KASU ENVIRONMENTAL SCIENCE JOURNAL (KESJ)
KASU Environmental Science Journal (KESJ) ISSN: 2734-2751
Volume 6, Issue 1, June 2026

ASSESSMENT AND SPATIAL ANALYSIS OF GROUNDWATER QUALITY IN A SEMI-ARID URBAN ENVIRONMENT: EVIDENCE FROM DAURA TOWN, NORTH-WESTERN NIGERIA

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ABSTRACT

Purpose: *Groundwater is the primary source of domestic water supply in most semi-arid regions of northern Nigeria due to limited surface water availability and inadequate municipal water infrastructure. This study assessed physicochemical quality and spatial distribution of groundwater in Daura Town, Katsina State, with the aim of evaluating its suitability for domestic use.*

Design/methodology/approach: *A systematic sampling approach was adopted, and twelve groundwater samples were collected from six boreholes and six hand-dug wells across the study area. Field sampling was supported by Global Positioning System (GPS) measurements, while laboratory analyses were conducted to determine pH, Total Dissolved Solids (TDS), Total hardness, Chloride, Calcium, Magnesium, Iron, Copper, and Bicarbonate concentrations.*

Findings: *Results revealed that groundwater pH values ranged from neutral to slightly alkaline and fell within the permissible limits set by the World Health Organisation (WHO) and the Standard Organisation of Nigeria (SON). TDS, total hardness, chloride, magnesium, copper, and bicarbonate concentrations were generally low and within acceptable standards, indicating fresh and low-mineralised groundwater. However, localised elevated iron concentrations were observed in some borehole samples, likely due to geogenic sources and corrosion of borehole infrastructure. Spatial analysis showed variability in groundwater quality across Daura Town, influenced by land use patterns, population density, and source protection conditions.*

Research limitations/Implications*: The limitations include the use of selected elements and the total number of samples used in the paper.*

Practical implications: *The study concludes that groundwater in Daura Town is largely suitable for domestic use, but recommends regular monitoring, improved sanitation practices, and enforcement of groundwater protection measures to prevent future contamination and ensure sustainable water resource management.*

Originality/value*: It is clear from the findings that groundwater quality is safe in the study area, but effective measures for monitoring and improved water infrastructure remain crucial in the provision of portable water in the Daura area.*

Keywords: Groundwater quality; GIS; Physicochemical parameters; Semi-arid environment; Daura Town

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1.0 INTRODUCTION

Groundwater constitutes one of the most critical freshwater resources globally, accounting for approximately 26% of total freshwater withdrawals and supplying nearly half of the world's drinking water (Van der Gun, 2012; Siebert et al., 2010). Its strategic importance is particularly evident in arid and semi-arid regions, where surface water availability is highly seasonal and unreliable. Groundwater also supports irrigation, industrial activities, base flow in rivers, and groundwater-dependent ecosystems. Due to natural filtration through soil and rock strata, groundwater is often of better microbiological quality than surface water; however, once polluted, remediation is technically difficult and economically expensive (Purandara & Varadarajan, 2003).

In Nigeria, groundwater represents the dominant source of potable water for both rural and urban populations. Over 60% of Nigerians depend on wells and boreholes for domestic water supply due to inadequate municipal water infrastructure (Abbas et al., 2019). Rapid population growth, unregulated abstraction, expanding urbanisation, and industrial activities have significantly increased pressure on groundwater resources (Adeyemi et al., 2003). Although groundwater is less vulnerable to contamination than surface water, anthropogenic activities such as indiscriminate waste disposal, agricultural runoff, and poor sanitation increasingly threaten its quality.

Groundwater quality is controlled by the initial chemistry of recharge water, subsurface geochemical processes, and human activities at the surface or within aquifers (Milovanovic, 2007). Pollutants such as nitrates, chlorides, sulphates, and heavy metals may originate from fertilizers, industrial effluents, septic systems, and solid waste dumps (Brindha & Kavitha, 2015). Climate variability further complicates groundwater quality by altering recharge rates and contaminant transport pathways (World Water Quality Alliance, 2021).

In Katsina State, particularly in Daura Town, poor urban planning has resulted in close proximity between residential areas, industries, and waste disposal sites, increasing the risk of groundwater contamination (Abotalib et al., 2016). With the persistent inadequacy of public water supply, households increasingly rely on privately constructed wells and boreholes, often without adequate quality monitoring. This situation underscores the need for systematic groundwater quality assessment and spatial analysis to safeguard public health.

Despite the growing dependence on groundwater in Daura Town, there is limited integrated assessment combining laboratory analysis and spatial mapping of groundwater quality parameters. Excessive abstraction, coupled with poor wastewater management, poses risks of declining water quality and water-related diseases. Previous studies in northern Nigeria have assessed groundwater quality at local scales (Adamu et al., 2013; Jidauna et al., 2017), but few have applied Geographic Information System (GIS)-based spatial analysis to visualise contamination patterns in Daura. This knowledge gap limits effective groundwater management and policy formulation.

