GEOSPATIAL ANALYSIS OF GROUNDWATER QUALITY VARIATION FOR DOMESTIC USE IN GOMBE METROPOLIS, NIGERIA

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Abstract
Groundwater remains a vital resource for domestic use in rapidly urbanizing environments such as Gombe Metropolis, Nigeria, yet its quality is increasingly threatened by human activities and poor waste management. This study investigates the spatial variability of groundwater quality for domestic use in Gombe Metropolis, Nigeria, using a geospatial approach. This study assessed groundwater suitability by comparing physicochemical and microbiological parameters with World Health Organization (WHO) and Nigerian Standard for Drinking Water Quality (NSDWQ) guidelines. A multistage random sampling technique was adopted to select 42 groundwater samples across 14 wards across Gombe, Akko, Kwami, and Yamaltu-Deba LGAs. Water samples were analyzed for temperature, pH, electrical conductivity (EC), total dissolved solids (TDS), major cations (Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}), anions (Cl^{-}, NO_3^{-}, SO_4^{2-}, PO_4^{3-}, HCO_3^{-}, F^{-}), heavy metals (Pb, As, Cu, Fe), and microbial indicators (total coliforms, E. coli), using standard laboratory procedures including Atomic Absorption Spectrophotometry (AAS). Spatial analysis and kriging interpolation in ArcGIS were employed to generate geospatial distribution maps, while inferential statistics such as ANOVA and T-tests assessed parameter variation. Findings revealed significant spatial disparities in water quality. Notably, high nitrate (32.23 mg/L) and arsenic (0.40 mg/L) concentrations were detected in Barunde and Jeka da fari respectively, while Shamaki and Ajiya showed elevated EC (1348.63 µS/cm) and TDS (239.22 mg/L) levels. Microbiological contamination was highest in Jeka da fari and Nasarawo. Kriging maps revealed hot spots of chemical and microbial contamination primarily in urbanized wards, indicating anthropogenic influence. Conversely, Liji and GRA exhibited relatively low contaminant concentrations, suggesting minimal pollution. The study recommends routine groundwater monitoring, improved urban waste management, community education on sanitation, and targeted treatment technologies to ensure safe drinking water. This integrated geospatial framework provides an essential tool for water quality management and sustainable planning in fast-growing urban centres.

Keywords: *Groundwater quality, GIS, domestic use, kriging, Gombe, Nigeria.*

INTRODUCTION

Groundwater is a vital freshwater resource that supports domestic, agricultural, and industrial activities worldwide. It accounts for approximately one-third of the global drinking water supply and remains a primary source of potable water in both urban and rural areas (Nickson et al., 2005; Ocheri, Odoma, & Umar, 2014). Despite its perceived natural protection through subsurface filtration, groundwater is increasingly vulnerable to contamination from anthropogenic activities, such as urbanization, agricultural runoff, industrial discharge, and inadequate waste disposal systems (Postigo et al., 2018; Ponniah, Chandrasekar, & Saravanan, 2012). These threats pose significant risks to public health, particularly in densely populated areas with inadequate sanitation and water infrastructure (Raju, Shukla, & Ram, 2011).

In Africa, and particularly in arid and semi-arid regions, groundwater serves as the principal source of drinking water due to limited or polluted surface water. Communities often rely on wells and boreholes, which are frequently susceptible to contamination from septic tanks, agrochemicals, and industrial effluents (UNICEF, 2013; Yang et al., 2024). Ensuring safe groundwater quality is therefore critical to achieving Sustainable Development Goal 6 (SDG 6), which promotes access to clean water and sanitation for all (United Nations Department of Economic and Social Affairs, 2020).

In Nigeria, groundwater contamination has become a pressing concern in urban areas, where rapid population growth and unregulated land use exacerbate environmental challenges. Gombe Metropolis, the capital of Gombe State in northeastern Nigeria, exemplifies this trend. Its strategic location and relative stability amid regional insecurity have led to rapid urbanization, resulting in increased reliance on groundwater for domestic use. However, groundwater in Gombe is threatened by contamination from leachates, waste dumps, poorly constructed boreholes, and inadequate sanitation infrastructure (Sabo & Abubakar, 2013; Lapworth et al., 2023; Mbae et al., 2024).

Despite its importance, the spatial variation of groundwater quality in Gombe Metropolis remains poorly understood, limiting the effectiveness of water resource management and public health planning (Adnan & Iqbal, 2014). Most previous studies have overlooked spatial dynamics and failed to integrate Geographic Information Systems (GIS) and laboratory analysis. This study, therefore, employs a geospatial approach to analyze groundwater quality for domestic use in Gombe Metropolis. By integrating laboratory analysis of physicochemical and microbiological parameters with Geographic Information Systems (GIS), the study provides a spatially explicit assessment aligned with WHO and NSDWQ (2015) standards. The findings aim to support evidence-based interventions that protect public health and promote sustainable groundwater management (Crystal et al., 2024; Rajapakse, Otoo, & Danso, 2023).

MATERIALS AND METHODS

Study Area

Gombe Metropolis, situated in northeastern Nigeria, lies between latitudes 10°14'N and 10°19'N and longitudes 11°07'E and 11°12'E (Geodatos, 2024). It is bordered by Kwami LGA to the north, Akko LGA to the southwest, and Yamaltu Deba LGA to the east. The metropolis spans approximately 54 km² at an altitude of 500 meters above sea level (Gombe Master Plan 2003-2030, 2003; Maina et al., 2016). The geology and Hydrogeology are underlain by Cretaceous sandstone formations, overlain by tertiary and quaternary deposits. The hydrology is shaped by ephemeral streams and ravines, influenced by ferruginous soils derived from basement rock weathering (Amos et al., 2015; Hati et al., 2011). Hydrogeological conditions are governed by crystalline and sedimentary formations impacting groundwater availability (Sabo et al., 2013; Mayomi et al., 2016). Relief and Drainage, the elevation ranges from 330 to 721 meters, with conical hills from Late Cretaceous deposits. Gully erosion is a concern, altering groundwater recharge, particularly in high-susceptibility zones identified through GIS studies (Mayomi et al., 2018; Abashiya & Sule, 2024).

The climate and Soil fall within the Sudan Savannah zone, characterised by a wet season (April-October) and a dry season (November-March). August records the highest rainfall (264.78 mm), while March and April see peak temperatures of up to 35°C (Mbaya et al., 2017; Maina & Eziashi, 2015). Sandy soils promote infiltration, whereas clay soils restrict it, affecting groundwater recharge (Danladi & Ray, 2014; Mbaya et al., 2012). The Study area population grew from 169,894 in 1996 to 312,467 in 2006, with a projected 573,000 by 2024 (NPC, 2006). Economic activities include agriculture, commerce, and services, supporting the region's role as a commercial hub (Ahmad et al., 2018; Maina et al., 2006).

