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ASSESSMENT OF SPATIAL DISTRIBUTION OF PUBLIC BOREHOLES IN SOKOTO METROPOLIS, NIGERIA

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Abstract https://doi.org/10.65760/sjgs.v4.i2.14

The increasing dependence on groundwater for domestic water supply in rapidly urbanizing cities has heightened the need for equitable and sustainable distribution of public borehole infrastructure. This study assessed the spatial distribution of public boreholes in Sokoto Metropolis, Nigeria, with the aim of evaluating their distribution pattern, accessibility, and governance to support evidence-based urban water planning. A census survey of all 71 public boreholes distributed across 27 administrative wards was undertaken using handheld Global Positioning System (GPS) receivers, field observations, and institutional records obtained from the Sokoto State Water Board. Geographic Information Systems (GIS) techniques, including Average Nearest Neighbour (ANN) and buffer analyses, were employed alongside descriptive statistics to evaluate spatial distribution, accessibility, and management characteristics. The results revealed pronounced spatial inequalities in borehole allocation, with Arkilla Ward accounting for 35.2% (25 boreholes) of the total infrastructure, while 10 wards had no public boreholes despite supporting substantial populations. The ANN analysis produced a Nearest Neighbour Ratio of 0.856864 (Z = –2.258050; p = 0.023943), indicating a statistically significant clustered distribution. Buffer analysis further identified extensive accessibility gaps, particularly within densely populated and peripheral communities. The study concludes that sustainable urban water security in Sokoto Metropolis requires GIS-based groundwater planning and equitable infrastructure allocation, to enhance groundwater sustainability and support the achievement of Sustainable Development Goal 6 and Integrated Water Resources Management (IWRM) principles.

Keywords: *Boreholes, Geographic Information Systems, Spatial distribution, Sokoto Metropolis, Nigeria*.

1.1 Introduction

Access to safe and reliable drinking water is essential for human health, socioeconomic development, and environmental sustainability. Despite improvements in water supply systems, about 2.2 billion people worldwide still lack safely managed drinking water, with the greatest burden in developing countries (WHO & UNICEF, 2023). Groundwater has become a critical freshwater resource, supplying nearly half of the global population with drinking water and supporting about 43% of irrigated agriculture (UNESCO, 2024). Its reliability during droughts and seasonal variability makes it particularly valuable in semi-arid and arid regions. The rapid expansion of groundwater abstraction, often described as the "silent groundwater revolution," has been driven by advances in drilling technology, hydrogeological exploration, and pumping systems (Giordano, 2009; UNESCO, 2022). While groundwater now provides about 36% of global potable water and nearly half of domestic freshwater consumption (UNESCO, 2024), increasing dependence has raised concerns

about sustainable abstraction, infrastructure management, and equitable access, particularly in rapidly urbanizing cities across Sub-Saharan Africa (Taylor et al., 2013; Foster & MacDonald, 2021). Although groundwater resources are generally abundant, access remains uneven due to disparities in infrastructure distribution and governance. In many developing countries, public boreholes are the main source of groundwater for urban and peri-urban communities. However, their distribution is often unequal, with politically or economically advantaged neighbourhoods receiving better services than densely populated and vulnerable communities (Aliyu et al., 2020; Kouadio et al., 2022). These inequalities limit access to safe water and hinder sustainable urban development.

Nigeria possesses significant groundwater resources, yet access to safe water remains inadequate because of deteriorating public water infrastructure, rapid urbanization, climate variability, and poor maintenance (Akujieze et al., 2003; Tukur et al., 2016). More than half of the country's public boreholes are estimated to be partially functional or non-functional due to mechanical failure, weak institutional coordination, and inadequate maintenance (Rural Water Supply Network, 2015; UNICEF Nigeria, 2023). In Northern Nigeria, particularly Sokoto Metropolis, boreholes have become the principal source of domestic water because centralized water systems are insufficient. However, increasing borehole numbers have not ensured equitable access. Their concentration in selected neighbourhoods has created significant disparities, forcing residents of underserved areas to travel long distances, depend on unsafe sources, or purchase expensive water from vendors. Excessive clustering may also increase groundwater depletion and contamination risks (Lawali et al., 2021). These inequalities reflect weaknesses in urban planning, infrastructure investment, and evidence-based decision-making. Borehole siting is often influenced by political or administrative considerations rather than hydrogeological suitability, population density, and service demand (Obeta, 2019; Foster & MacDonald, 2021). Consequently, Geographic Information Systems (GIS) have become increasingly important for assessing infrastructure distribution and promoting equitable groundwater management (Kumar et al., 2021). Previous GIS-based studies have identified inequalities in borehole distribution in cities such as Delhi, Abidjan, Lapai, and Okene (Yaro et al., 2019; Aliyu et al., 2020; Kumar et al., 2021; Kouadio et al., 2022). However, few studies have comprehensively examined borehole distribution, accessibility, functionality, and management in Sokoto Metropolis despite its growing dependence on groundwater. This study therefore assesses the spatial distribution and management of public boreholes in Sokoto Metropolis using Geographic Information Systems (GIS), Nearest Neighbour Analysis, buffer analysis, and descriptive statistics. It evaluates borehole accessibility, distributional equity, functionality, and management to provide evidence for improving groundwater governance, equitable infrastructure allocation, and sustainable urban water management. The findings are expected to support the achievement of Sustainable Development Goal 6 (SDG 6) by informing policies that improve water security and reduce spatial inequalities in public water supply.