2.0 LITERATURE REVIEW

Water quality refers to the suitability of water for specific uses such as drinking, irrigation, and industrial activities, based on its physical, chemical, and biological characteristics (Jidauna et al., 2013). Water quality assessment involves systematic evaluation of these parameters to determine potability and ecological safety (Akpoborie et al., 2008). Groundwater is generally preferred for domestic use due to its relatively stable quality and minimal treatment requirements, but it remains vulnerable to contamination from both geogenic and anthropogenic sources (Okeola et al., 2010).

Groundwater contamination arises from natural mineral dissolution as well as human activities such as fertilizer application, industrial discharge, and improper waste disposal (Abu El-Ella, 1999).

Elevated concentrations of iron, chloride, magnesium, and total dissolved solids can affect water taste, plumbing systems, and long-term health. Pathogenic contamination, often linked to poor sanitation, leads to waterborne diseases such as cholera, typhoid, and diarrheal infections (WHO, 2011). Several studies in Nigeria report that groundwater sources located near refuse dumps and septic systems exhibit elevated contamination levels (Shittu et al., 2008; Isma'il & Yola, 2012).

Water quality standards provide benchmark values for assessing suitability for drinking and other uses. In Nigeria, groundwater quality assessment commonly relies on guidelines issued by the World Health Organisation (WHO) and the Standard Organisation of Nigeria (SON). These standards define permissible limits for parameters such as pH, total dissolved solids, hardness, chloride, iron, and heavy metals (Jidauna et al., 2013). Compliance with these standards is essential for protecting public health and guiding water resource management.

Recent studies (Jidauna et al., 2013; Jidauna et al., 2014; Ndabula et al., 2018; Abotalib & Heggy, 2019) emphasise the use of Geographic Information Systems (GIS) for spatial analysis of groundwater quality, enabling visualization of contamination patterns and identification of high-risk zones. GIS-based approaches enhance decision-making by integrating field data, laboratory results, and spatial information, thereby supporting sustainable groundwater management.

3.0. AREA OF THE STUDY

Daura Town is located in Daura Local Government Area (LGA) of Katsina State, northern Nigeria. The area lies between latitudes 13°06′–13°38′ N and longitudes 08°21′–08°45′ E, approximately 80 km east of Katsina metropolis and close to the Nigeria–Niger Republic border (Figure 1). Daura LGA occupies a land area of about 217.3 km² and is bounded by Mai'Adua LGA to the north, Dutsi to the south, Sandamu to the east, and Mashi to the west. According to the 2006 National Population Census, the population of Daura LGA was about 401,900, predominantly of the Hausa and Fulani ethnic groups (NPC, 2006).