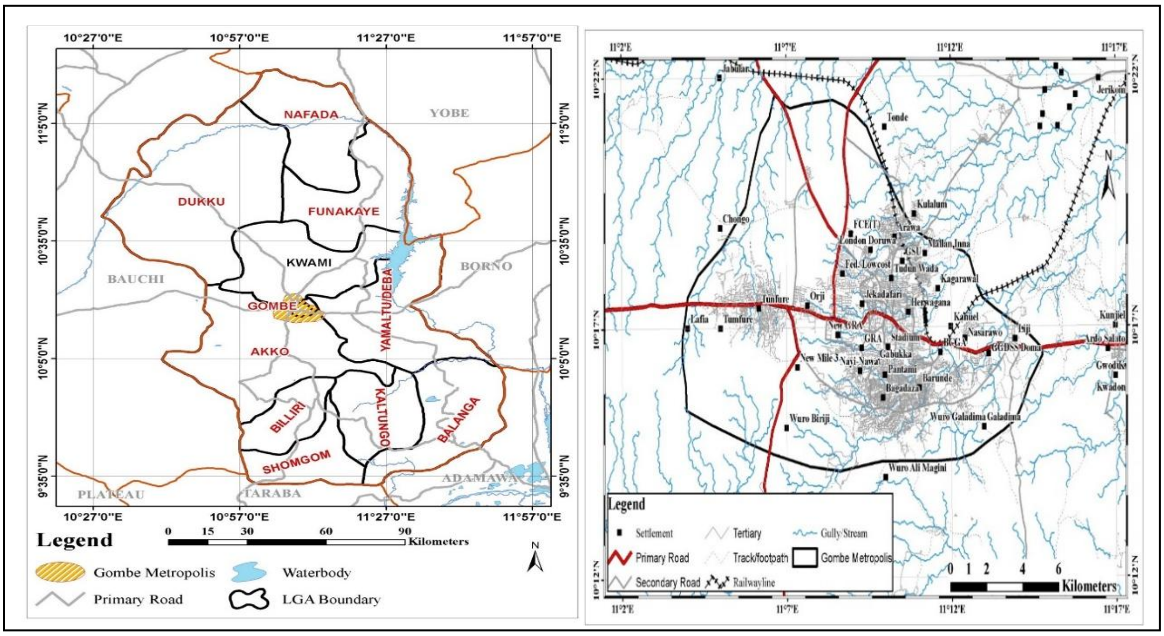

Figure 1: Gombe State, Gombe Metropolis.
Source: Gombe State Geographic Information System (GOGIS), 2024

This study adopted a mixed-methods design combining laboratory analyses, field surveys, and geospatial mapping to investigate spatial variations in groundwater quality across Gombe Metropolis, Nigeria. The approach enabled a robust and comprehensive understanding of environmental, demographic, and anthropogenic influences on water quality amidst urban expansion. Primary data were collected through laboratory tests of groundwater samples, and field observations, while secondary data included published literature, reports, and government documents providing contextual insights on geology, climate, and land use. The groundwater samples for this study were collected from 14 wards across Gombe Metropolis. These include Barunde, Liji, Herwagana, Jekadafari, Ajiya, Nasarawo, Kumbiya-Kumbiya, Dawaki, Shamaki, Bolari East, and Bolari West. Additional samples were collected from GSU (located in Tudun Wada), G.R.A. (situated in Pantami), and F.C.E. (located in Kwami Ward), ensuring comprehensive spatial coverage of both residential and institutional areas within the metropolis, using a multistage random sampling technique. A total of 42 samples were obtained each community, three samples for physicochemical, bacteriological, and cation analysis. Samples were collected using sterilized polyethylene containers see plate 2, and preserved using nitric acid for cations analysis. Samples were stored at 4°C and transported to the laboratory for analysis. Field instruments such as pH meters, EC meters, turbidity meters, and GPS devices were used to record on-site physical parameters and geospatial coordinates of each sample location were collected and records accordingly.

Laboratory analyses assessed using Atomic Abortion Spectro photo metre (ASS) and other equipment to analyses key parameters including pH, temperature, EC, TDS, turbidity, total hardness, DO, BOD, COD, major cations (Na^+, K^+, Ca^{2+}, Mg^{2+}), anions (Cl^-, SO_4^{2-}, NO_3^-, PO_4^{3-}, HCO_3^-, F^-), and heavy metals (Pb, Cd, Cr, As, Fe, Cu, Ni). Microbiological tests were conducted for total coliforms and *E. coli* see plate 2, to evaluate potential health risks. Geospatial analysis using ArcGIS software and kriging interpolation methods enabled spatial modeling and mapping of groundwater quality across the study area. Inferential statistical tools including ANOVA and T-tests were employed to test for spatial variations and compliance with WHO and NSDWQ standards, with hypotheses tested at a 0.05 significance level.

Plate 1: Collected labelled Water Sample and Atomic Abortion Spectro photo metre (ASS) used
Source: Author, 2024

Plate 2: Researcher counting Bacteria Colony and Labeling Samples
Source: Author, 2024

RESULTS AND DISCUSSION

Physicochemical and Microbiological Parameters

The results of this study reveal clear spatial variation in groundwater quality across Gombe Metropolis, reflecting the combined influence of anthropogenic activities, land-use dynamics, and geological heterogeneity. A total of 42 groundwater samples were analyzed for physicochemical and microbiological parameters, and results were compared against the standards established by the World Health Organization (WHO) and the Nigerian Standard for Drinking Water Quality (NSDWQ).

Physicochemical Groundwater Parameters Characteristics in the study area

The analysis of physicochemical parameters across the 14 wards of Gombe Metropolis reveals spatial variation in groundwater quality, shaped by both natural and anthropogenic factors. pH values varied from 6.37 in Barunde to 8.18 in Herwagana, indicating fluctuations from slightly acidic to mildly alkaline groundwater. Areas such as Herwagana, Bolari, and Liji exhibited higher pH levels, potentially influenced by bicarbonate buffering and carbonate-rich lithology, as earlier observed by Ocheri et al. (2022). Temperature across the wards ranged from 22.10°C in Kumbiya Kumbiya to 28.00°C in Liji and Herwagana, with elevated temperatures pointing to increased urban surface heat and shallow aquifer influence, corroborating findings by Unigwe et al. (2023) and Bouteraa et al. (2019). Electrical conductivity and total dissolved solids displayed are high in Shamaki, Jekadafari, and Bolari West, signifying greater ionic loads likely due to leaching of minerals and increased human activity. These trends align with Gbadebo et al. (2012), who reported similar urban ionic enrichment in Agbara, Nigeria. Salinity levels remained low across the study area, suggesting limited salinization. However, elevated dissolved oxygen levels in FCE and Kumbiya may imply good recharge and minimal organic pollution, while lower DO in parts of GSU and Barunde may indicate oxygen depletion due to microbial activity. Total hardness ranged broadly, with higher values recorded in GSU and Jekadafari, pointing to geological controls as noted by Ishaku et al. (2011). Turbidity, colour, and odour were generally within acceptable aesthetic ranges, though elevated turbidity in Bolari and Ajiya suggests potential particulate contamination. These results collectively underscore the need for localized monitoring and tailored groundwater management strategies in Gombe Metropolis.