2.0 Materials and Methods

2.1 Research Design

This study adopted a cross-sectional spatial survey design that integrated field data collection with Geographic Information Systems (GIS) and spatial statistical techniques to assess the distribution and management of public boreholes in Sokoto Metropolis. Descriptive, quantitative, and geospatial methods were combined to evaluate spatial equity, accessibility, functionality, and management of groundwater infrastructure. GIS provided a framework for identifying spatial inequalities in water service delivery (Longley et al., 2021), while spatial statistical analyses determined whether borehole distribution was clustered, random, or dispersed. Accessibility analysis was also conducted to evaluate the adequacy of public water service coverage across the metropolis.

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2.2 Study Area

The study was conducted in Sokoto Metropolis, northwestern Nigeria, located between latitudes 12°55′N–13°10′N and longitudes 5°07′E–5°19′E. The metropolis comprises Sokoto North and Sokoto South Local Government Areas and adjoining urban settlements in Wamakko, Dange-Shuni, and Kware LGAs, covering approximately 16 km from Giginya Memorial Stadium. Situated within the Sudan Savannah ecological zone, the area has a semi-arid climate with prolonged dry seasons, high temperatures, low rainfall, and high evapotranspiration. Rapid urban growth has increased pressure on public water supply systems, making groundwater from boreholes a major domestic water source. The metropolis lies within the Sokoto Basin, whose sedimentary formations constitute important groundwater-bearing aquifers supporting domestic water supply (Ibrahim et al., 2023; Wali et al., 2022).

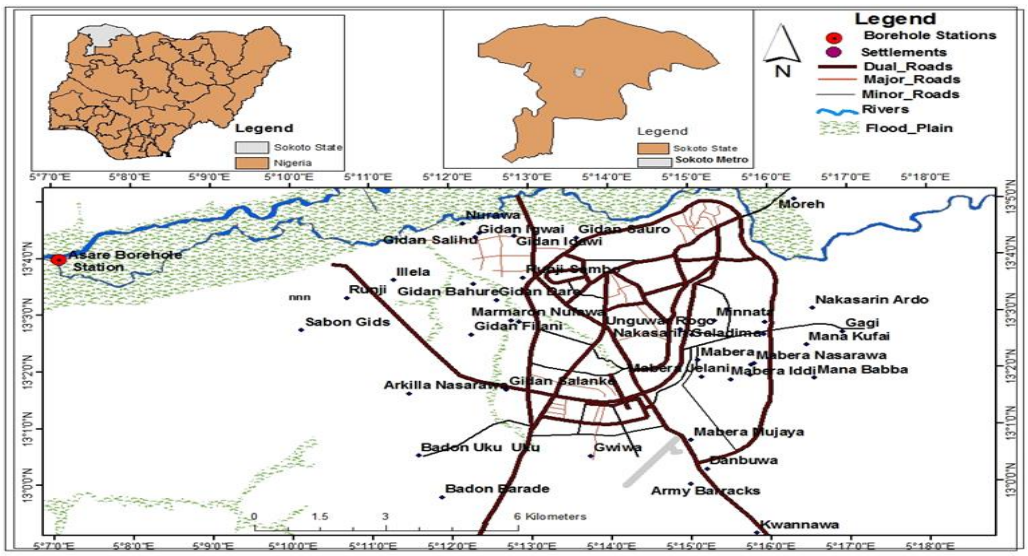

Figure 1: Location of Sokoto Metropolis in Nigeria

2.3 Sources of Data

The study utilized both primary and secondary data. Primary data were obtained through field surveys, during which the geographic coordinates of all public boreholes were captured using a Garmin GPSMAP 78s handheld GPS receiver. Field observations also assessed borehole functionality, physical condition, accessibility, maintenance status, and the presence of community management committees. Secondary data, including borehole records, administrative boundaries, population data, geological information, and urban development data, were obtained from the Sokoto State Water Board, National Population Commission, Sokoto Urban and Regional Planning Board, and relevant literature. Combining both data sources enhanced the reliability of the spatial analysis.

2.4 Population of the Study and Sampling Procedure

The study population comprised all seventy-one (71) public boreholes managed by the Sokoto State Water Board across twenty-seven (27) administrative wards of Sokoto Metropolis. A census

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approach was adopted, with all boreholes included in the study. This eliminated sampling bias and ensured complete spatial representation of public groundwater infrastructure.

2.5 Data Collection Procedure

All public boreholes were visited for field verification using the official inventory provided by the Sokoto State Water Board. Geographic coordinates were recorded with a Garmin GPSMAP 78s receiver, while observations were made on borehole functionality, physical condition, accessibility, maintenance, and community management. Field data were cross-checked with institutional records to improve accuracy and consistency.

2.6 Spatial Data Processing

GPS coordinates were downloaded into Microsoft Excel and imported into ArcGIS Pro Version 3.x for analysis. Spatial data were projected to the Universal Transverse Mercator (UTM) Zone 31 North using the WGS 1984 datum. A geodatabase containing spatial and attribute data was created and integrated with administrative boundaries and other spatial layers to produce thematic maps and support spatial analyses.

2.7 Spatial and Statistical Analysis

Spatial analysis was conducted using Geographic Information Systems (GIS) and spatial statistical techniques to evaluate the distribution and accessibility of public boreholes in Sokoto Metropolis. The Average Nearest Neighbour (ANN) analysis was used to determine whether borehole distribution was clustered, random, or dispersed by comparing the observed mean nearest-neighbour distance ((Do)) with the expected distance ((De)) under complete spatial randomness: The Nearest Neighbour Ratio (R) was computed as:

$$R = \frac{D_o}{D_e}$$

where:
where Do represents the observed mean nearest-neighbour distance, while De denotes the expected mean distance calculated as:

$$\mathrm{D_e} = \frac{0.5}{\sqrt{\mathrm{n/A}}}$$

and *n* is the number of boreholes while *A* is the study area. The statistical significance of the distribution pattern was evaluated using the Z-score at the 95% confidence level. Values of (R<1), (R=1), and (R>1) indicate clustered, random, and dispersed distributions, respectively (Clark & Evans, 1954). Buffer analysis was also performed by creating 200 m and 500 m buffer zones around each borehole to assess accessibility and identify adequately served, underserved, and unserved areas. Descriptive statistics, including frequencies, percentages, means, and standard deviations, were used to summarize borehole functionality, management, and distribution, with results presented in tables, charts, and thematic maps.