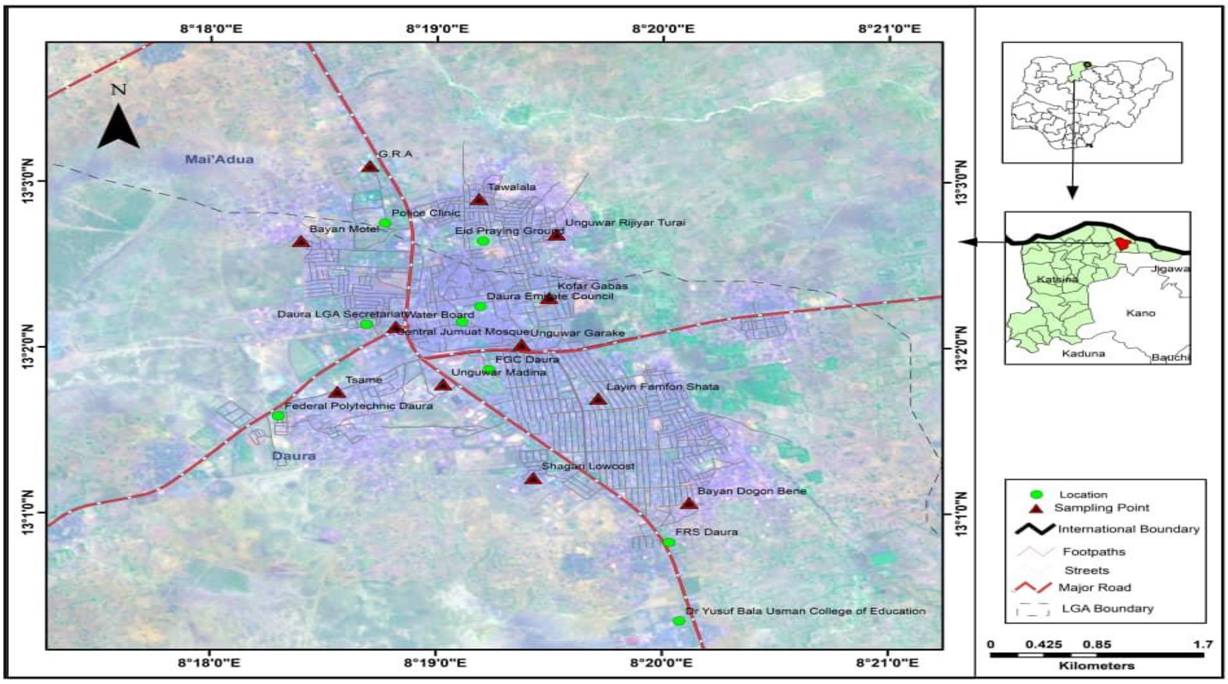

Figure 1: Study area showing sample points

Source: FUDMA GIS Lab. 2024

Climatically, Daura falls within the semi-arid Sahel–Sudan savannah zone, characterised by a long dry season and a short rainy season between June and September. Mean annual rainfall ranges from 400 to 600 mm, while temperatures are generally high throughout the year, often exceeding 38°C during the hot season (Ajayi et al., 2021). Geologically, the area is underlain by sedimentary formations of the Gundumi Formation within the Sokoto Basin, which influence groundwater occurrence and quality (Offodile, 1992). Drainage is dominated by ephemeral seasonal streams, leading to water scarcity during the dry season. Soils are mainly sandy loam and tropical ferruginous types, supporting savannah vegetation adapted to drought conditions, although extensive deforestation and desertification have significantly degraded the natural environment (Katsina State Ministry of Environment, 2002).

4.0 METHODOLOGY

This study adopted a field-based and laboratory analytical approach to assess groundwater quality in the study area. Both primary and secondary data sources were utilised to achieve the stated research objectives. Primary data consisted mainly of groundwater samples collected from boreholes and hand-dug wells, while secondary data were obtained from relevant published and unpublished materials. Materials used for field sampling included clean plastic bottles for sample collection and storage, masking tape for labeling and recording sampling details, black polythene bags to prevent light penetration, and a Global Positioning System (GPS) device for determining the geographic coordinates of sampling locations (Jidauna et al., 2018). Microsoft Excel was used for data entry and statistical analysis, while ArcGIS software was employed for spatial mapping of groundwater quality parameters.

Primary data collection involved systematic sampling of groundwater sources across the study area. Twelve (12) sampling points were selected using a systematic sampling technique to ensure adequate spatial coverage (Jidauna et al., 2013). A geo-referenced map of the study area was overlaid with a grid, from which six boreholes and six hand-dug wells were selected. Sampling locations were identified using longitude and latitude coordinates obtained through GPS. Water samples were collected using sterilised plastic bottles, which were clearly labeled with location, date, and time of collection (Jidauna et al., 2013, 2014). The bottles were filled carefully, leaving minimal air space, and immediately sealed. After collection, samples were placed in black polythene bags to prevent exposure to sunlight, which could alter chemical and biological properties (Balarabe et al., 2000). All samples were transported to the laboratory for analysis.

Laboratory analysis focused on selected physical and chemical parameters, including pH, total dissolved solids (TDS), total hardness, chloride, iron, magnesium, copper, and bicarbonate. Analyses were conducted at the Soil and Water Laboratory of the Federal University Dutsin-Ma and the Federal Ministry of Agriculture and Rural Development using standard instruments such as a HACH DR/2000 spectrophotometer, Hanna pH meter (Model I.H. 98129), and TDS/Conductivity meter (Model 446000.00). The results were analysed in relation to the study objectives and compared with national and international drinking water quality standards provided by the World Health Organisation (WHO) and the Standard Organisation of Nigeria (SON) (Jidauna et al., 2013 & 2014). Emphasis was placed on the spatial distribution of groundwater sources, the physicochemical characteristics of groundwater, and the suitability of groundwater for domestic use. The systematic sampling approach adopted in this study ensured adequate spatial representation of both boreholes and wells. Data analysis involved descriptive statistical techniques and graphical presentation.

5.0 PRESENTATIONAND DISCUSSION OF RESULTS

5.1 Groundwater Sources and Vulnerability Assessment

Groundwater in Daura Town is primarily sourced from boreholes and hand-dug wells, which constitute the major domestic water supply for residents. Field observations revealed that many households rely directly on these sources for drinking, cooking, and other domestic purposes due to limited access to piped water supply. However, the condition and protection status of these groundwater sources vary significantly across the study area.

Several hand-dug wells observed during fieldwork were uncovered or poorly protected, making them highly susceptible to contamination. Plates 1 and 2, showing exposed wells at Rijiyar Turai and Famfon Shata, indicate direct exposure to surface runoff, refuse dumping, and domestic wastewater. Such conditions increase the risk of groundwater pollution through infiltration and percolation, especially during the rainy season. Boreholes, although generally better protected, are not completely immune to contamination, particularly where they are located close to drainage channels, waste dumps, or densely populated residential areas. This perspective agrees with the work of Jidauna et al. (2018) in Dutsin-Ma town where some of the samples from wells close to dumpsites that were analysed showed elevated concentration of Mg, Pb, and Fe.

