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SPATIAL MICROBIOLOGICAL ANALYSIS OF WATER SOURCES IN PUBLIC SECONDARY SCHOOLS IN SOKOTO METROPOLIS

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ABSTRACT

This study aimed to assess the water quality in public secondary schools within Sokoto Metropolis, Nigeria, with a focus on evaluating microbial contamination levels and identifying spatial disparities in water facilities. Comprehensive assessment checklist based on WHO and UNICEF standards was used to evaluate the availability and adequacy of water facilities. Water samples were collected from 13 public secondary schools using a stratified and proportionate sampling techniques, ensuring representation across different water sources, including boreholes, pipe-borne water, and dug wells. The samples were then transported to the Sokoto State Water Board laboratory for microbial testing. The analysis specifically targeted the presence of indicator bacteria, including *Escherichia coli* (E. coli), total coliforms, and fecal streptococcus, to assess the microbial quality of the water sources. The findings revealed significant spatial disparities in the distribution of schools and highlighted areas with inadequate water facilities. Microbial analysis indicated varying levels of contamination across the different water sources, with dug wells having the highest E. coli count, averaging 11.33 CFU/100ml. The total average E. coli count across all water sources was 6.08 CFU/100ml, which exceeds the Nigerian Industrial Standard (NIS) Maximum Permissible Limit (MPL) of 0 CFU/100ml, indicating a concerning level of contamination. These results suggest a substantial risk to public health, particularly for students and staff relying on these water sources. The study emphasises the urgent need for interventions such as reconstruction and rehabilitation of water infrastructure and regular water quality testing to ensure safe drinking water is provided in public secondary schools in Sokoto Metropolis.

Keywords: *E. Coli*, Contamination, Water quality, Public secondary school, Sokoto metropolis

INTRODUCTION

Access to clean drinking water is central to human health, well-being, and development (United Nations, 2016). UNICEF and WHO (2020) reported that despite progress, 584 million children lacked basic drinking water services at their schools.

Access to safe drinking water remains a significant challenge in Sub-Saharan Africa, where providing the required daily quantity is often difficult, leading to poor sanitation and hygiene practices (Zerbo et al., 2021). This situation contributes to the prevalence of waterborne and WASH-related diseases such as cholera, typhoid, dysentery, and diarrheal illnesses, which disproportionately affect women and children (WHO and UNICEF, 2019). Water scarcity, poor water quality, and inadequate wastewater management in densely populated urban areas of low-income countries, including Nigeria, pose serious threats to public health and well-being (Ngasala et al., 2019).

The WHO/UNICEF Joint Monitoring Program (JMP) report (2018) revealed that nearly half of the schools in Sub-Saharan Africa and more than a third of schools in Small Island Developing States lack basic drinking water services. Rural schools are even more disadvantaged, with lower coverage of safe drinking water compared to urban schools in almost every country with disaggregated data (WHO/UNICEF, 2018).

In Tanzania, a study by Antwi-Agyei et al. (2017) identified boreholes and tube wells, followed by piped water around school yards, as the primary water sources in schools. Additional sources included protected dug wells, unprotected springs, rainwater collection, tanker trucks, and surface water. In South Sudan, 45% of schools and 16% of schools in Ethiopia had functional water systems within their compounds, while the remaining schools relied on nearby community water sources. Boreholes with hand pumps and roof water harvesting systems were the main water sources. In Mbale, Uganda, many water sources are prone to contamination due to these factors, posing significant health risks to the community (Awino, 2020).

Schools in Nigeria face severe challenges with unstable water supplies, especially during drought-prone summer months when the water table drops. Despite the presence of submersible pumps, many schools experience water scarcity (Hassan & MAgSc, 2017). Obi et al., (2016) observed that faecal coliform was detected in 40.0% of the water samples from borehole water in private schools in Umuahia Abia State and suggested that there is need to adopt continuous treatment, analysis and examining of these boreholes water sources. Maria et al., (2021) conducted a systematic examination of water quality in Dutse, Jigawa state using E. coli and total coliform. their findings indicate significant contamination during dry season.

Fecal coliform bacteria, particularly E. coli, are key indicators of human and animal waste contamination in water, suggesting the potential presence of harmful pathogens. When such contamination is detected (The Sphere Project, 2011). This is especially concerning given that children are more susceptible to diseases from contaminated water (Morgan et al., 2021). Lawal (2017) highlights that water source contamination often results from poor sanitation practices, aging infrastructure, and the proximity of latrines to water sources, issues that are particularly pressing in densely populated areas. Therefore, ensuring access to safe drinking water is essential for public health, particularly in schools where children face heightened risks from waterborne diseases (Ahmed et al., 2020).