Heavy Metals Groundwater Parameters Characteristics in the study area

The spatial distribution of heavy metals and major elements across 14 wards in Gombe Metropolis revealed localized contamination and geological influences. Lead (Pb) was highest in Herwagana (0.07 mg/L) and Barunde (0.01 mg/L), suggesting anthropogenic sources such as aging plumbing and vehicular emissions, consistent with Eyankware & Ephraim (2021). Arsenic (As) was markedly elevated in Jekadafari (0.40 mg/L), indicative of geogenic leaching, a trend also reported in the Niger

Delta by the same authors. Chromium (Cr) concentrations ranged from BDL to 0.10 mg/L, with notable values in Jekadafari and FCE 2, aligning with findings by Adnan & Iqbal (2014) on industrial impacts in groundwater. Cadmium (Cd) was present up to 0.04 mg/L in Kumbiya and Nasarawo, indicating potential agrochemical or solid waste infiltration. Nickel (Ni) levels were moderate, peaking at 0.07 mg/L in FCE 2, likely from geologic weathering, similar to Agbalagba et al. (2011) in Nigeria.

Iron (Fe) levels peaked in Barunde (0.32 mg/L), likely due to iron-rich substrata or corroding infrastructure. Copper (Cu) remained low across sites but was highest in Dawaki and Herwagana (0.10 mg/L), consistent with urban effluent discharge. Sodium, calcium, potassium, and magnesium levels showed moderate spatial variability, with higher values in Herwagana and Shamaki, suggesting rock dissolution and domestic input.

Anions Characteristics in the study area

The spatial distribution of anions across the 14 wards in Gombe Metropolis revealed significant spatial variation, largely shaped by land use patterns and anthropogenic activities. Nitrate (NO_3^-) levels were highest in Barunde (32.23 mg/L), Bajoga (25.26 mg/L), and Ajiya (25.36 mg/L), indicating possible fertilizer leaching and domestic wastewater intrusion. These findings align with Eyankware & Ephraim (2021), who reported nitrate contamination in the Niger Delta linked to poor sanitation and agricultural runoff. Phosphate (PO_4^{3-}) levels peaked in FCE (46.38 mg/L) and Herwagana (32.58 mg/L), suggesting significant domestic and sewage effluent contributions in urban zones, similar to the observations by Raji et al. (2015) in Ibadan. Notably, several locations including Jekadafari, Ajiya, and Shamaki recorded negligible phosphate values, possibly due to lower population density or limited fertilizer application.

Sulfate (SO_4^{2-}) concentrations were exceptionally high in Jekadafari, Nassarawo, and Dawaki (250 mg/L each), likely due to geogenic inputs from sulphur-bearing rocks or historic industrial discharge. This pattern supports the findings of Tlili-Zrelli et al. (2016), who noted the influence of geology on sulfate variability in arid zones. Chloride (Cl^-) also showed elevated levels in Herwagana (79 mg/L) and FCE 2 (74 mg/L), pointing to domestic waste infiltration, as reported by Babiker et al. (2007). Fluoride was noticeable in most wards, implying limited geogenic or industrial sources. Bicarbonate (HCO_3^-) levels ranged from 9.57 mg/L in GRA to over 140 mg/L in Kumbiya and Jekadafari, indicating carbonate rock dissolution, consistent with Ocheri et al. (2022). These results underscore the need for continued monitoring and localized water treatment interventions to mitigate potential health risks.

Microbiological Contamination

The bacteriological analysis revealed that *Escherichia coli and total coliforms* were present in all groundwater samples, confirming widespread *fecal* contamination. This suggests significant infiltration from pit latrines and septic tanks, especially in densely populated districts lacking adequate sanitation systems. Similar findings by Raju, Shukla, and Ram (2011) emphasize that microbial pollution is common in urban areas where waste management is poor. These pathogens present acute risks of gastrointestinal infections and other waterborne diseases, particularly among vulnerable groups such as children and the elderly.

Hypothesis Testing for Physicochemical Parameters one

H_{01}: There is no significant variation in groundwater parameters' concentration levels across the metropolis.

The ANOVA results for physicochemical parameters (pH, temperature, EC, TDS, salinity, DO, BOD, COD, total hardness, and turbidity) indicate significant variations across the 14 wards in Gombe Metropolis, with all parameters showing p-values less than 0.05. For instance, electrical conductivity ($F = 66.713$; $p = 0.000$), total dissolved solids ($F = 88.490$; $p = 0.000$), and turbidity ($F = 4933.123$; $p = 0.000$) reveal pronounced differences in groundwater characteristics across locations. These findings support the rejection of the *null hypothesis (H_{01}), indicating that groundwater physicochemical quality significantly varies across the metropolis*. Such variation can be attributed to differing land-use patterns, urban runoff, wastewater disposal, and geological heterogeneity. Similar spatial variations have been observed in Agbara by Gbadebo et al. (2012) and in Niger Delta studies by Eyankware & Ephraim (2021), linking variation in pH, EC, and TDS to industrial and anthropogenic factors. See table 1.

Table 1: Analysis of Variance of the Selected Physiochemical Parameters

Parameter	Between Groups SS	Df	Mean Square	F	Sig.
Ph	7.508	15	0.578	19.075	0.000
Temperature	76.066	15	5.851	7.559	0.000
Electrical Conductivity	4272145.405	15	328626.570	66.713	0.000
Total Dissolved Solids	902182.405	15	69398.647	88.490	0.000
Salinity	1150.573	15	88.506	12.057	0.000
Dissolved Oxygen	29.355	15	2.258	9.725	0.000
Biochemical Oxygen Demand	8.557	15	0.658	7.531	0.000
Chemical Oxygen Demand	18.713	15	1.439	4.184	0.001
Total Hardness	80746.455	15	6211.266	7.232	0.000
Turbidity	71.256	15	5.481	4933.123	0.000
Oduor	0.000	15	0.000	-	-
Color	0.000	15	0.000	-	-

Source; Author analysis, 2024

Testing Hypothesis One for Heavy Metals

Significant spatial variation was also observed in the concentration of key heavy metals including Pb ($F = 46.139$; $p = 0.000$), As ($F = 57.534$; $p = 0.000$), Cd ($F = 81.705$; $p = 0.000$), Cr, Ni, Fe, Cu, Na, and Ca ($p < 0.05$). Only potassium and magnesium did not show statistically significant differences across locations ($p > 0.05$). These findings provide strong grounds to *reject the null hypothesis (H_{01}), affirming that concentrations of heavy metals vary significant varietion across the metropolis.* These results align with Eyankware & Ephraim (2021), who linked such heavy metal variations in groundwater to localized geogenic sources and anthropogenic inputs, such as industrial effluents and improper waste disposal.