Plate 1: An exposed wells (Rijiyar Turai)

Plate 2: An exposed wells (Fanfom Shata)

Plate 3: TAwalala

Plate 4: Water Board

Urban activities such as indiscriminate waste disposal, poor drainage systems, and uncontrolled siting of wells and boreholes contribute significantly to groundwater vulnerability. Effluents from households and runoff from open dumpsites can introduce contaminants into the subsurface, especially in areas characterised by sandy or porous soils, which facilitate rapid infiltration. Similar observations have been reported in other urban centres in northern Nigeria, where groundwater contamination has been linked to inadequate sanitation and land-use practices (Balarabe et al., 2000; Akpoborie, 2008).

Despite these risks, groundwater remains a reliable and dependable source of water in Daura Town due to its year-round availability (Plates 1-4). However, the observed vulnerability underscores the need for regular monitoring, proper well construction, and enforcement of sanitary setback regulations to protect groundwater quality.

5.2 Spatial Distribution of Groundwater Sources in Daura Town

The spatial distribution of groundwater sources in Daura Town reveals a non-uniform pattern influenced by population density, land use, and infrastructural development. Groundwater sources are more concentrated within the urban core and residential neighbourhoods, where water demand is highest. Areas such as GRA, Tawalala, Unguwar Garake, and Shagari Low-Cost have relatively higher densities of boreholes, reflecting better infrastructure and higher socioeconomic status, which similar to the results of Jidauna et al. (2018) that greater independent water infrastructure were notice more at the GRA/ low-cost area of Dutsin-Ma with 76% not connecting to the government erratic pipelines for household water supply.

In contrast, hand-dug wells are more common in older settlements and densely populated areas such as Rijiyar Turai, Famfon Shata, Bayan Motel, and Bayan Dogon Bene. These areas often lack adequate access to treated pipe-borne water, compelling residents to depend on shallow groundwater sources. The reliance on shallow wells in such locations increases exposure to contamination due to their proximity to surface activities, which is in line with Jidauna et al. (2018) that with such high risk factors, it has health implications on households.

The spatial distribution pattern indicates that groundwater accessibility in Daura Town is largely demand-driven, but not necessarily regulated. Similar spatial trends have been reported in semi-arid urban centres where groundwater development occurs largely through private initiatives rather than coordinated planning (Sarkar et al., 2007).

Overall, the spatial distribution analysis confirms that while groundwater is widely available in Daura Town, its development lacks uniform regulation, thereby increasing the risk of localised groundwater quality deterioration.

5.3 Physicochemical Characteristics of Groundwater in Daura Town

5.3.1 pH Characteristics of Groundwater

The results on pH values of groundwater analysed for Daura Town ranged between 7.5 and 8.5, indicating neutral to slightly alkaline conditions as presented in Table 1. All sampled boreholes and wells fell within the WHO and SON recommended range of 6.5–8.5 for drinking water. Slight alkalinity observed in locations such as Famfon Shata, Unguwar Madina, and Kofar Gabas may be attributed to the dissolution of carbonate and bicarbonate minerals within the sedimentary formations underlying the area.

Table 1: pH Result from Sample Points

Sample	Wards	pH	WHO (2019)	SON (2020)
1	Water Board	7.5	6.5 — 8.5	6.5 — 8.5
2	Tawalala	7.8	6.5 — 8.5	6.5 — 8.5
3	Tsame	7.9	6.5 — 8.5	6.5 — 8.5
4	Rijiyar Turai	8.2	6.5 — 8.5	6.5 — 8.5
5	Famfon Shata	8.5	6.5 — 8.5	6.5 — 8.5

6	Unguwar Garake	7.5	6.5 — 8.5	6.5 — 8.5
7	GRA	8.1	6.5 — 8.5	6.5 — 8.5
8	Shagari Lowcost	7.6	6.5 — 8.5	6.5 — 8.5
9	Unguwar Madina	8.4	6.5 — 8.5	6.5 — 8.5
10	Kofar Gabas	8.3	6.5 — 8.5	6.5 — 8.5
11	Bayan Motel	7.7	6.5 — 8.5	6.5 — 8.5
12	Bayan Dogon Bene	7.9	6.5 — 8.5	6.5 — 8.5

Source: Field Work, 2023

Neutral to slightly alkaline pH is generally desirable for domestic water use, as it minimizes corrosion of pipes and enhances palatability. The pH values recorded in this study suggest that groundwater in Daura Town is chemically stable and suitable for drinking. Similar pH ranges have been reported in groundwater studies across northern Nigeria, where sedimentary geology influences groundwater chemistry (Offodile, 1992).

5.3.2 Total Dissolved Solids (TDS)

The results on Total Dissolved Solids (TDS) concentrations across the twelve sampling points ranged from 33.33 mg/L to 166.7 mg/L, which are well below the WHO and SON permissible limit of 500 mg/L (Table 2). These low TDS values indicate low mineralisation of groundwater and suggest minimal influence from industrial effluents or saline intrusion.