Despite global efforts such as the Sustainable Development Goal 6 (SDG 6), which aims to improve WASH (Water, Sanitation, and Hygiene) by 2030, the state of water infrastructure and services in public secondary schools within

Sokoto Metropolis remains a critical concern. These schools, accommodating a large number of students and educators, play a crucial role in promoting better health and hygiene practices. However, inadequate provision of water facilities poses a significant barrier to achieving SDG 6, compromising the health and well-being of students and staff alike.

This study aimed at evaluating the spatial bacteriological analysis of water sources in public secondary schools across Sokoto Metropolis, with the following objectives: to identify different sources of water in public secondary schools, to determine quality and safety of these water sources and to assess the spatial distribution of water contamination in Sokoto metropolis. The research provided insights into the existing water infrastructure and identify key areas requiring intervention to safeguard the health of school environments.

MATERIALS AND METHODS

A comprehensive list of public secondary school within Sokoto Metropolis was obtained from the Sokoto State Ministry of Education. This list served as the baseline for the data collection process. Field surveys were conducted using Global Positioning System (GPS) device (GARMIN Etrex 10 handheld) to accurately capture the geographic coordinates (latitude and longitude) of each public secondary school within the metropolis. To ensure the accuracy of the GPS data, the collected coordinates were cross-verified with satellite imagery and existing GIS databases. Discrepancies were addressed by revisiting the schools in question and re-collecting the coordinates. The validated coordinates were recorded in a structured format, including the name of the school and the corresponding GPS coordinates. This information was organized in a database for further analysis. The collected coordinates were analysed using ArcGIS 10.7 to create a spatial distribution map of selected public secondary school in Sokoto Metropolis.

Assessment Checklist

An assessment checklist was employed to physically evaluate the water facilities and water sources in public secondary school within Sokoto Metropolis. This tool was integral in systematically identifying the current status of water infrastructure and services in these schools at the time of the survey (Chukwuma, 2018). The design of the checklist adhered to the standards set by the World Health Organization (WHO) and the United Nations Children's Fund (UNICEF) Joint Monitoring Program for WASH assessment in low-income countries (Byford, 2014; Cronk et al., 2015; WHO, 2024). These standards provided a robust framework for evaluating the adequacy and functionality of WASH facilities, encompassing parameters such as water sources, availability and accessibility. The study included all 88 public secondary schools in the metropolis. This comprehensive approach was informed by Krejcie and Morgan's (1970) sample size determination formula. According to their guidelines, the sample size for a population of 35 public junior secondary schools would be 32, and for 53 senior secondary schools, it would be 48. Given that only a few schools would be excluded using the sampling formula, the study opted to assess the entire population of public secondary schools to ensure a more robust and inclusive analysis.

Water Sample Collection

A multi-stage sampling method was employed to select the schools and water sources for this study. Water samples were collected from 13 public secondary schools in the study area using stratified sampling in order to ensure adequate representation of different Local Government Areas, school types and water sources within the Sokoto metropolis. The selection process involved first categorizing the schools based on their water sources to maintain a balanced representation across different types. The final sample comprised seven schools with boreholes, three schools with pipe-borne water, and three schools relying on alternative water sources, such as dug wells. This proportional selection strategy ensured that the study captured a representative distribution of the diverse water sources available in schools across the metropolis (Schreier, 2018).

The proportionate sampling formula is given by:

$n_h = (N_h / N) * n$

where;

n_h = Sample size for h^{th} stratum

N_h = population size for the h^{th} stratum

N = size of the entire population

n = size of entire sample

Water Quality Testing

All water samples were transported to the Sokoto State Water Board laboratory for microbial testing. The microbial water quality was assessed by analysing the presence of indicator bacteria, specifically *Escherichia coli (E. coli),* total coliforms, and fecal streptococcus (Devane et al., 2020). These bacteria serve as reliable indicators of recent fecal contamination and the presence of harmful microorganisms in various drinking water sources (NIS, 2007; Schets et al., 2002). E. coli and fecal streptococcus are particularly valuable as they are exclusively fecal in origin, indicating contamination by fecal matter. Additionally, enterococci species, which are part of the fecal streptococcus group, are used to augment testing for E. coli due to their longer survival rates in water (NIS, 2007).

Water samples were meticulously collected in sterilized bottles and placed in ice-packed containers to maintain a temperature of approximately 4°C during transportation to the laboratory. Maintaining this temperature was crucial to prevent bacterial proliferation before analysis. All samples were analysed within 12 hours of collection to ensure the accuracy and reliability of the results.

The analysis involved enumerating the colony-forming units (CFUs) of E. coli and enterococci by using 100-ml aliquots of the water samples. This procedure adhered to the Nigerian Standard Methods, specifically ES ISO 9308-1:2001 for E. coli and ES ISO 7899-2:2005 for enterococci. These standards provide precise methodologies for detecting and quantifying microbial contaminants in water, ensuring that the results are both reliable and comparable to international benchmarks.