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2.8 Data Quality Assurance

To ensure data reliability, GPS coordinates were verified through repeated field measurements, while field observations were cross-checked with records from the Sokoto State Water Board. Attribute data were cleaned to remove inconsistencies, missing values, and duplicates, and GIS topology validation was performed to eliminate spatial errors before the final analyses.

3.0 Results and Discussion

3.1 Spatial Distribution of Public Boreholes

The spatial assessment identified a total of 71 public boreholes distributed across 27 administrative wards in Sokoto Metropolis, serving an estimated population of 739,235 people. The distribution pattern reveals considerable spatial disparities in the allocation of groundwater infrastructure, indicating that public borehole provision is not proportional to population distribution across the metropolis (Table 1).

Table 3.1 Boreholes and Population Distribution in Sokoto Metropolis

S	Name of ward	Population	Number of Boreholes	% Of Bh Area/ward
1	Arkilla	35,586	25	35.2
2	Bado	20,176	7	9.86
3	Gagi A	44,463	5	7.04
4	Gagi B	30,853	3	4.23
5	Gagi C	43,550	3	4.23
6	Kalambaina	25,958	1	1.41
7	Magajin Gari A	30,798	2	2.82
8	Magajin Gari B	35,387	4	5.63
9	Magajin Rafi A	27,468	0	0.00
10	Magajin Rafi B	23,420	2	2.82
11	More	13,070	3	4.23
12	Rijia A	14939	0	0.00
13	Rijia B	17,864	1	1.41
14	Sarkin Adar K/Atiku	20,960	0	0.00
15	Sarkin Adar Kwanni	17,864	0	0.00
16	SarkinAdar G/Igwai	44,845	2	4.28
17	Sarkin Adar Gandu	44,845	0	0.00
18	Sarkin Musulmi A	9,804	1	1.41
19	Sarkin Musulmi B	9,675	0	0.00
20	Sarkin Zamfara A	13,798	0	0.00
21	Sarkin Zamfara B	20,510	2	4.28
22	Tudun Wada A	21,350	0	0.00
23	Tudun Wada B	24,276	5	7.04
24	Tuntube /Tsefe	47,600	4	5.63
25	Waziri A	51,207	0	0.00
26	Waziri B	27,756	0	0.00
27	Waziri C	21,213	1	1.41
	TOTAL	**739,235**	**71**	**100.00**

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Arkilla Ward recorded the highest concentration of public boreholes, with 25 installations (35.2% of the total), despite having only 35,586 residents. In contrast, densely populated wards such as Waziri A, Tuntube/Tsefe, Sarkin Adar Gandu, Gagi C, and Gagi A had relatively few or no public boreholes. Ten administrative wards lacked any public borehole despite several having populations exceeding 20,000. These findings reveal a clear mismatch between borehole distribution and population demand, indicating that population size has not been the primary determinant of infrastructure allocation. This imbalance reflects significant inequalities in access to groundwater infrastructure and weaknesses in urban water planning. Rather than aligning with population density and water demand, borehole distribution appears to have evolved independently of demographic realities. Consequently, residents of densely populated wards face longer travel distances, greater competition for water, and increased dependence on vendors and unsafe alternative sources, with adverse effects on public health and household welfare. The concentration of boreholes in relatively low-density areas such as Arkilla and Bado may be attributed to larger land availability, planned urban layouts, and administrative or political priorities rather than objective assessments of community needs. Similar patterns have been reported across Africa, where infrastructure distribution is often shaped by governance and political decisions instead of evidence-based planning (Foster & MacDonald, 2021; Kouadio et al., 2022).

The findings are consistent with previous studies in Nigeria and elsewhere. Aliyu et al. (2020) and Yaro et al. (2019) reported significant inequalities in public water infrastructure distribution in Lapai and Okene, while Kumar et al. (2021) and Kouadio et al. (2022) identified comparable socioeconomic disparities in groundwater access in Delhi and Abidjan. This suggests that inequitable groundwater infrastructure allocation is a common challenge in rapidly urbanizing cities across the Global South. Beyond accessibility, the uneven distribution raises concerns about groundwater sustainability. Excessive clustering of boreholes may accelerate localized aquifer depletion, increase pumping costs, and affect groundwater quality, while underserved areas with groundwater potential remain underutilized. These findings highlight the need for infrastructure planning based on hydrogeological suitability, population distribution, and projected urban growth. Overall, the results indicate that groundwater infrastructure development in Sokoto Metropolis has not fully incorporated principles of spatial equity and sustainable urban planning. Achieving Sustainable Development Goal 6 (SDG 6) requires shifting from politically driven borehole allocation to evidence-based planning that integrates Geographic Information Systems (GIS), population density, groundwater potential, and social vulnerability. Such an approach would promote more equitable, efficient, and sustainable groundwater management.

3.2 Spatial Configuration of Public Boreholes in Sokoto Metropolis

The spatial distribution of public boreholes in Sokoto Metropolis (Figure 2) is highly uneven, with pronounced clustering in selected neighbourhoods and limited coverage across much of the metropolis. Rather than being uniformly distributed to maximize accessibility, boreholes are concentrated mainly in the southwestern axis, particularly within Arkilla and Bado wards, while several densely populated and peripheral settlements remain poorly served or entirely without public borehole facilities.