Table 2: Distribution of TDS Water sources

Sample	Wards	TDS mg/l	WHO (2019)	SON (2020)
1	Water Board	66.7	500	500
2	Tawalala	166.7	500	500
3	Tsame	33.33	500	500
4	Rijiyar Turai	100	500	500
5	Famfon Shata	100	500	500
6	Unguwar Garake	33.33	500	500
7	GRA	33.33	500	500
8	Shagari Low-cost	33.33	500	500
9	Unguwar Madina	100	500	500
10	Kofar Gabas	66.7	500	500
11	Bayan Motel	33.33	500	500
12	Bayan Dogon Bene	133.3	500	500

Source: Field Work, 2023

Low TDS concentrations are typical of groundwater in semi-arid environments where recharge is limited and aquifers are shallow. Although high TDS levels can pose aesthetic and health concerns, the values recorded in this study do not present such risks. The results imply that groundwater in Daura Town is fresh and suitable for domestic consumption. This finding aligns with studies conducted in similar geological settings in northwestern Nigeria (Ajayi et al., 2021).

5.3.3 Total Hardness

Total hardness values recorded across the study area (Figure 2) were relatively low, with the highest values observed in borehole samples from Tawalala and Water Board areas. All measured hardness values were far below the WHO (500 mg/L) and SON (150 mg/L) limits. Low hardness indicates limited concentrations of calcium and magnesium salts in groundwater.

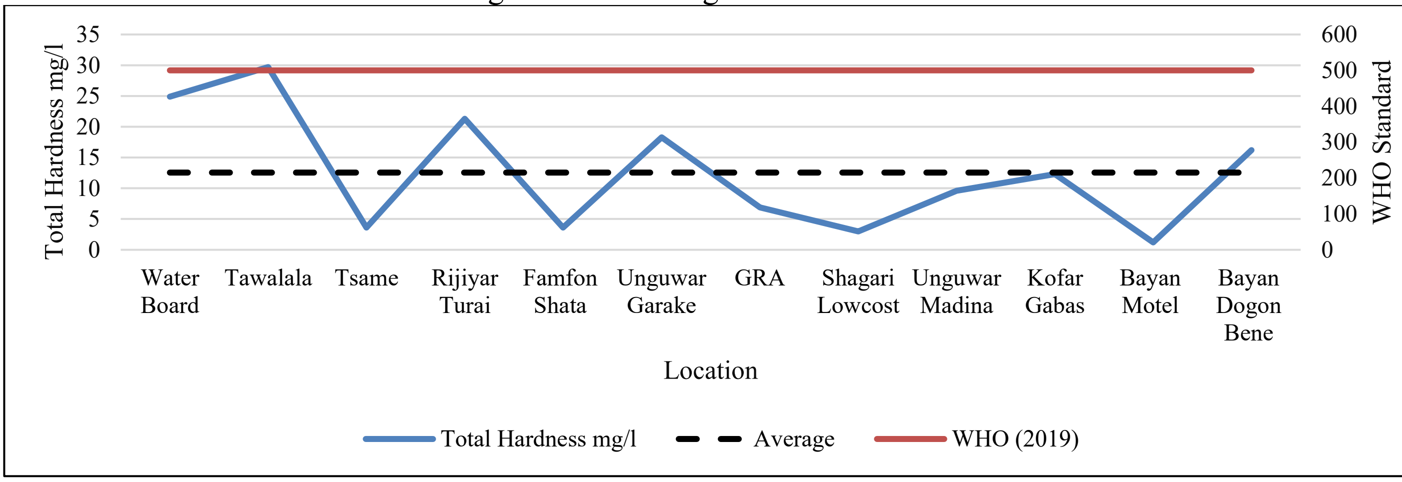

Figure 2: Distribution of Total Hardness for Water samples

Soft water, as observed in this study, is advantageous for domestic use because it reduces soap consumption and prevents scaling in pipes and household appliances, which is similar to the findings of Jidauna et al. (2014) that reveal over 87% of the groundwater within the metropolis (Jos-Plateau) has a fair spatial distribution of soft water. However, extremely soft water may be slightly corrosive, emphasising the need for balanced mineral content. Overall, groundwater hardness in Daura Town poses no health risk and confirms suitability for domestic use.

5.3.4 Chloride Concentration

Chloride concentrations in groundwater samples ranged between 37.22 mg/L and 115.21 mg/L, all within WHO (250 mg/L) and SON (400 mg/L) standards (Figure 3). Chloride in groundwater typically originates from natural sources such as mineral dissolution and anthropogenic activities including sewage infiltration and waste disposal (Jidauna et al., 2018; Ajayi et al., 2021)