The bacteriological analysis was conducted to quantify the colony-forming units (CFUs) of *Escherichia coli* and enterococci in water samples collected from various sources. The procedures followed in this analysis adhered to the Nigerian Standard Methods for microbiological water testing, ensuring consistency with international benchmarks.

The enumeration of *E. coli* was conducted using the membrane filtration method as outlined in ES ISO 9308-1:2001. For each sample, a 100-ml aliquot was passed through a sterile membrane filter (pore size: 0.45 µm), which retains bacterial cells. The filter was then placed on Chromogenic Coliform Agar (CCA) and incubated at 37°C for 24 hours. Following incubation, colonies exhibiting a characteristic dark blue to violet color were counted as *E. coli*. The colony count was expressed as CFUs per 100 ml of water.

Enterococci enumeration followed the procedures detailed in ES ISO 7899-2:2005. Similar to *E. coli*, a 100-ml water sample was filtered through a 0.45 µm membrane filter (NIS, 2017). The filter was then transferred onto Slanetz and Bartley (S&B) agar and incubated at 37°C for 48 hours. Typical enterococci colonies appear as small, red, and shiny. The number of these colonies was recorded and expressed as CFUs per 100 ml of water. To ensure the accuracy and reliability of the results, positive and negative controls were included in each batch of analysis. Duplicate samples and repeated tests were conducted periodically to check for consistency in the results. Moreover, the laboratory environment and materials were sterilized according to standard procedures to prevent cross-contamination. The colony counts for *E. coli* and enterococci were interpreted in accordance with the guidelines provided by the Nigerian drinking water quality standards. The results were compared to threshold levels for safe water quality, enabling an assessment of the contamination levels in the sampled water sources.

RESULTS AND DISCUSSION

Analysis of water sources in public secondary school in Sokoto metropolis, as presented in Figure 1, reveals that majority of public secondary school rely on borehole water, accounting for 53.4%. This high reliance on boreholes is likely due to inadequate supply from pipe-borne water networks. Studies, such as those by Wada and Oloruntoba (2021) in badagry, Lagos state indicate that borehols are the dorminant water storage in public schools in badagry. Similarly, research by Mohammed et al. (2021) on schools in Minna, Niger State, shows a prevalent use of boreholes, with some schools also using wells and pipe-borne water. In Sokoto metropolis, 22.7% of the schools use erratic pipe-borne water, and 18.2% rely on protected dug wells, with a small percentage (5.7%) sourcing water from other external sources (outside the school).