Testing Hypothesis One for Anions

Among the anion parameters, nitrate ($F = 2.83$; $p = 0.01$), phosphate ($F = 3.357$; $p = 0.004$), and bicarbonate ($F = 2.395$; $p = 0.026$) show significant variations across the study area, indicating spatial inconsistency in pollution levels, particularly in agricultural and urban zones. Sulfate, chloride, and fluoride, however, did not show significant differences ($p > 0.05$), suggesting more uniform distribution. *The null hypothesis (H_{01}) is thus rejected for anions show significant variation across the study areas while others do not*. These findings highlight the impact of land use and sewage effluents on anion concentration, consistent with studies by Eyankware & Ephraim (2021) and Ayoade et al. (2014), which emphasized the interplay of natural processes and anthropogenic activities in shaping anion profiles in urban groundwater systems see table 3.

Table 2: Analysis of Variance of the Selected Anions Parameters

ANOVA						
		Sum of Squares	df	Mean Square	F	Sig.
NO_3 (mg/L)	Between Groups	1968.901	13	151.454	2.83	0.01
	Within Groups	1498.556	28	53.52		
	Total	3467.457	41			
PO_4 (mg/L)	Between Groups	2297.432	13	176.726	3.357	0.004
	Within Groups	1474.194	28	52.65		
	Total	3771.626	41			
SO_4 (mg/L)	Between Groups	47751.04	13	3673.157	1.048	0.438
	Within Groups	98110.065	28	3503.931		
	Total	145861.11	41			
Cl (mg/L)	Between Groups	36312.56	13	2793.274	0.695	0.752
	Within Groups	112533.16	28	4019.041		
	Total	148845.72	41			
Fluoride (mg/L)	Between Groups	0.001	13	0	0.913	0.552
	Within Groups	0.002	28	0		
	Total	0.003	41			
HCO_3 (mg/L)	Between Groups	14305.164	13	1100.397	2.395	0.026
	Within Groups	12862.57	28	459.378		
	Total	27167.734	41			

Source; Author analysis, 2024

Testing Hypothesis Two for Physicochemical Parameters

H_{01}: There is no significant difference between the groundwater quality with the WHO/NSDWQ in the area.

The statistical comparison using one-sample t-tests revealed significant variation with key physicochemical parameters from the WHO and NSDWQ standards. The mean pH was significantly lower than the NSDWQ minimum of 6.5 (mean = 5.28, t = -17.552, p < 0.001), suggesting slight acidity, which may increase corrosion risks in plumbing systems. Electrical conductivity (EC) also showed a significant difference from the standard (mean difference = -929.119 µS/cm, t = -18.36, p < 0.001), indicating low mineralization and potential dilution effects. Turbidity exceeded the WHO limit of 0.3 NTU (t = -17.677, p < 0.001), pointing to poor filtration or contamination by suspended solids. However, temperature did not significantly differ from the WHO/NSDWQ threshold of 30°C (t = 1.00, p = 0.500), implying thermal stability. See table 3.

Chemical parameters such as total hardness, dissolved oxygen (DO), biochemical oxygen demand (BOD), and chemical oxygen demand (COD) also varied significantly with both standards. Total hardness was below the acceptable range (mean diff = -76.47 mg/L, p < 0.001), suggesting soft water and risk of metal leaching (Kortatsi, 2007).

Table 4: Student t-test for Turbidity

One-Sample Test						
	Test Value-WHO= 0.3- NSDWQ Standards = 5.0					
	T	Df	Sig. (2-tailed)	Mean Difference	95% Confidence Interval of the Difference	
					Lower	Upper
Turbidity	-17.677	40	0	-3.68537	-4.1067	-3.264

Source; Author analysis, 2024

DO levels were low (mean diff = -2.05 mg/L, $p < 0.001$), potentially due to high organic load or limited recharge (Ravikumar et al., 2011). BOD and COD also showed significantly low values ($p < 0.001$), indicating reduced organic and chemical pollution, respectively (Chidambaram et al., 2010). These deviations affirm rejection of H_{02} and suggest water quality issues linked to land use and anthropogenic activities.

Testing Hypothesis Two for Heavy Metals

Among the heavy metals analyzed, chromium (Cr), nickel (Ni), and copper (Cu) were significantly below WHO/NSDWQ limits ($p < 0.001$), indicating minimal contamination from industrial or geogenic sources. In contrast, arsenic (As), cadmium (Cd), and lead (Pb) were above regulatory thresholds, see tables 5, 6 and 7. Arsenic levels averaged 0.076 mg/L ($p = 0.001$), and cadmium 0.013 mg/L ($p < 0.001$), exceeding limits of 0.00 and 0.003 mg/L, respectively, highlighting contamination risks (Edmunds & Smedley, 2012). Although lead (mean = 0.00128 mg/L) was statistically non-significant ($p = 0.714$), its presence above 0.00 mg/L is toxicologically concerning. These results validate previous observations by Adekunle et al. (2007) and necessitate urgent remediation. Hence, H_{02} is rejected.

Table 5: Student t-test for Lead

One-Sample Test						
	Test Value-WHO/NSDWQ Standards = 0.00					
	t	Df	Sig. (2-tailed)	Mean Difference	95% Confidence Interval of the Difference	
					Lower	Upper
Lead (Pb)	0.37	42	0.714	0.00128	-0.0057	0.0083

Source; Author analysis, 2024

Testing Hypothesis Two for Anions

Key anions, including nitrate (NO_3^-), phosphate (PO_4^{3-}), fluoride (F^-), and nitrite (NO_2^-), displayed significant deviations from WHO/NSDWQ standards. Fluoride exceeded the WHO limit (0.5 mg/L) with a mean difference of -1.4955 mg/L ($p < 0.001$), risking dental/skeletal fluorosis (Edmunds & Smedley, 2012). Nitrite also surpassed permissible levels (mean = -34.93 mg/L, $p < 0.001$), a known indicator of sewage and fertilizer infiltration and a cause of methemoglobinemia (Raju et al., 2011). Conversely, chloride and sulphate concentrations were significantly lower than regulatory limits ($p < 0.001$), suggesting minimal salinity or industrial effluents. Phosphate also showed significant variation ($t = 2.64$, $p = 0.012$), linked to urban effluents. Thus, H_{02} is rejected for all anionic parameters.