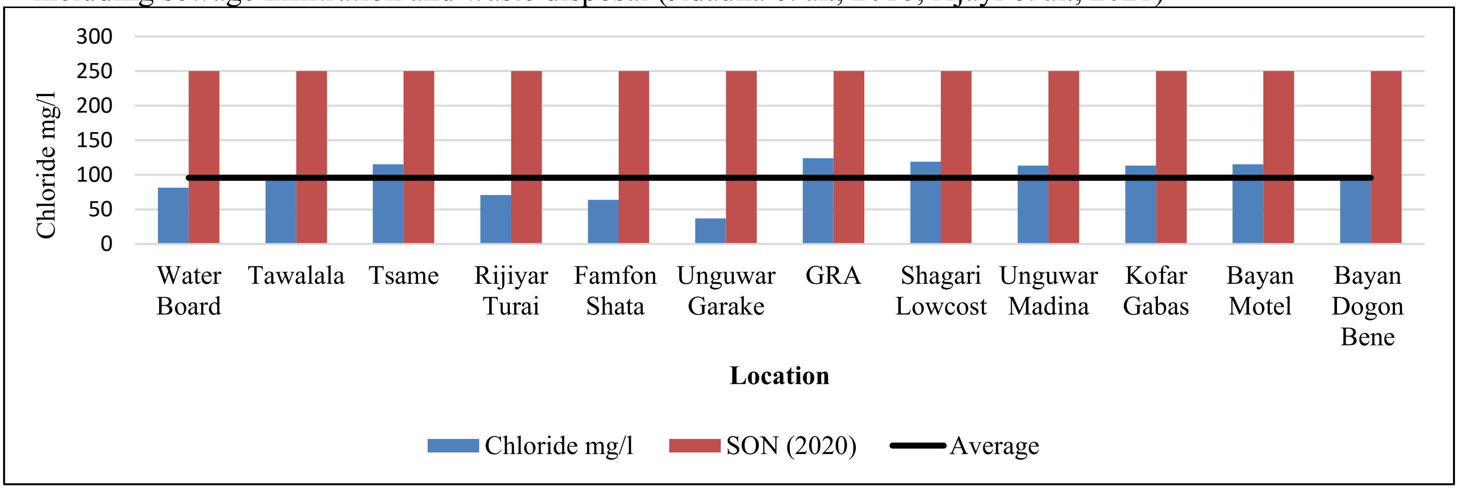

Figure 3: Chloride concentration in water sources

The moderate chloride levels observed in Tsame and Bayan Motel may reflect localised human activities, but the values remain within safe limits. Excessive chloride can impart a salty taste to water and corrode plumbing systems; however, such effects are unlikely in the study area given the recorded concentrations. Though Ajayi et al. (2021) attributed isolated factors that are human induced easily elevate the concentration, but then the nature of the geological formation is equally crucial.

5.3.5 Magnesium, Iron, Copper, and Bicarbonate

The results on Magnesium concentrations across the study area as presented in Figure 4 indicates low level concentration. Similarly, copper concentrations were below the WHO and SON guideline value of 1 mg/L, suggesting minimal contamination from plumbing materials or industrial sources. Similarly, in a study conducted by Jidauna et al. (2018) in Dutsin-Ma on groundwater quality reported Cu values below the standard, which could be attributed to absence of chemical base factories within the study area.

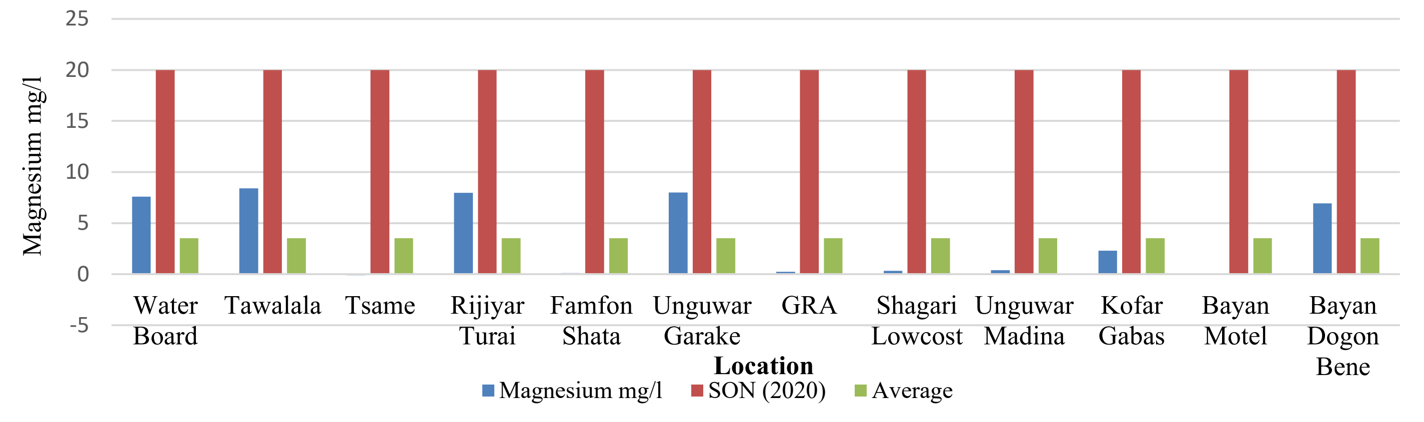

Figure 4: Magnesium Concentration from Water Sources

Iron concentrations, however, showed localised elevation in some borehole samples, exceeding recommended limits in specific locations. Elevated iron levels may be attributed to the dissolution of iron-bearing minerals in the aquifer or corrosion of borehole casings. While iron is an essential nutrient, excessive concentrations can cause aesthetic problems such as staining and unpleasant taste. Jidauna et al. (2013 & 2014) reveals that human induced activities are the major drivers of groundwater pollution with heavy metals elements being the most hazardous to human health.