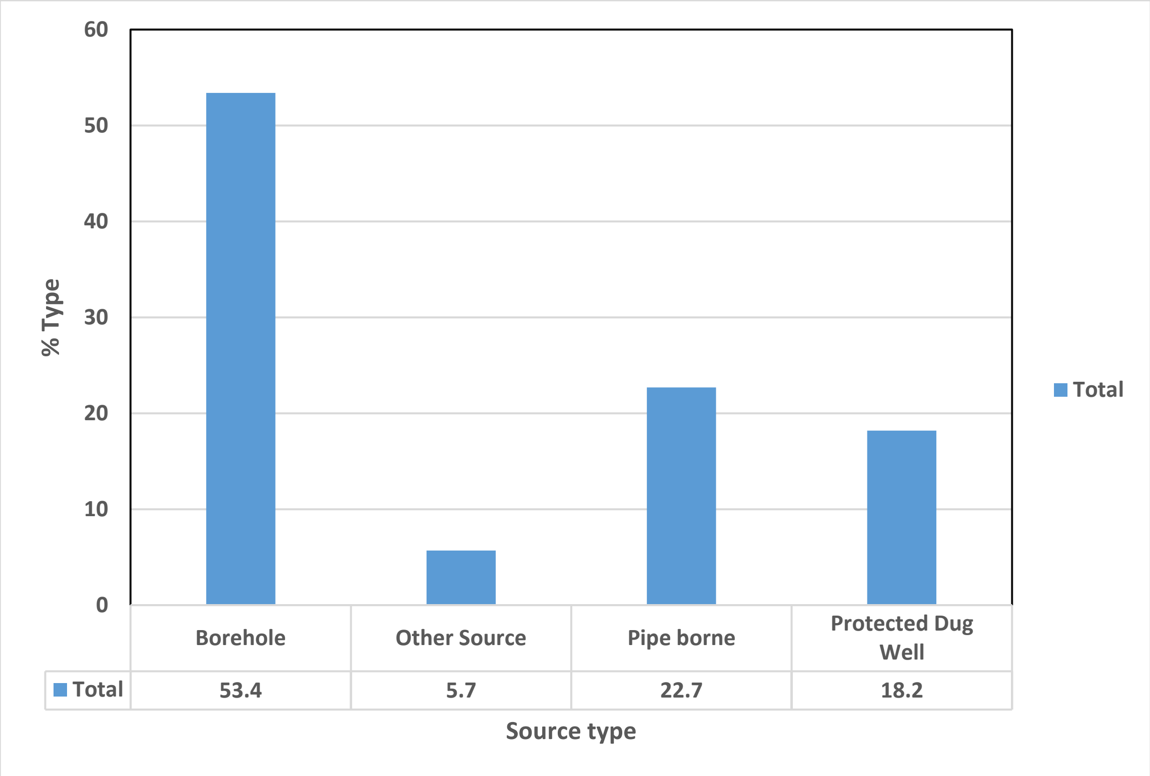

Figure 1: Sources of water in public secondary school in Sokoto metropolis
Source: Field Survey, 2023.

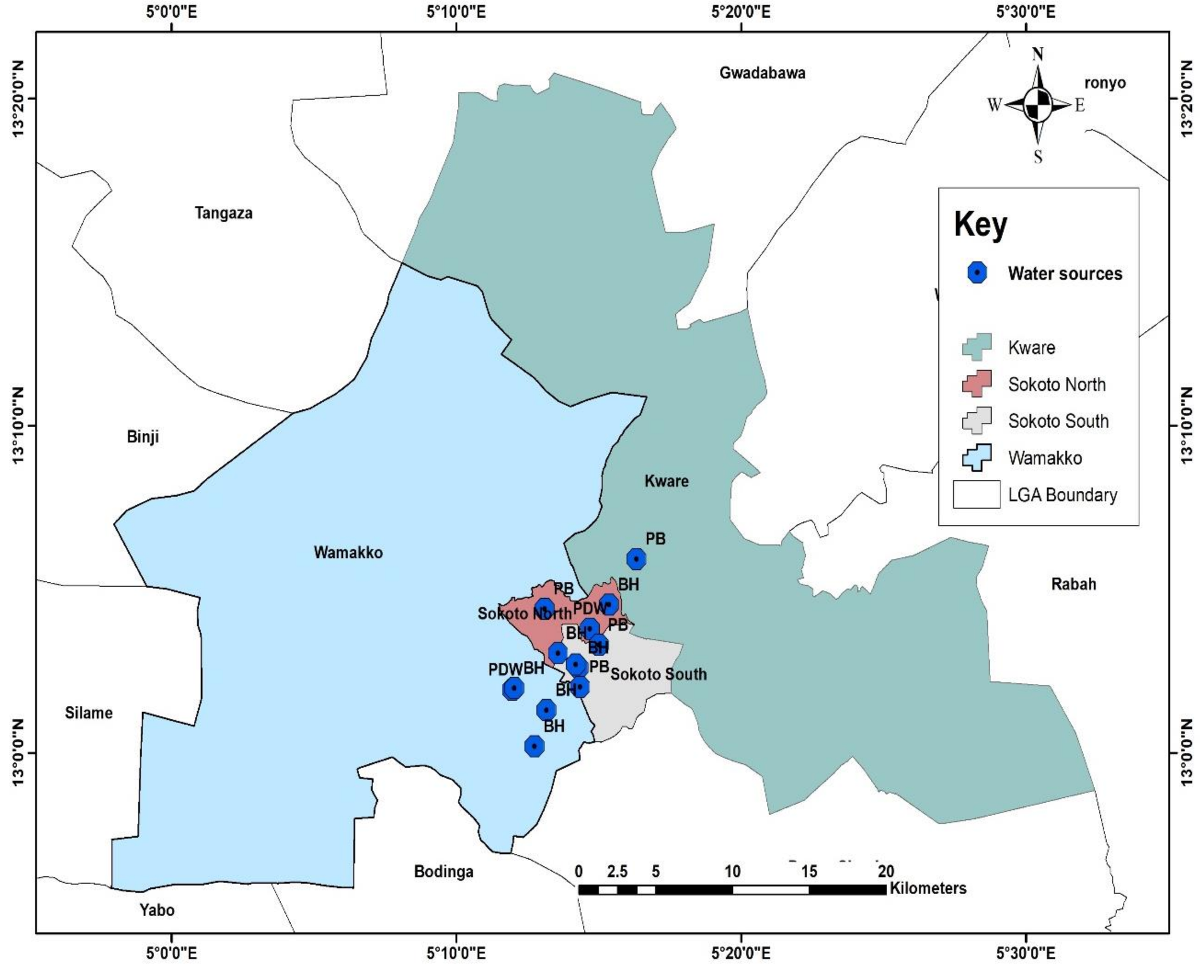

Figure 2: Map of Sokoto Metropolis showing distribution of water sources in Selected Public secondary school
Source: Authors' work, 2024.