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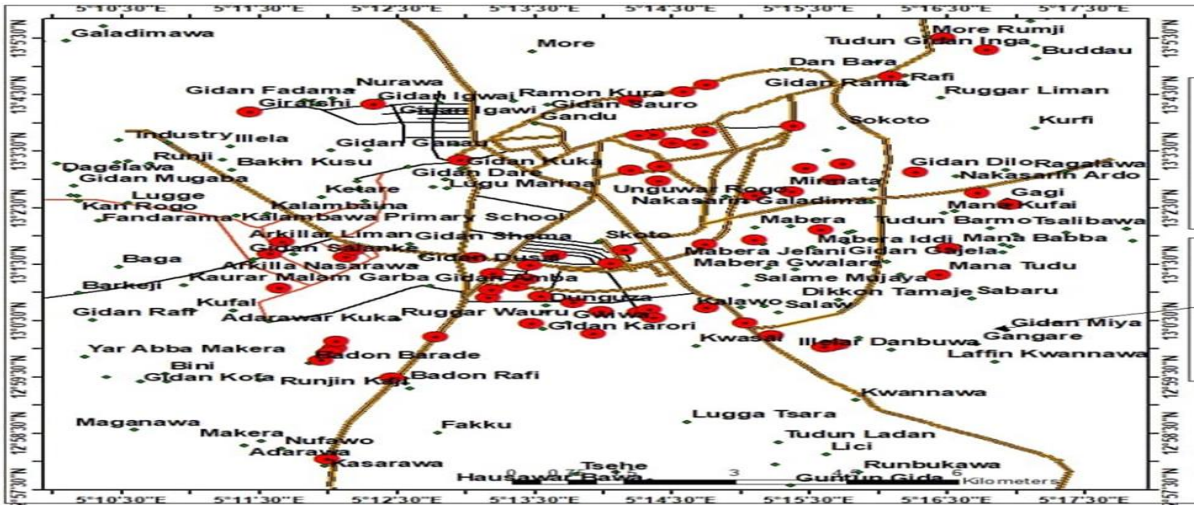

Figure 2 Spatial Configuration of Public Boreholes in Sokoto Metropolis

Visual assessment of the spatial distribution shows that public boreholes are unevenly distributed, forming distinct clusters separated by large underserved areas. Arkilla Ward contains the densest concentration of boreholes, whereas neighbourhoods such as Mabera, Kofar Rini, Sabon Birni, and parts of the southeastern metropolis have few or no facilities. This pattern indicates that groundwater infrastructure has developed unevenly rather than through systematic planning for equitable service coverage. The concentration of boreholes in relatively low-density neighbourhoods may be explained by both physical and institutional factors. These areas generally have lower building densities, wider road networks, and more available land, making borehole installation and maintenance easier. In contrast, the densely built-up sections of Sokoto North and Sokoto South offer limited space for new infrastructure. Administrative priorities, political influence, and historical investment patterns may also have shaped borehole allocation more than population needs or groundwater accessibility (Foster & MacDonald, 2021). This spatial concentration has important implications for groundwater sustainability. Closely spaced abstraction points may increase localized groundwater withdrawal, raising the risk of declining water tables, higher pumping costs, and reduced groundwater quality (UNESCO, 2022). Although groundwater recharge was not assessed, the observed clustering highlights the need for regular hydrogeological monitoring. The uneven distribution also affects water accessibility. Residents outside the main borehole clusters are likely to travel longer distances or depend on alternative water sources, increasing the burden on women and children and affecting household welfare, public health, education, and productivity (WHO & UNICEF, 2023).

These findings are consistent with studies in Delhi, Abidjan, and Nigeria, which reported that groundwater infrastructure is often concentrated in relatively advantaged areas rather than being distributed according to population needs (Kumar et al., 2021; Kouadio et al., 2022; Adah *et al.,* 2019). This suggests that spatial inequality in groundwater infrastructure is a widespread challenge in developing countries. The results underscore the importance of integrating Geographic Information Systems (GIS) into urban water planning. GIS can combine demographic, hydrogeological, land-use, and accessibility data to identify optimal locations for future boreholes, improving service efficiency and equity. Future groundwater development in Sokoto Metropolis should therefore prioritize underserved communities while avoiding unnecessary clustering, an approach consistent with Integrated Water Resources Management (IWRM) and Sustainable Development Goal 6.

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3.3 Spatial Disparity in Public Borehole Distribution in Sokoto Metropolis

The ward-level inventory reveals significant spatial disparities in the distribution of public boreholes across Sokoto Metropolis, indicating unequal access to safe drinking water. Although public boreholes are intended to ensure equitable water supply, their distribution across the twenty-seven administrative wards varies considerably in both number and coverage. While some wards contain several closely spaced boreholes, others remain poorly served or completely lack public groundwater facilities (Tables 2 a–c).