Table 6: Student t-test for Fluoride

Fluoride (mg/L) **One-Sample Test**
Test Value-WHO = 0.5 - NSDWQ Standards = 1.5
95% Confidence Interval of the Difference
Upper
-1.4955

Source; Author analysis, 2024

Testing Hypothesis Two for Cations

Analysis of cations such as sodium (Na^+), potassium (K^+), calcium (Ca^{2+}), and magnesium (Mg^{2+}) indicated statistically significant differences from WHO/NSDWQ standards ($p < 0.001$). Sodium and potassium were well below thresholds (Na: -181.01 mg/L; K: -5.26 mg/L), implying low salinity or geological leaching (Adnan & Iqbal, 2014; Agbalagba et al., 2011). Calcium and magnesium were also deficient (Ca: -64.94 mg/L; Mg: -46.16 mg/L), pointing to reduced hardness and buffering capacity (Ishaku et al., 2011; Kortatsi, 2007). While such levels reduce scaling risks, they also pose concerns for human mineral intake and water taste. Thus, H_{02} is rejected, reinforcing the influence of local geology on groundwater chemistry.

Table 7: t-test for Sodium

One-Sample Test Sodium					
Test Value =WHO Standards = 200					
T	Df	Sig. (2-tailed)	Mean Difference	95% Confidence Interval of the Difference	
				Lower	Upper
-237.69	42	0	-181.01	-182.97	-179.05

Source; Author analysis, 2024

The rejection of the null hypothesis across all parameters confirms that groundwater in Gombe Metropolis deviates significantly from WHO and NSDWQ standards. These variations, driven by geogenic, anthropogenic, and land-use factors, call for comprehensive groundwater management, regular quality monitoring, and public health interventions to ensure safe water for domestic use

Spatial Distribution of the Physicochemical Parameters in the Study Area

This section presents the spatial distribution of key groundwater quality parameters in Gombe Metropolis using the Kriging interpolation technique, known for its geostatistical precision in environmental modeling. Parameters mapped include including pH, temperature, EC, TDS, turbidity, total hardness, DO, BOD, COD, major cations (Na^+, K^+, Ca^{2+}, Mg^{2+}), anions (Cl^-, SO_4^{2-}, NO_3^-, PO_4^{3-}, HCO_3^-, F^-), and heavy metals (Pb, Cd, Cr, As, Fe, Cu, Ni). were also spatially analyzed. These maps allow for visualization of contamination hotspots and hydrogeological influences across the metropolis.

The spatial distribution of groundwater temperature, pH, electrical conductivity (EC), and total dissolved solids (TDS) across Gombe Metropolis reveals elevated temperatures (26.2–28°C) in FCE and Liji wards, likely due to urban heat retention and limited groundwater recharge, echoing findings by Unigwe et al. (2023). Lower temperatures (22.1–24.0°C) in Barunde and Kumbiya suggest minimal anthropogenic influence and better groundwater quality. pH distribution ranges from 6.37 to 8.18, with higher alkalinity observed in urbanized areas such as Ajiya and Bolari, possibly due to carbonate lithology (Ocheri et al., 2022). Acidic zones like Shamaki and Barunde reflect agricultural runoff and industrial pollution (Akinbile & Olatunji, 2021), raising risks of metal leaching. EC levels are highest (1098–1348 µS/cm) in Shamaki and Ajiya, linked to urban runoff and poor waste disposal, consistent with Orebiyi et al. (2010). Conversely, the lowest EC values (<350 µS/cm) in Liji and Barunde indicate reduced human impact. TDS concentrations are elevated in Shamaki, Jekadafari, and GSU, suggesting dissolved solids from waste infiltration, yet still within WHO limits. These trends affirm that groundwater quality in the metropolis is spatially heterogeneous and closely tied to urbanization and geology. Continuous monitoring and localized management are essential to mitigate potential health and environmental risks. See figure 2.

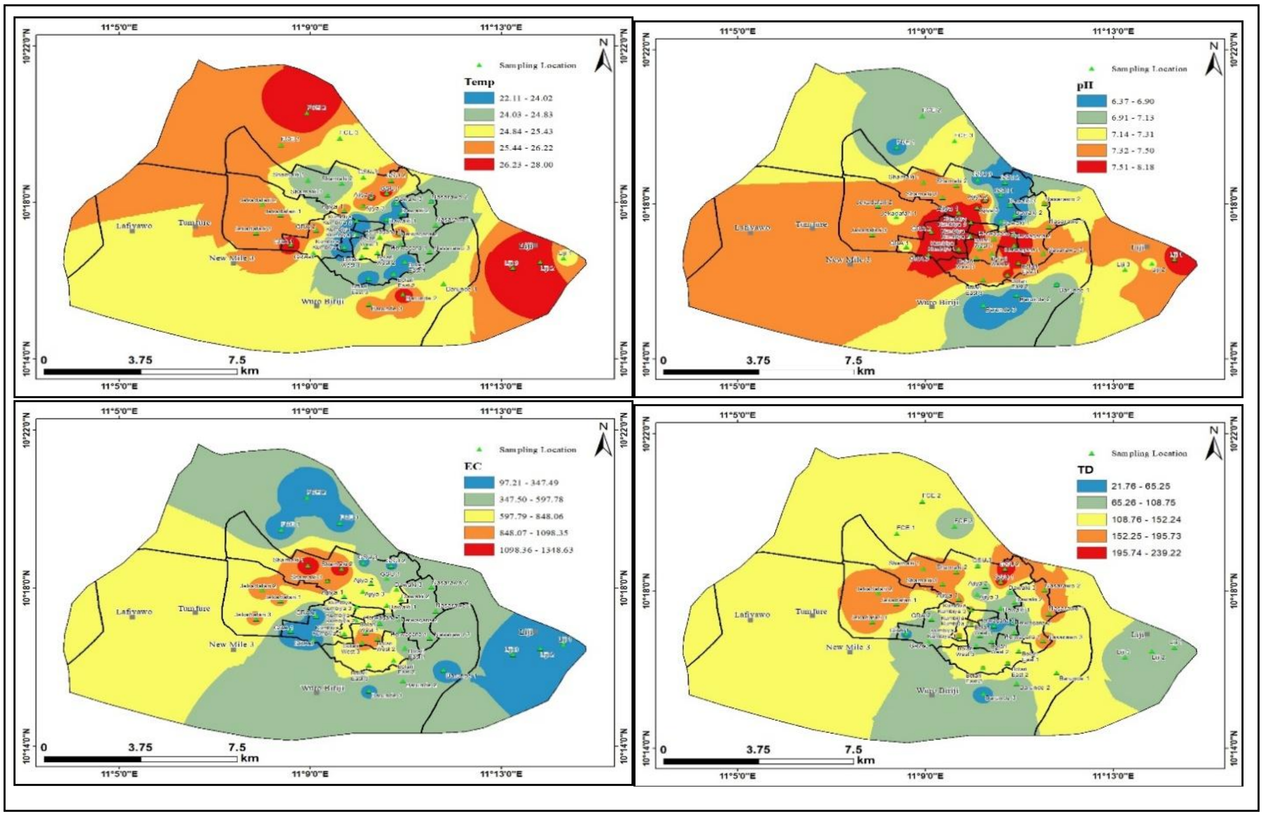

Figure 2: Temperature, pH, EC and Total Dissolved Solid Distribution in the Study Area, 2024, Source; Author analysis, 2024