The map reveals a concentrated distribution of water sources primarily within Sokoto North and Sokoto South local government areas. Several schools in these areas have access to water sources, as indicated by the clustering of blue dots. In contrast, Wamakko and Kware local government areas show a sparser distribution of water sources in the public secondary school.

Table 1 delineates the distribution of schools categorized by their mode of water storage, revealing variations across different school types, including boarding (boys and girls), day schools (boys and girls), mixed schools, and schools catering to special needs. Among the categories, mixed schools demonstrated the highest diversity in water storage methods, with overhead tank storage being the most prevalent (30%), followed by underground water storage (20%) and other forms of storage (38%). Day schools for boys exhibited a similar trend, with multiple faucet usage (27%) and underground water storage (18%) being prominent. In contrast, boarding schools for both genders predominantly relied on overhead tank storage, indicating a consistent preference for this method among Boarding Schools.

Table 1: Distribution of Public secondary school according to mode of water Storage

School Type	Mode of Storage				Total
	Piped through multiple faucets	**Overhead tank storage**	**underground water storage**	**other forms of storage**	
Boarding (Boys)	0	7	1	0	**8**
Boarding (Girls)	0	3	0	0	**3**
Day (Boys)	3	2	2	4	**11**
Day (Girls)	1	5	2	7	**15**
Mixed	6	15	10	19	**50**
Special need	0	1	0	0	**1**
Total	**10**	**33**	**15**	**30**	**88**

Source: Field Survey, 2023.

The analysis reveals a clear dominance of overhead tank storage, which is the most common water storage method used across all school types. Out of the 88 public secondary schools surveyed, 33 schools (37.5%) store water using overhead tanks. Other forms of storage, including containers, drums, and barrels, are also widely used, with 30 schools (34.1%) utilizing such methods. Underground water storage is employed by 15 schools (17.0%), while direct piping through multiple faucets is the least common method, found in only 10 schools (11.4%).

The distribution of water storage modes across various school types depicted the diverse approaches employed in managing water resources within these schools. Prevalence of overhead tank storage among boarding and mixed schools suggested a practical preference likely influenced by operational requirements and infrastructure capabilities as opposed to Tran et al., (2010) who asserted that communities in Mekong Delta preferred storing water in their small containers in their homes. Other findings of the research by Sikder et al, (2020) indicated that water trucking is the most common form of water supply and storage in Congo and Bangladesh. This could be related to the assertion made by Ndhlovu, (2022) who conducted a research on the determinants of water insecurity in informal settlements of Lusaka. Their findings indicated that key drivers of water insecurity in George settlement are centred on water scarcity and long distances to safe water sources (communal water sources).

Table 2: Micrbiological analysis of water samples from Boreholes from selected public secondary school in Sokoto Metropolis

SN	Test Parameter(s)	Result (CFU/100ml)								MPL (NIS)
		B1	B2	B3	B4	B5	B6	B7	Average	
1	Total Coliform count	8	12	19	5	18	10	14	12.29	10
2	E. coli	3	7	5	7	1	3	6	4.57	0
3	Fecal streptococcus	2	1	0	0	1	0	0	0.57	0

Source: Laboratory Analysis, 2023.

Biological analysis of water samples from boreholes in selected public secondary school in Sokoto Metropolis, as presented in Table 2, reveals significant contamination concerns. The table examines three key microbial parameters: Total Coliform count, E. coli, and Fecal streptococcus. The results show varying degrees of contamination across the seven borehole samples (B1 to B7). The average Total Coliform count is 12.29 CFU/100ml, which exceeds the Maximum Permissible Limit (MPL) of 10 CFU/100ml set by the Nigerian Industrial Standards (NIS). This indicates that the water from these boreholes is generally not safe for consumption without treatment, posing potential health risks to students and staff as supported by Odeyemi et al, (2024) in their assessment of water quality from selected borehole locations in Ado Ekiti, Ekiti State. Another study in some parts of Ghana indicated high counts of Total coliforms, E. Coli and in 88% of the sampled water from packaged drinking water of pre-schools children (Banu et al., 2018).

The presence of E. coli in the water samples further exacerbates the contamination issue. The average E. coli count is 4.57 CFU/100ml, significantly above the NIS standard of zero, indicating fecal contamination. This presence of E. coli suggests that the water sources are likely contaminated with human or animal waste, which can cause severe gastrointestinal illnesses and other health problems. Among the samples, B2 and B4 show the highest E. coli counts (7 CFU/100ml each), highlighting critical points of contamination that require immediate attention and remediation.

Fecal streptococcus levels are relatively low, with an average count of 0.57 CFU/100ml, but the NIS standard for this parameter is also zero. Even small amounts of Fecal streptococcus indicate contamination and potential health risks (WHO, 2024; Ucheana et al.,2024).