Bicarbonate concentrations were generally low and within permissible limits, reflecting the dominance of carbonate weathering processes in the aquifer system.

5.3.6 Calcium Concentrations from Water Sources

The Results of Calcium Concentrations water sample from the different sources are presented below in figure 5.

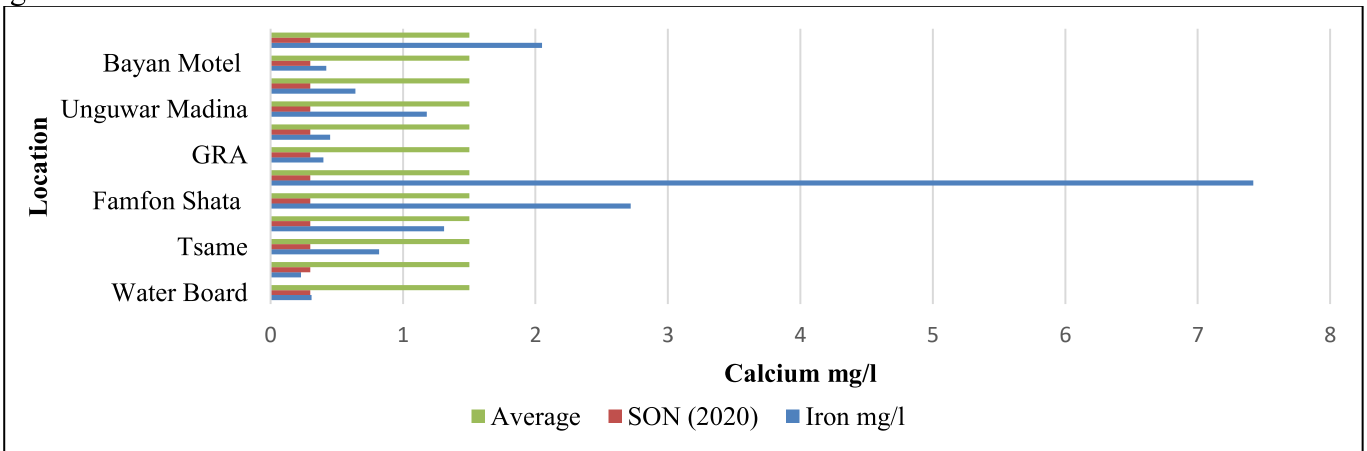

Figure 5. Calcium Concentration from Water Sources

The spatial distribution of calcium within the study area are relatively beyond the acceptable limits for both SON and WHO standard for water quality, with Ungwar Garake (7.6 mg/l) recording the highest level of concentration.

High calcium concentration in drinking water contributes to water hardness, which can cause several domestic and health-related effects. Hard water reduces the efficiency of soaps and detergents, leading to increased soap consumption and scale formation in pipes, boilers, and household appliances, thereby increasing maintenance costs (WHO, 2011). Excessive calcium may also affect the taste of water, making it less palatable. Although calcium is an essential nutrient that supports bone and dental health, very high intake through drinking water may contribute to kidney stone formation in susceptible individuals (Murray, 2017; Jidauna et al., 2018). Consequently, monitoring calcium levels in drinking water is important to balance health benefits and potential adverse effects.

5.4 Comparison with National and International Standards

The overall comparison of groundwater quality parameters with WHO and SON standards indicates that groundwater in Daura Town is largely suitable for domestic use. Most physicochemical parameters fall within acceptable limits, with only localised iron enrichment requiring attention. These findings highlight the relative safety of groundwater resources in the area while emphasizing the importance of routine monitoring and source protection.

6.0 CONCLUSION AND RECOMMENDATIONS

This study provides a comprehensive assessment of groundwater quality and its spatial variability in Daura Town, Katsina State. Findings indicate that groundwater remains a reliable and generally safe source of domestic water, with most physicochemical parameters complying with WHO and SON drinking water standards. Neutral to slightly alkaline pH levels, low total dissolved solids, and minimal hardness reflect favorable hydrogeochemical conditions influenced by the sedimentary geology of the area. Nonetheless, the presence of localised elevated iron concentrations highlights the influence of both natural geological formations and anthropogenic factors such as borehole construction materials and land-use practices. The observed vulnerability of shallow wells, particularly those that are poorly protected and located near waste disposal sites, underscores the need for improved groundwater source protection. Spatial analysis using GIS proved effective in visualising groundwater quality patterns and identifying potential risk zones. Overall, sustainable groundwater management in Daura Town requires routine water quality monitoring, improved urban sanitation, adherence to well-siting regulations, and public awareness of groundwater protection. These measures are essential for safeguarding public health and ensuring long-term water security in semi-arid urban environments.