The spatial distribution of groundwater quality indicators (Figure 3), shows salinity, dissolved oxygen (D.O.), chemical oxygen demand (COD), and biochemical oxygen demand (BOD) reveals distinct hotspots of concern across Gombe Metropolis. High salinity levels (10.11–18.55) are concentrated in FCE 2, GSU 1, and GSU 2, marked in red on the map (Figure 3), suggesting anthropogenic influences such as fertilizer runoff, wastewater intrusion, and poor sanitation. These findings align with Adimalla and Qian (2019), who identified urban and agricultural pressures as key contributors to groundwater salinity. Dissolved oxygen levels are highest (5.50–6.11 mg/L) in FCE 2, FCE 3, and GRA 1 (red zones on reflecting minimal organic contamination and good recharge. In contrast, Jekadafari, Dawaki, and Barunde show low D.O. levels (3.00–3.62 mg/L), indicative of microbial activity and pollution stress, supporting Act (2017) on oxygen depletion from wastewater impacts. Hotspots for COD (15.15–62.79 mg/L) appear in Dawaki 1 and Dawaki 2 (Figure 3), reflecting high organic loads from domestic sewage or industrial effluents, consistent with EPA (2024). Moderate levels appear in Nasarao, Shamaki, and Ajiya, while lowest concentrations are found in FCE 1 and Barunde. BOD hotspots (4.00–4.58 mg/L) are seen in GRA 1 and Liji 3, shown in red on Figure 17, suggesting significant organic pollution due to urban activities and inadequate waste treatment. Cleaner zones, like GSU 1 and GSU 2, exhibit lower BOD (1.63–2.22 mg/L), implying better groundwater quality and effective waste regulation. These patterns highlight areas needing urgent water quality management and infrastructure interventions.

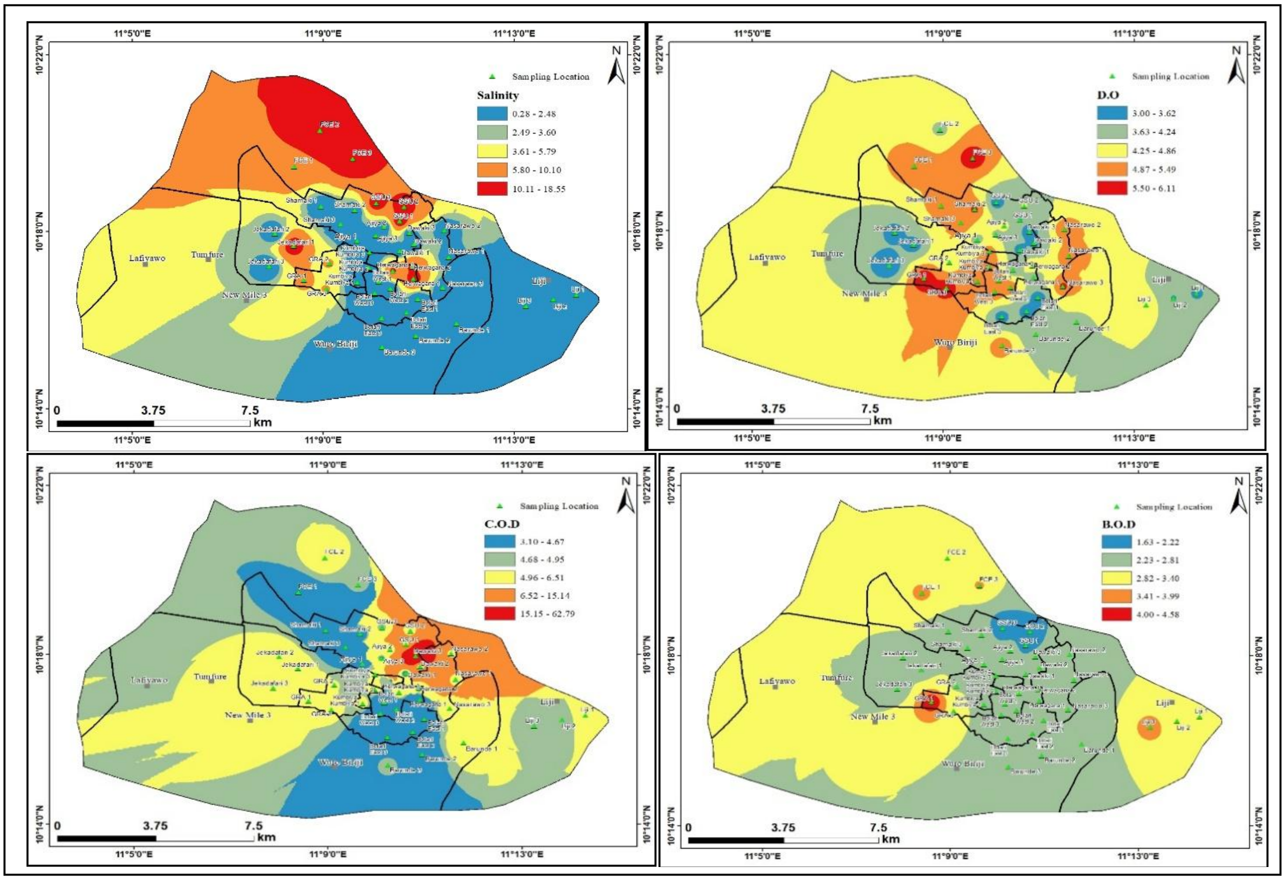

Figure 3: Salinity, D.O., COD, and BOD in the Study Area, 2024
Source; Author analysis, 2024

The spatial distribution of total hardness (TH) in groundwater reveals significant variability across the study area. Hotspots of high hardness (229.7–273.53 mg/L), marked in red, are concentrated in Barunde and its surroundings, likely influenced by lithological features and anthropogenic inputs. Conversely, low TH values (54.33–98.17 mg/L), depicted in blue, and are observed in FCE, GRA, and Liji, suggesting minimal geological influence and better water quality. High TH levels, driven by calcium and magnesium ions, may cause pipe scaling and reduce domestic water efficiency (WHO, 2017; USGS, 2020). Sodium (Na^+) concentrations (21.81–37.57 mg/L) in FCE 2 and Barunde 2, highlighting potential contamination from agricultural and urban activities. Low sodium zones (5.13–9.71 mg/L) in Bolari East/West, Ajiya, and Shamaki indicate safer water quality. Prolonged intake of high sodium water can lead to hypertension (WHO, 2011). Iron (Fe) hotspots (0.17–0.32 mg/L) appear in FCE 2 and Barunde 2, with low Fe levels (0.00–0.03 mg/L) seen in Liji, Nassarawo, and Dawaki, indicating minimal contamination. Elevated Fe affects taste and may cause health issues (WHO, 2022).