Table 3: Microbiological analysis of water samples from Pipe borne water from selected public secondary school in Sokoto Metropolis

SN	Test Parameter(s)	Result (CFU/100ml)				MPL (NIS)
		PB1	PB2	PB3	Average	
1	Total Coliform count	13	8	10	10.33	10
2	E. coli	3	4	0	2.33	0
3	Fecal streptococcus	0	1	0	0.33	0

Source: Laboratory Analysis, 2023.

Table 3 presents the biological analysis of water samples from pipe-borne water sources in selected public secondary school in Sokoto Metropolis. The analysis examines three critical microbial parameters: Total Coliform count, E. coli, and Fecal streptococcus. The results from the three sampled sites (PB1, PB2, and PB3) show that the average Total Coliform count is 10.33 CFU/100ml, slightly exceeding the Maximum Permissible Limit (MPL) of 10 CFU/100ml set by the Nigerian Industrial Standards (NIS). This finding indicates a marginal but concerning level of contamination that necessitates further investigation and potential remedial action to ensure water safety for the school populations.

Presence of E. coli in the pipe-borne water samples is particularly troubling. The average E. coli count across the samples is 2.33 CFU/100ml, which is above the NIS standard of zero. This indicates fecal contamination, suggesting that the water supply is compromised and potentially poses significant health risks to students and staff. The highest E. coli count was observed in sample PB2 (4 CFU/100ml), while sample PB3 reported no E. coli presence. This variability highlights the inconsistency in water quality and underscores the need for a comprehensive assessment and consistent treatment protocols to address these contamination issues.

Fecal streptococcus levels were found to be low, with an average count of 0.33 CFU/100ml, though the NIS standard is also zero for this parameter. Even minimal presence of fecal streptococcus points to contamination and potential health hazards. The detection of these bacteria, albeit in low quantities, necessitates prompt measures to improve water quality (Onyango et al., 2018).

Table 4: Microbiological analysis of water samples from protected dug well water from selected public secondary school in Sokoto Metropolis

SN	Test Parameter(s)	Result (CFU/100ml)				MPL (NIS)
		PDW1	PDW2	PDW3	Average	
1	Total Coliform count	45	27	50	40.67	10
2	E. coli	2	7	25	11.33	0
3	Fecal streptococcus	4	10	35	16.33	0

Source: Laboratory Analysis, 2023.

Table 4 presents the microbiological analysis of water samples from protected dug wells in selected public secondary school in Sokoto Metropolis, focusing on three key microbial parameters: Total Coliform count, E. coli, and Fecal streptococcus. The results indicate that the average Total Coliform count is 40.67 CFU/100ml, significantly exceeding the Maximum Permissible Limit (MPL) of 10 CFU/100ml set by the Nigerian Industrial Standards (NIS). This substantial level of contamination suggests that the water from these protected dug wells is not safe for consumption without proper treatment. The high coliform counts are indicative of inadequate protection from surface contamination, possibly due to poor well maintenance or structural deficiencies. This assertion is also supported by Edegbene et al., (2024) in their evaluation of microbial counts of borehole water in Benue State. their findings suggested that environmental factors play a role in contamination of borehole water.

The presence of E. coli in the water samples further highlights severe contamination issues. The average E. coli count is 11.33 CFU/100ml, which starkly contrasts with the NIS standard of zero, indicating fecal contamination. This poses serious health risks to students and staff, as E. coli is a strong indicator of the presence of pathogenic microorganisms that can cause gastrointestinal illnesses. The variability among the samples, with PDW3 showing the highest E. coli count of 25 CFU/100ml, underscores the urgent need for targeted interventions to address specific contamination sources and to ensure consistent water quality across all sampled wells. Djaouda et al., (2014) in their findings on Bacteriological quality of well waters in Garoua, North Cameroon indicated *Escherichia coli* and faecal streptococci concentrations showed high spatial and seasonal variations from one well to another. The Fecal streptococcus counts also raise significant concerns, with an average of 16.33 CFU/100ml, far exceeding the NIS standard of zero. The elevated levels of Fecal streptococcus in the water samples indicate ongoing fecal pollution, which can be attributed to surface runoff entering the wells or inadequate sanitary protection measures around the well sites. The highest count was observed in PDW3 (35 CFU/100ml), suggesting that this particular well is highly vulnerable to contamination.

Table 5: Total Average Microbiological analysis of water samples from Boreholes, Pipe borne and protected dug well water from selected public secondary school in Sokoto Metropolis

SN	Test Parameter(s)	Result (CFU/100ml)				MPL (NIS)
		Boreholes	Pipe Borne	Dug Well	Total Average	
1	Total Coliform count	12.28571429	10.33333	40.67	21.09	10
2	E. coli	4.571428571	2.333333	11.33	6.08	0
3	Fecal streptococcus	0.571428571	0.333333	16.33	5.74	0

Source: Author’s Analysis, 2023.

