microbiological surveillance remains essential to detect any future deterioration in water quality. The findings of this study confirm that groundwater in Tombia is microbiologically safe with respect to faecal contamination. Studies have shown that saltwater intrusion is indicated by general increases in chloride and decreases in bicarbonate content towards the coast. The encroachment of saltwater into freshwater aquifers has been observed to produce total dissolved solids, electrical conductivity, and chloride values in excess of 500 mg/L, 1000 μ S/cm, and 250 mg/L, respectively (Amadi et al., 2012).

Conclusion

This study has shown that the physicochemical parameters are all within limits, no faecal contamination and excellent water quality. There was evidence of salt water intrusion at some stations. Based on the findings of this study, it is recommended that comprehensive groundwater monitoring programme should be established in the community to track seasonal and long-term changes in water quality.

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