Lastly, copper (Cu) hotspots (0.050–0.100 mg/L) in FCE 2 and Bolari East 2, with minimal Cu presence in Liji and Barunde 3. While values are below WHO/NSDWQ limits, long-term exposure still poses risks to liver and kidney health (WHO, 2017). These findings stress the need for targeted water quality monitoring and management.

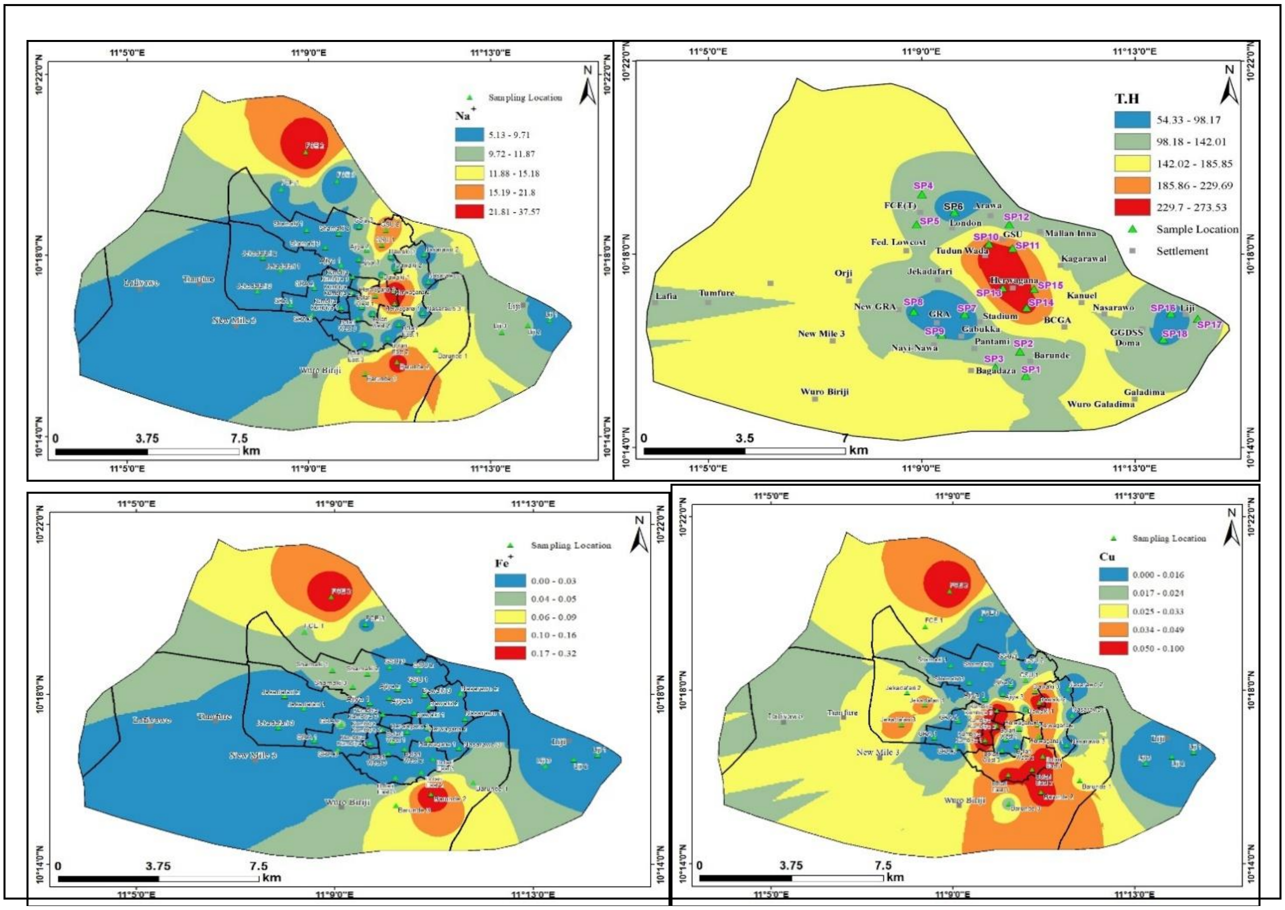

Figure 4: Sodium, Total hardness, Iron and Cupper in the Study Area, 2024
Source; Author analysis, 2024

The spatial distribution of calcium (Ca^{2+}) concentrations reveals hotspots in Barunde 3, Bolari East 3, and Nasarawo 3 (14.50–28.14 mg/L, red zones), likely due to geological deposits and urban runoff. Moderate levels (10.72–14.49 mg/L, orange) occur in Dawaki and Herwagana, while the lowest concentrations (1.36–6.29 mg/L, blue) are recorded in Liji, GRA, and FCE, indicating less water hardness and better domestic usability. Excessive Ca^{2+}, though essential for health, can cause scaling in pipes (WHO, 2011; USGS, 2020).

For arsenic (As), Jekadafari 1–3 are hotspots (0.24–0.40 mg/L, red), indicating urban-induced contamination, while Liji and FCE show minimal levels (0.00–0.05 mg/L, blue). Chronic As exposure is linked to cancers and cardiovascular issues (Smith et al., 2018; WHO, 2017).

Lead (Pb) shows higher levels in Shamaki and Herwagana (0.033–0.070 mg/L, red), suggesting urban pollution sources. Liji and Barunde 3 show lowest Pb levels (0.000–0.004 mg/L). This aligns with Odewande & Abimbola (2008), who reported Pb hotspots near industrial zones in Nigeria.

Nitrate (NO_3^-) hotspots (25.78–32.21 mg/L) are found in Barunde 3 and Bolari East 3, likely due to sewage infiltration. Lower levels (0.01–6.45 mg/L) in Liji, GRA, and Dawaki indicate reduced anthropogenic pressure. High nitrate exposure risks include blue baby syndrome and cancer (EPA, 2023; WHO, 2021).