Table 5 presents the total average biological analysis of water samples collected from boreholes, pipe-borne sources, and protected dug wells in selected public secondary school within Sokoto Metropolis. The analysis focuses on three test parameters: Total Coliform count, E. coli, and Fecal streptococcus, with results expressed in colony-forming units per 100 millilitres (CFU/100ml). For Total Coliform count, boreholes had an average of 12.29 CFU/100ml, pipe-borne sources had 10.33 CFU/100ml, and dug wells had a significantly higher average of 40.67 CFU/100ml. The total average across all sources was 21.10 CFU/100ml, which exceeds the maximum permissible limit (MPL) set by the Nigerian Industrial Standards (NIS) of 10 CFU/100ml. Regarding E. coli, the average counts were 4.57 CFU/100ml for boreholes, 2.33 CFU/100ml for pipe-borne sources, and 11.33 CFU/100ml for dug wells. The total average E. coli count across all water sources was 6.08 CFU/100ml, which is above the NIS MPL of 0 CFU/100ml, indicating a concerning level of contamination.

For Fecal streptococcus, boreholes showed an average of 0.57 CFU/100ml, pipe-borne sources had 0.33 CFU/100ml, and dug wells had a considerably higher average of 16.33 CFU/100ml. The total average for all sources was 5.75 CFU/100ml, again exceeding the NIS MPL of 0 CFU/100ml. Overall, the biological analysis reveals that water from boreholes and pipe-borne sources generally have lower contamination levels compared to dug wells, yet all sources show contamination levels that surpass the recommended standards, posing potential health risks to the students.

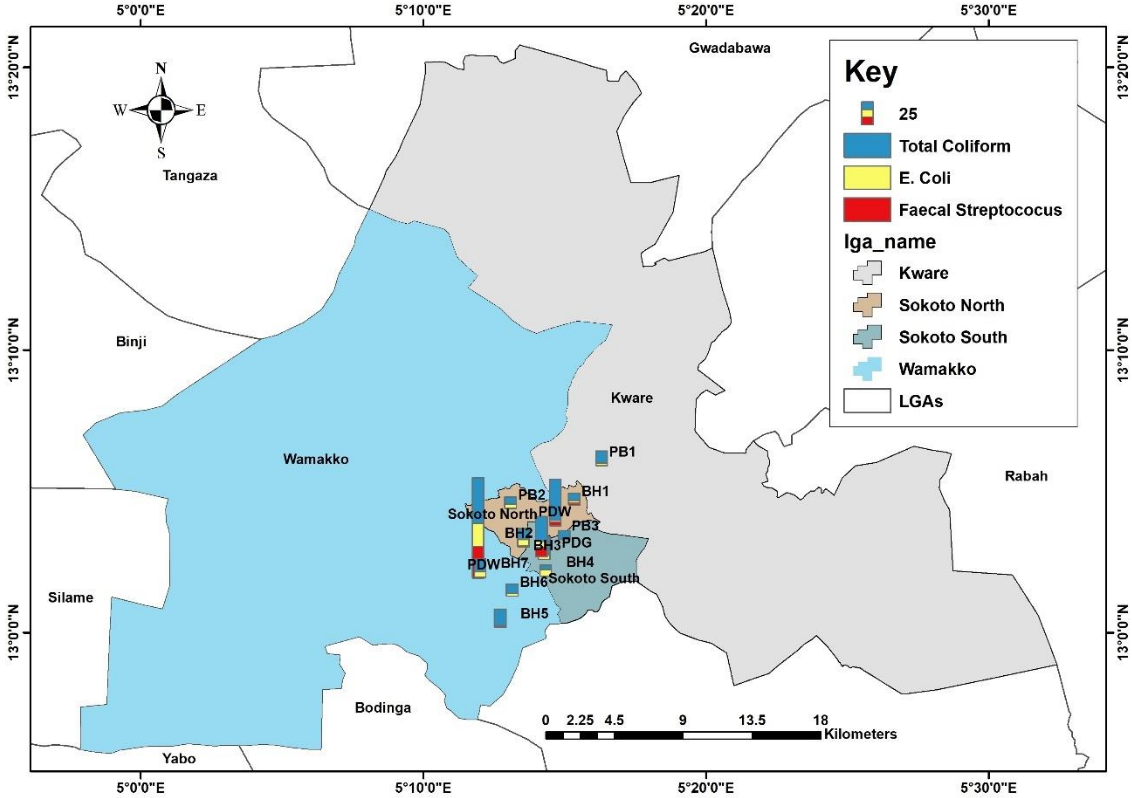

Figure 3: Spatial distribution of microbial contamination in public secondary schools across Sokoto Metropolis
Source: Authors' work, 2024.