Table 2 a Administrative Wards and Corresponding Boreholes Locations

Arkilla	Bado	Gagi A	Gagi B	Gagi C	Kalambaina	Magain Gari A	Magajin Gri B	Magajin Rafi A
Abuja Rd	Bado	Gagi 1	Bafarawa	Civil	Girafshi	Helele	Assada	
Arkilla	Kasarawa		Qtrs 1	service club				
Magagi								
Arkilla fedl	Bado	Gagi 2	Bafarawa	Mabera		Kofar	Dan Fili	
Low C 1	Quarters 1		Qtrs 2	Gidan		Kware		
Arkilla Fed				Zabira				
Low C 2								
Arkilla	Bado	Mana	D/S Pump	Tafida			Massallacin	
pumping	Quarters 2		Station	Aminu			Shehu	
station								
Arkilla state	Bada	Nakasari					Hubbare	
Low C 1	Quarters 3	Barebari						
Arkilla state	Bado	Sabaru						
Low C2	Village							
Arlilla	Kasarawa							
Liman 1								
Arkilla								
Liman 2								
Ex	Technical							
perliament	Farfaru							
Qtrs 1								
Ex								
perliament								
Qtrs 2								
Gwiwa								
Mangoro								
Rd								
Gwiwa								
G/line								
Gwiwa pri								
sch								
Kontagora								
Rd								
Natu Rd								
Polo Club								
Pumping S								
vi								
Supar								
quarters								
Talata								
Mafara Rd								
Wurno								
Road								
Yauri /Klm								
Road								
Yauri Flat								
Yauri								
Kaduna								
Zaga Road								

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Table 2 b Continuation of Administrative Wards and Corresponding Boreholes Locations

S/Musulmi B	S/Zamfara A	S/ Zamfara B	Tudun Wada A	Tudun Wada B	Tuntube/ Tsefe	Waziri A	Waziri B	Waziri C
		Yar Akija		Ibrahim Gusau Pri	Danbuwa Gabas			Filin Idi
		Yar Goriba		Minanata	Danbuwa G/Sarki			
				New BH	Danbuwa Illela			
				T/Wada	Danbuwa Fed lowcost			
				Behine				
				INEC				
				U/Rogo				

Table 2 c Continuation of Administrative Wards and Corresponding Boreholes Locations

Magajin Rafi B	More	Rijia A	Rijia B	Sarkin Adar K/Atiku	Sarkin Adar Kwanni	Sarkin Adar G/Igwai	Sarkin Adar Gandu	Sarkin Musulmi A
Sabon Birni A	More 1		Marna Gangu			G/Igwai		
Sabon Birni B	More 2					G/Ashana		

The inventory indicates that borehole allocation has not followed a balanced spatial pattern capable of meeting the domestic water requirements of the growing urban population. Instead, considerable disparities exist between neighbourhoods with relatively abundant groundwater infrastructure and those experiencing severe shortages. For example, Arkilla Ward contains numerous public boreholes distributed across several residential layouts, whereas many densely populated wards within Sokoto North and Sokoto South possess only one or two facilities or none at all. Such disparities imply that access to public water infrastructure is strongly influenced by location rather than population need, thereby creating unequal opportunities for residents to obtain safe and affordable drinking water. These inequalities are particularly significant in the context of rapid urbanization. Population growth in Sokoto Metropolis has increased demand for domestic water, but infrastructure development has not kept pace. Consequently, residents of underserved communities often travel longer distances to obtain potable water or rely on shallow wells, seasonal ponds, and commercial vendors, increasing household costs and the risk of waterborne diseases. The findings also raise concerns about spatial justice, which advocates equitable access to public services regardless of residential location (Soja, 2010). The unequal distribution of boreholes indicates that this principle has not been achieved in Sokoto Metropolis, leaving some communities with poorer sanitation, greater health risks, and reduced educational and economic opportunities. From a public health perspective, inadequate groundwater access is problematic. The World Health Organization recommends that households should reach a drinking water source within a 30-minute round trip (WHO & UNICEF, 2023). Many underserved wards are likely to exceed this limit, especially during the dry season, reducing water use for hygiene and increasing vulnerability to water-related diseases.

These findings agree with studies in Lapai, Okene, Abidjan, and Delhi, which also reported unequal groundwater infrastructure distribution linked to demographic, socioeconomic, and institutional factors (Aliyu et al., 2020; Yaro et al., 2019; Kouadio et al., 2022; Kumar et al., 2021). This suggests that inequitable groundwater allocation is a common challenge in developing cities. Institutional factors may explain these disparities. Borehole projects are often implemented through separate government, donor, and political initiatives without integrated spatial planning, leading to

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infrastructure duplication in some areas and inadequate coverage in others. This fragmented approach appears to have shaped borehole distribution in Sokoto Metropolis. Uneven borehole distribution also affects groundwater sustainability. Clustering may increase localized groundwater abstraction, while areas with suitable aquifers remain underutilized. More balanced planning should consider hydrogeological conditions, aquifer recharge, population density, and future urban growth. Overall, the findings highlight the importance of Geographic Information Systems (GIS) and spatial decision-support tools for identifying underserved communities, assessing accessibility, and optimizing borehole locations. Their integration into urban water planning would improve investment efficiency, equity, and the long-term sustainability of groundwater resources.

3.4 Description of the Uneven Spatial Distribution of Borehole Schemes in Sokoto Metropolis

The unevenness in borehole allocation is not merely a matter of physical placement, but reflects deeper structural inequalities tied to urban planning, political influence, socio-economic stratification, and infrastructural prioritization. A robust statistical characterization of this phenomenon is critical for guiding equitable policy interventions, optimizing resource allocation, and promoting spatial justice within the urban water sector (see Fig. 3).