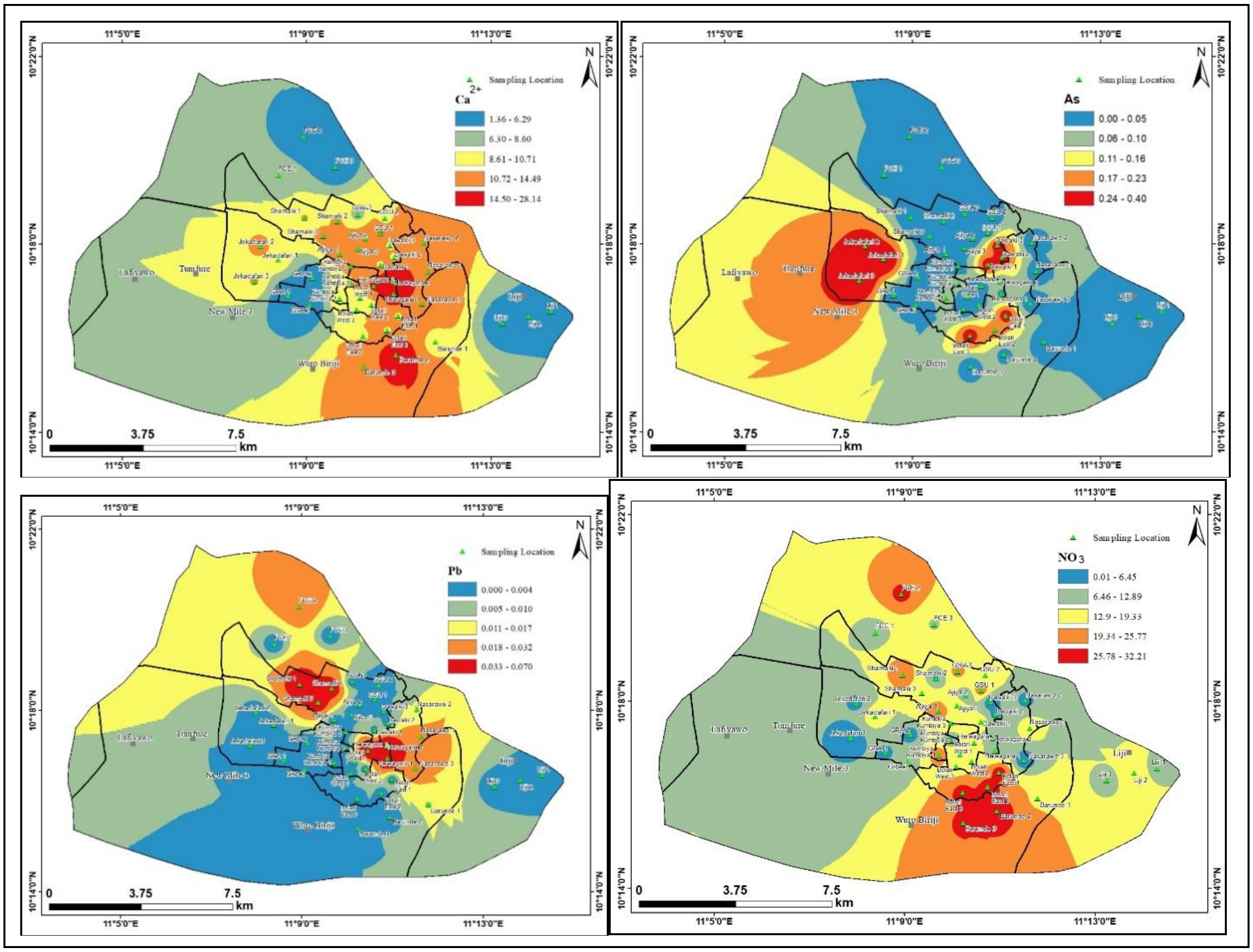

Figure 5: Calcium, Arsenic, Nitrate and Lead in the Study Area, 2024
Source; Author analysis, 2024

5.0 Conclusion and Recommendations

This study employed a geospatial analysis to investigate the spatial variation in groundwater quality for domestic use across Gombe Metropolis, Nigeria. A total of 42 water samples were collected from 14 political wards, covering key urban and peri-urban zones. The analysis integrated Kriging interpolation techniques with comprehensive laboratory assessments of physicochemical, cationic, anionic, heavy metal, and microbiological parameters to visualize and quantify groundwater quality variations.

The results revealed marked spatial variations in water quality, shaped by both geogenic and anthropogenic factors. Specifically, poor sanitation infrastructure, urban expansion, agricultural runoff, and indiscriminate waste disposal were identified as primary contributors to groundwater contamination. Contamination hotspots were concentrated in Jekadafari, Herwagana, FCE, Barunde, and Shamaki, where parameters such as arsenic, cadmium, nitrate, sodium, and several heavy metals exceeded permissible limits for domestic use. In contrast, groundwater quality in Liji, GRA, and parts of Bolari was comparatively safer, reflecting limited pollution input and better natural filtration.

Moreover, the detection of total and fecal coliforms in several wards signaled widespread microbiological contamination, highlighting significant public health risks. These findings underscore the urgent need for systematic groundwater monitoring, investment in urban sanitation, and targeted policy interventions to safeguard public water sources. This spatially driven approach offers a practical tool for water resource management, particularly in rapidly urbanizing environments such as Gombe Metropolis.

To ensure the long-term safety and sustainability of groundwater resources in Gombe Metropolis, several critical recommendations are proposed based on the study's findings. First, the establishment of a Gombe Groundwater Quality Observatory (GGQO) is imperative. This centralized body should be mandated to conduct real-time monitoring, spatial mapping, and public dissemination of groundwater quality information using advanced geospatial technologies. Such a framework would facilitate data-driven decision-making and improve transparency in water governance.

In addition, regulatory enforcement of groundwater protection zoning is essential. This involves the prohibition of borehole construction near identified contamination sources such as septic tanks, refuse dumpsites, and industrial effluent discharge points. This zoning approach will minimize the risk of contaminant infiltration into aquifers.

To address existing contamination, especially in identified hotspot wards, the deployment of localized, community-based water treatment systems including chlorination, filtration, and reverse osmosis is recommended. These systems will serve as immediate intervention tools to safeguard public health.

Furthermore, urban planning authorities should integrate groundwater vulnerability assessments into broader spatial development and infrastructure plans. This integration will ensure that construction and land use decisions are informed by hydrogeological risk, thereby preventing inadvertent pollution of groundwater sources.

Finally, sustained public education campaigns on groundwater hygiene, pollution prevention, and responsible usage must be intensified. Community engagement and behavioral change are essential to reinforcing safe water practices, especially in rapidly urbanizing zones. Together, these measures provide a comprehensive and sustainable pathway for improving groundwater quality management in Gombe Metropolis.

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