Sokoto Metropolis is situated in North-western Nigeria, characterized by a semi-arid climate with low annual rainfall, typically ranging from 500 to 700 mm (Abdulmajid, 2021). The geology of the area is dominated by sedimentary formations, particularly the Gwandu and Rima groups, which consist of sandstone, siltstone, and claystone. The region's groundwater is stored within these formations, which serve as the primary sources of water for domestic use, including boreholes and wells in public schools (Olatunji et al., 2024). The sandstone and siltstone formations in the area have varying levels of permeability, which can influence the movement of contaminants. In areas where the protective clay layers are thin or absent, contaminants can easily percolate into groundwater sources (Olatunji et al., 2024). This is particularly relevant for dug wells and poorly constructed boreholes, which are more susceptible to contamination due to their shallow depths.

The highest concentrations of microbial contaminants, particularly *E. coli* in figure 3 (represented in red), are observed in schools located within the urban centers of Sokoto North and Sokoto South LGAs. This is concerning because these areas are densely populated, with high human activities that increase the risk of fecal contamination. The presence of *E. coli* and fecal streptococcus indicates contamination from human or animal waste, which poses a significant health risk.

Schools in Wamakko LGA, which lies on the periphery of the metropolis, show fewer instances of microbial contamination compared to those in the more urbanized areas. This could be attributed to lower population density and reduced human activity in these regions, resulting in less environmental stress on groundwater sources. The central urban areas, particularly Sokoto North and Sokoto South, are hubs of commercial and residential activities. The improper disposal of waste, poor sanitation facilities, and the close proximity of latrines to water sources in these areas significantly contribute to groundwater contamination. This is reflected in the high levels of *total coliforms* and *fecal streptococcus* found in these locations. The widespread contamination underscores the challenges associated with inadequate water infrastructure and poor water management practices in the metropolis. Schools relying on boreholes, which are often shallow and poorly maintained, are at higher risk of contamination, as shown by the significant microbial presence in these areas.

Plate 1: Surroundings of underground Reservoir in Public secondary school in Sokoto Metropolis
Source: Authors' Survey, 2023.

Plates 1 and 2 indicates the surrounding environmental sanitation of the water sources. both plates reveal dirty environmental conditions of the water sources and therefore making the water vulnerable to contamination. Wada & Oloruntoba (2021) also reported bacteriological contamination of the water sources and related that to the surrounding environment such as proximity of the boreholes to septic tanks, the practice of open defecation by the students and lack of hand washing services in the schools especially, the public schools. Coliforms and E. coli were also found in the results of well water sampled in Ile-ife and were considered unfit for human consumption by (Adetunde et al., 2011; Adejuwon & Bisi-johnson, 2010). They asserted that, the observed sanitary conditions and quality of all the wells in Ile-Ife tells a lot about the laboratory result. that high coliform density recorded in all the wells is an indication of poor sanitary conditions in the surrounding environment.

Plate 2: Surroundings of underground Reservoir in Public secondary school in Sokoto Metropolis
Source: Authors Survey, 2023.

CONCLUSION

The spatial analysis of water quality in public secondary school within Sokoto Metropolis reveals significant disparities in water source distribution among different Local Government Areas (LGAs). Sokoto North and Sokoto South have a high concentration of water sources, while Wamakko and Kware show a sparser distribution, indicating the need for strategic interventions to ensure equitable water access across all schools.

Boreholes are the primary water source, accounting for 53.4% of the water supply, reflecting a broader trend in Nigeria due to inadequate pipe-borne water infrastructure. However, the reliability of boreholes is questionable, with many being dry or non-functional, posing health risks as highlighted by the WHO/UNICEF Joint Monitoring Program (JMP). Biological analysis of water samples from boreholes, pipe-borne sources, and protected dug wells indicates severe microbial contamination. Total Coliforms, E. coli, and Fecal streptococcus levels far exceed Nigerian Industrial Standards (NIS), with boreholes showing significant contamination, thereby posing health risks. Pipe-borne water also exhibits concerning contamination levels, particularly with E. coli, while protected dug wells have the highest contamination levels among the three sources (40.67, 11.33 and 16.33 Total Coliforms, E. coli, and Fecal streptococcus respectively).

Urgent remedial actions are necessary to protect school communities, including regular water quality monitoring, infrastructure maintenance, and effective sanitation practices around water sources. Disparities in water storage methods among different school types further highlight the need for tailored interventions. Boarding schools prefer overhead tank storage, whereas day schools use diverse storage practices. Addressing these disparities through targeted infrastructure development and maintenance can enhance water storage efficiency and safety.

Finally, this study highlights the urgent need for comprehensive water management strategies to ensure safe and reliable water access in all public secondary school within Sokoto Metropolis and this will promote a healthier learning environment.

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