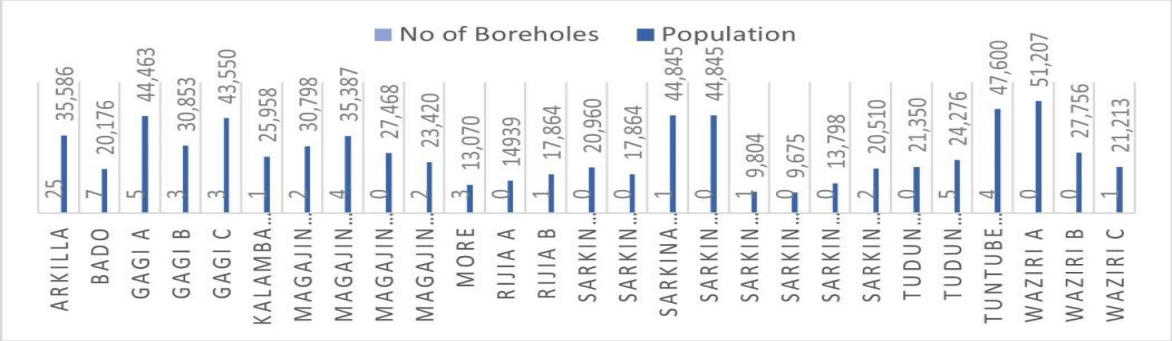

Figure 3 Uneven Distribution of Public Boreholes in The Metropolis
Source: Fieldwork, 2025

Figure 3 and accompanying statistics clearly confirm that Arkilla ward is an extreme outlier in borehole distribution, receiving significantly more borehole investments than any other ward. This overconcentration may be attributed to political or economic prioritization. In contrast, many wards receive minimal attention, with negligible numbers of boreholes indicating inequitable access to public borehole infrastructure.

The mean is inflated by Arkilla ward and a few mid-level wards such as Bado, Gagi A and Tudun wada B wards, while the median remains low, highlighting the fact that the majority of wards have low borehole counts. The positive skewness confirms the distribution's heavy tail, and the high variance reflects a lack of uniformity in borehole allocation across the metropolis.

These disparities raise critical questions for urban water governance. The current spatial pattern reinforces water injustice, particularly in peri-urban and underserved wards. The lack of rationalized, data-driven planning results in overburdened infrastructure in some areas and neglect in others. Future planning and allocation must be guided by spatial targeting, incorporating demographic and socio-economic criteria.

3.5 Average Nearest Neighbour Analysis of Public Borehole Distribution

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To objectively determine the spatial pattern of public borehole distribution in Sokoto Metropolis, the Average Nearest Neighbour (ANN) analysis was employed. The technique compares the observed mean distance between each borehole and its nearest neighbouring borehole with the expected mean distance that would occur under a completely random spatial distribution. The results provide robust statistical evidence regarding whether borehole locations are clustered, randomly distributed, or spatially dispersed. The findings of the analysis revealed an observed mean nearest-neighbour distance of 588.97 m, which is substantially lower than the expected mean distance of 687.54 m under conditions of complete spatial randomness. Consequently, the computed Nearest Neighbour Ratio (NNR) of 0.856864 indicates a clustered spatial pattern because values less than unity signify that feature are located closer together than would be expected by chance. Furthermore, the analysis produced a Z-score of –2.258050 with a corresponding p-value of 0.023943, confirming that the observed clustering is statistically significant at the 95% confidence level and is therefore unlikely to have resulted from random spatial processes.

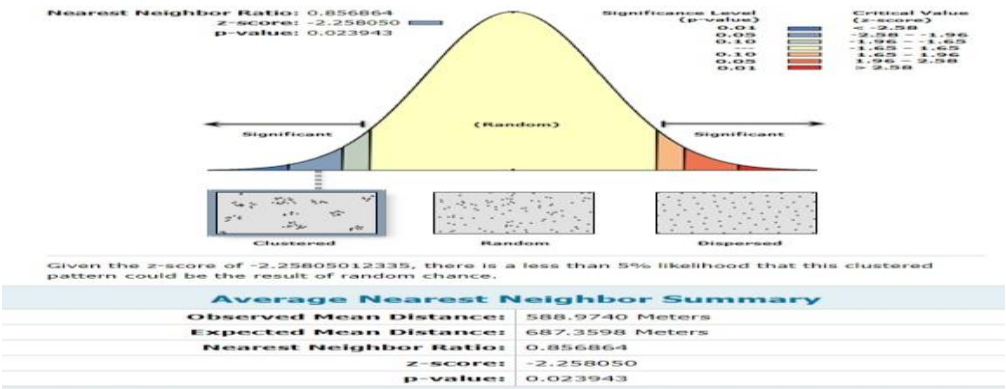

Figure 4 Average Nearest Neighborhood Analysis
Source: Fieldwork 2025

The statistically significant clustering shown in Figure 4 indicates that public boreholes in Sokoto Metropolis are not evenly distributed across the urban area. Instead, groundwater infrastructure is concentrated in a few neighborhoods, while many others remain underserved or without facilities. This pattern suggests that borehole development has largely followed localized planning decisions and historical investment trends rather than a citywide strategy based on population needs and service accessibility. The ANN results align with both the GIS map (Figure 2) and the ward-level data (Table 1). Arkilla and nearby areas show high densities of boreholes located close to one another, whereas several wards in Sokoto North and Sokoto South have wide gaps between facilities. This consistency between statistical and spatial outputs confirms that the clustering reflects a real spatial pattern. Several factors may explain this distribution. Urban expansion and infrastructure development have historically focused on selected layouts with better land availability and access. Political and constituency-based projects may also have contributed to repeated investments in certain areas, while others were neglected. In addition, favourable hydrogeological conditions may have influenced borehole siting, although this was not directly assessed in the study. The clustered pattern has important sustainability implications. Concentrated abstraction may place pressure on local aquifers, especially in semi-arid environments with limited recharge, leading to declining water tables, higher pumping costs, and reduced borehole performance. At the same time, areas without boreholes may have underutilized groundwater potential, indicating inefficient resource use. From an accessibility perspective, clustering creates inequality in water access. Residents within borehole-dense areas benefit from easier access, while those outside these zones travel longer distances and