7.0 LIMITATION OF THE STUDY

The study was limited to selected chemical elements, and the sample size was insufficient to cover the entire study area, owing to financial constraints and the limited timeframe for the work.

REFERENCES

Abbas, A. A., Abotalib, A. Z., Sultan, M., & Elkadiri, R. (2019). Groundwater quality assessment using hydrochemical analysis and GIS techniques in semi-arid regions of Nigeria. Environmental Earth Sciences, 78(4), 1–15.

Abotalib, A. Z., & Heggy, E. (2019). Groundwater sustainability in Africa: Current challenges and future prospects. Hydrogeology Journal, 27(7), 2475–2487.

Adeyemi, O., Adesile, A., & Obayomi, O. (2003). Groundwater exploitation and quality deterioration in Nigeria. Journal of Environmental Studies, 12(2), 45–56.

Ajayi, O. O., Adeyemi, D. A., & Yusuf, A. A. (2021). Assessment of groundwater quality in semi-arid regions of northern Nigeria. Journal of Environmental Hydrology, 29(3), 45–60.

Ajayi, O. O., Adeyemi, D. A., & Yusuf, A. A. (2021). Climatic variability and environmental conditions in semi-arid northern Nigeria. Journal of Climate and Environmental Studies, 13(2), 45–58.

Akpoborie, I. A., Etobro, A. A., & Odagwe, S. (2008). Water quality assessment of groundwater in Nigeria. Journal of Applied Sciences, 8(4), 637–645.

Balarabe, M. L., Igwe, E. C., & Lawal, K. M. (2000). Urban groundwater pollution in northern Nigeria. Nigerian Journal of Geography and the Environment, 2(1), 33–44.

Jidauna, G. G., Dabi, D. D., & Saidu, B. J. (2013). Assessment of well water quality in selected locations of Jos Plateau State, Nigeria. International Journal of Environmental Sciences, 3(4), 1239–1250.

Jidauna, G.G., Dabi, D.D., Saidu, B.J., Ndabula, C., & Abaje, I.B. (2014). Chemical Water Quality Assessment in Selected Location in Jos, Plateau State, Nigeria. Research Journal of Environmental and Earth Sciences, 6, (5), 284-291. e-ISSN: 2041-0492. http://www.maxwellsci.com/jp/abstract.php?jid=RJEES&no=438&abs=06

Jidauna, G.G., Barde, S.R., Ndabula, C., Oche, C.Y., & Dabi, D.D (2017). Water quality assessment of selected domestic water sources in Dutsinma town, Katsina State, Science World Journal, 12(4), 43-50.

Jidauna, G.G., Joseph, N.N., Ndabula, N., & Oyatayo, K.T. (2018). Assessment of Landuse Landcover Changes in Dutsinma LGA of Katsina State, Nigeria (1988-2014). Journal of Environmental Sciences, 19, (1&2), 133-145.

Katsina State Ministry of Environment. (2002). Environmental baseline survey of Katsina State. Katsina, Nigeria: Ministry of Environment.

Milovanovic, M. (2007). Water quality assessment and pollution control. Water Resources Management, 21(3), 573–591.

Murray, K. S. (2017). Calcium and magnesium in drinking water and their association with kidney stone disease. Journal of Water and Health, 15(6), 890–899.

National Population Commission (NPC). (2006). Population and housing census of the Federal Republic of Nigeria. Abuja, Nigeria: NPC.

Ndabula, C., Jidauna, G.G., Abaje, I. B., Adamu, G. K., Ubogu, A. E, Ati, O. F., & Odigie, V. A. (2018). Spatial analysis of sulphate and phosphate levels of major domestic water intake Sources in Dutsin-ma town, Katsina State, Nigeria. FUDMA Journal of Sciences (FJS), 2 (3), 146 – 153.

Offodile, M. E. (1992). An approach to groundwater study and development in Nigeria. Jos, Nigeria: Mecon Geology and Engineering Services Ltd.

Purandara, B. K., & Varadarajan, N. (2003). Impacts of groundwater pollution on drinking water quality. Environmental Monitoring and Assessment, 82(1), 45–58.

Sarkar, A., Pandey, P., & Singh, R. (2007). GIS-based groundwater quality mapping using IDW interpolation technique. Environmental Monitoring and Assessment, 132(1–3), 123–135.

Siebert, S., Burke, J., Faures, J. M., Frenken, K., Hoogeveen, J., Döll, P., & Portmann, F. T. (2010). Groundwater use for irrigation – A global inventory. Hydrology and Earth System Sciences, 14, 1863–1880.

Standard Organisation of Nigeria (SON). (2020). Nigerian standard for drinking water quality. Abuja, Nigeria: SON.

Van der Gun, J. (2012). Groundwater and global change: Trends, opportunities and challenges. Paris, France: UNESCO.

World Health Organisation (WHO). (2011). Guidelines for drinking-water quality (4th ed.). Geneva, Switzerland: WHO.

World Health Organisation (WHO). (2019). Guidelines for drinking-water quality (4th ed.). Geneva, Switzerland: WHO.