face greater collection burdens. This disproportionately affects women and children and has implications for health, welfare, and social equity (WHO & UNICEF, 2023). These findings are consistent with studies in Delhi, Abidjan, Lapai, and Okene, which also reported clustered or uneven groundwater infrastructure linked to socioeconomic and planning factors (Kumar et al., 2021; Kouadio et al., 2022; Aliyu et al., 2020; Yaro et al., 2019). This suggests that such spatial inequality is common in rapidly urbanizing regions. The results highlight the value of integrating Average Nearest Neighbour analysis with GIS-based planning tools to identify service gaps and guide future infrastructure development. Incorporating spatial, demographic, and hydrogeological data can support more balanced and efficient allocation of boreholes. Overall, the findings underscore the need for spatially informed planning consistent with Integrated Water Resources Management principles. Future borehole development should prioritize underserved areas while balancing population demand and groundwater sustainability, in line with Sustainable Development Goal 6.

3.6 Buffer Zone Analysis of Public Borehole Accessibility in Sokoto Metropolis

The spatial accessibility of public boreholes in Sokoto Metropolis was further evaluated using buffer analysis within a Geographic Information Systems (GIS) environment. Buffer zones of 200 m and 500 m were generated around each public borehole to assess the extent to which residents can reasonably access potable groundwater facilities. The two buffer distances represent different levels of accessibility, with the 200 m buffer approximating convenient walking access of about five minutes, while the 500 m buffer represents a reasonable walking distance of approximately 10–15 minutes under normal urban conditions.

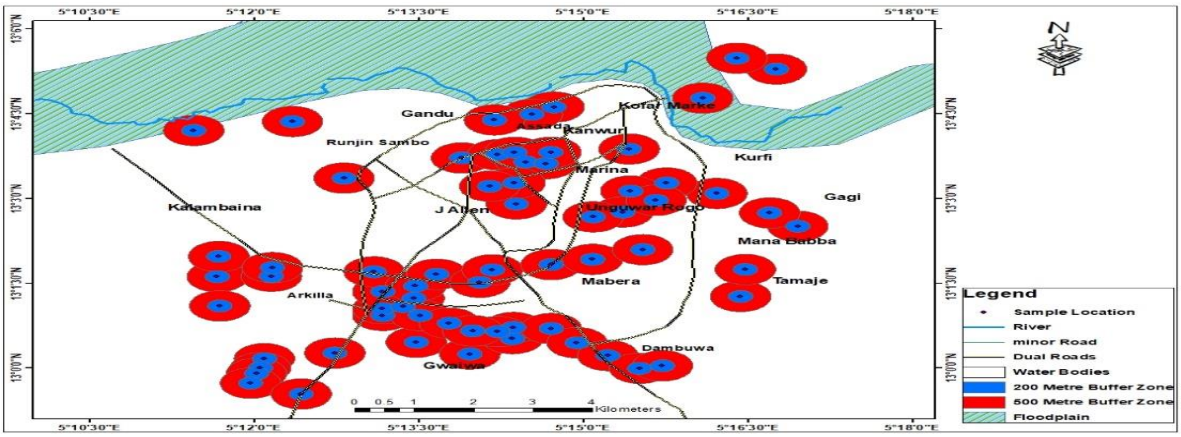

Figure 5 Buffer of Boreholes in Sokoto Metropolis
Source: Fieldwork, 2025

Figure 5 shows clear variations in groundwater accessibility across Sokoto Metropolis. The southwestern area records the highest accessibility levels, with overlapping 200 m buffer zones around Arkilla, Super Quarters, Natu Road, Ex-Parliamentary Quarters, and parts of Gwiwa. This indicates a high concentration of boreholes, giving residents multiple nearby water sources and improving reliability through redundancy. In contrast, large portions of the southeastern and peripheral areas fall outside both the 200 m and 500 m buffer zones. Communities such as Kwannawa, Sabaru, Tudun Wada, and surrounding settlements show limited coverage, meaning residents must travel longer distances to access water. These gaps indicate inadequate spatial coverage of groundwater infrastructure relative to population needs. Accessibility is a key measure of service effectiveness, as proximity determines actual use of water facilities. According to WHO & UNICEF (2023), water sources should be close enough to minimize travel time and encourage

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adequate consumption. The large unserved zones suggest that many residents may not have acceptable access levels. Poor accessibility has important public health implications. Long distances reduce water use for hygiene and may force households to rely on unsafe sources such as shallow wells, ponds, and seasonal streams, increasing the risk of diseases like diarrhoea, cholera, and typhoid. Vulnerable groups such as children and the elderly are most affected. The disparities also have gender and socio-economic impacts, as women and children often bear responsibility for water collection. Increased travel time reduces opportunities for schooling and income-generating activities, affecting household welfare and productivity (UNESCO, 2024). Although some areas show dense clustering of overlapping buffer zones, this does not translate into equitable service coverage. Instead, it reflects uneven infrastructure distribution, where some neighbourhoods have multiple nearby facilities while others remain underserved, reducing overall efficiency of public investment.

These findings align with studies in Abidjan, Delhi, and several Nigerian cities, which also reported significant inequalities in borehole accessibility (Kouadio et al., 2022; Kumar et al., 2021; Aliyu et al., 2020). This suggests that accessibility inequality is a common issue in urban water systems in developing regions. From a planning perspective, GIS-based buffer analysis is essential for identifying service gaps and guiding future borehole placement. Combining accessibility modelling with demographic and environmental data can improve equity, efficiency, and resilience in urban water supply planning.

3.7 Spatial Disparities in Service Coverage and Water Infrastructure Equity

The classification of public borehole coverage across Sokoto Metropolis reveals pronounced disparities in the spatial distribution of groundwater infrastructure and provides further evidence of inequitable access to potable water. Based on the inventory of public boreholes, administrative wards were categorized into over-served, underserved, and unserved areas according to the number of functional public boreholes available within each ward (Table 3). This classification provides a practical framework for evaluating the effectiveness of existing groundwater infrastructure and identifying priority areas requiring future intervention.

Table 3: Public Boreholes Coverage and Service Equity across Sokoto Metropolis

Sn	Over Served Areas	Underserved Areas	Unserved
1	Arkilla	Bado	Magajin Rafi A
2		Gagi A	Rijia A
3		Gagi B	Sarkin Adar K/Atiku
4		Gagi C	Sarkin Adar Kwanni
5		Kalambaina	Sarkin Adar Gandu
6		Magajin Gari A	Sarkin Musulmi B
7		Magajin Gari B	Sarkin Zamfara A
8		Magajin Rafi B	Tudun Wada A
9		More	Waziri A
10		Rijia B	Waziri B
11		Sarkin Adar G/Igwai	
12		Sarkin Musulmi A	
13		Sarkin Zamfara B	
14		Tudun Wada B	
15		Tuntube Tsefe	
16		Waziri C	

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From Table 3, Arkilla is the only clearly over-served ward, with a disproportionately high number of public boreholes compared to other areas. However, field observations show that this apparent advantage is limited, as several boreholes are partially functional or non-operational. In addition, the breakdown of the Asare Water Treatment Plant has increased reliance on groundwater within the ward, placing further pressure on existing facilities. This indicates that borehole numbers alone do not reflect effective service delivery, making functionality an important consideration. Most wards are underserved, with limited borehole coverage insufficient to meet domestic water demand. These include Bado, Gagi A–C, Kalambaina, Magajin Gari A–B, Magajin Rafi B, More, Rijia B, Sarkin Adar Gidan Igwai, Sarkin Musulmi A, Sarkin Zamfara B, Tudun Wada B, Tuntube/Tsefe, and Waziri C. In these areas, inadequate infrastructure likely results in congestion at water points, long waiting times, and increased dependence on private boreholes and vendors. Several wards are completely unserved, including Magajin Rafi A, Rijia A, Sarkin Adar K/Atiku, Sarkin Adar Kwanni, Sarkin Adar Gandu, Sarkin Musulmi B, Sarkin Zamfara A, Tudun Wada A, Waziri A, and Waziri B. Residents in these communities rely on alternative sources such as shallow wells, surface water, or commercial supply, increasing both financial costs and exposure to unsafe water. These patterns highlight weaknesses in infrastructure planning, which appears not to consistently consider population size, settlement growth, groundwater potential, or community need. Instead, borehole distribution reflects uneven historical investment that has concentrated services in some areas while excluding others. The disparities represent clear infrastructural inequality and raise concerns about social equity. Unequal access to safe water disproportionately affects low-income households, reinforcing wider inequalities in health, education, and economic opportunity. This contradicts the principle of water justice, which frames access to safe water as a basic human right and is central to Sustainable Development Goal 6 (United Nations, 2015).

The findings align with studies in Lapai, Okene, Abidjan, and Delhi, which also reported uneven water infrastructure distribution linked to planning and socio-economic factors (Aliyu et al., 2020; Yaro et al., 2019; Kouadio et al., 2022; Kumar et al., 2021). This suggests that such disparities are common in rapidly urbanizing cities in developing countries. Beyond accessibility, the uneven distribution affects groundwater sustainability. Over-concentration of boreholes can increase localized abstraction pressure, while under-served areas leave groundwater resources underutilized. More balanced planning is therefore required to improve both equity and resource efficiency. These findings emphasize the need to integrate Geographic Information Systems (GIS) into water infrastructure planning. GIS-based tools can identify service gaps, guide investment decisions, and promote more equitable and sustainable groundwater development.

4.0 Conclusion

The study concludes that achieving sustainable urban water security requires an integrated and spatially informed approach to groundwater infrastructure and planning that prioritizes equity, accessibility and effective governance. As rapid urbanization, population growth, and increasing pressure on freshwater resources continue to challenge water supply systems, the adoption of Geographic Information Systems (GIS) and spatial analytical techniques provides a robust decision-support framework for optimizing the allocation and monitoring of public boreholes. Equally important is the strengthening of institutional capacity to enhance the long-term sustainability and resilience of groundwater infrastructure. By promoting evidence-based planning and integrated groundwater governance, urban authorities can improve water service delivery, reduce spatial inequalities, and build more resilient cities capable of meeting present and future water demands. This approach offers a practical pathway towards sustainable urban water supply and supports the

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realization of Integrated Water Resources Management (IWRM) principles and Sustainable Development Goal 6, which advocate universal, equitable, and sustainable access to safe drinking water for all.

The paper recommends that:

1. Public borehole allocation should be guided by Geographic Information Systems (GIS), population distribution, groundwater potential, and accessibility analyses to ensure equitable water service delivery across all wards.
2. Community-based borehole management committees should be established and strengthened through capacity building to enhance local ownership, accountability, and long-term infrastructure sustainability.
3. The Sokoto State Water Board should develop a comprehensive GIS-based groundwater information system for continuous monitoring, maintenance planning, and evidence-based decision-making.
4. Government and development partners should integrate groundwater infrastructure planning into broader urban development policies to promote equitable access to safe drinking water and support the achievement of Sustainable Development Goal 6 (SDG 6) and the principles of Integrated Water Resources Management (IWRM).

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