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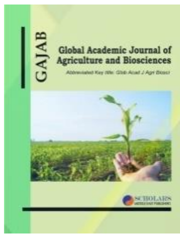

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Original Research Article

Microbiological and Physicochemical Quality of Groundwater Sources in Wamakko, Nigeria

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Abstract: Water is an indispensable natural resource and have remained a cause for worry in both urban and rural communities in Nigeria. A total of 15 samples were obtained from different groundwater sources in Wamakko, LGA, Sokoto State, Nigeria. Physicochemical and microbiological analysis were performed on the samples to ascertain changes in the proxies and presence of indicator organisms in the water samples. The *p*H of the groundwater samples obtained from point 6 was observed to have a *p*H of 5.6 this index was far below WHO /NIS/ NAFDAC specification for potable water. Total dissolved solids (TDS) of the groundwater samples ranged from 57.6mg/L to 529.96 mg/L while samples obtained from sampling point 7 had the lowest concentration values. The concentration of phosphates in the groundwater was observed to range from 0.16 ± 0.01^a to 5.21 ± 0.12^h mg/L. Pearson Correlation showed strong correlation between turbidity and BOD of groundwater at r=0.800, Salinity and hardness of the groundwater with a correlation coefficient of 0.88 at p-value < 0.0. The samples obtained from point 6 were observed to have a fecal coliform count of 6 MPN/100ml and 40MPN/100ml for total coliform The samples obtained from samples obtained from points 1 and 4 had a bacterial load of 1.1×10^5CFU/ml while the samples obtained from point 14 had a bacterial load of 1.3×10^4 CFU/ml The microbial diversity ascertained by the biochemical evaluation showed that the bacterial flora obtained from point 14 were *Pseudomonas, Salmonella sp., E. coli and Enterobacter sp.* The groundwater sources were tained by the anthropogenic activities in the Wamakko LGA as this have shown a shift in the microbiological qualities of the water samples. There is need for Sokoto State Government to look into the remote cause of the water pollution and come up with a risk-oriented strategies to stem these tides.

Keywords: Anthropogenic, Bacterial Load, Correlation, Groundwater, Microbiological; Physicochemical.

1.0 BACKGROUND TO THE STUDY

Water remains an irreplaceable, indispensable and invaluable natural resource that plays a vital role in every biota. It is said to be the most widely circulated and abundant substance found on earth (Dhanaji *et al*., 2016). The uses of water range from personal, domestic, recreational, agricultural and industrial; yet access to wholesome and fit supplies of potable water has remained a challenge to a wide array of populace in the world today (Bashir *et al*., 2018). This substantiates the role of water as an important component of the environment, which is necessary for life to exist. In most developing countries like Nigeria, the integrity of drinking water sources has been constantly threatened by activities population explosion, urbanisation and industrialization by several forms of pollution from leachates and seepages (Asionye *et al*., 2023). Contaminants such as; bacteria, fungi, protozoans, viruses, heavy metals, nitrates and salts have polluted water supplies, as a result of inadequate treatment and poor disposal of wastes from humans and livestock, industrial discharges; and over-use of limited water resources (Onyango *et al.,* 2018; WHO 2018). International conventions have identified global water security as one of the leading interventions of international organizations to edge out the increasing trend of water stress (Aboh *et al*., 2015).

Groundwater is a vital freshwater resource and an essential moderator of hydrogeologic processes throughout the hydrological cycle (Wali *et al*., 2022). It is the most useful component of the water cycle and a source of domestic water in most developing nations. It constitutes about two-thirds of the freshwater resources of the world. This form of water is not evenly distributed or accessible to large sections of the global population. It provides a large constant supply for domestic use, livestock and irrigation, which is not likely to dry up under natural conditions thereby buffering the effects of rainfall variability across seasons. Groundwater is one of the most important environmental reserves exploited for industrial, agricultural, and domestic uses (Wagh *et al*., 2016). The composition of groundwater tends to be good in most natural aquifers, and as a result, groundwater; is increasingly being exploited as it meets the basic requirements for most uses. Sadly, groundwater is prone to pollution and contamination due to several reasons such as leachates from industrial waste disposal and dumpsites; as such puts the users of this source of potable water at risk (Sanga *et al*., 2023). A pollutant source within the proximity of 1000m can have a deleterious or harmful effect on non-target receptors depending on the concentration, partition efficiency and volatility of the pollutant. According to Nyirenda and Mwansa (2022) oxides of Sulphur and Nitrogen can be released from point sources while heavy metals may be associated with municipal waste effluents and sludge from factories and industries. The topology and seasonal activities affect the rate of percolation and sedimentation of pollutants (Donuma *et al.,* 2023). A related study Kayode *et al*., (2018) evaluated the effect of municipal solid waste dumpsites on the water quality of 15 boreholes and 5 wells along a slopy area of Lagos State. This research paper aims to assess the physicochemical attributes of groundwater sources in the Wamakko Local Government Area of Sokoto State, Nigeria.

2.0. METHODS

2.1. Study Area

The study was carried out in Wamakko local government area of Sokoto state, Nigeria. It is a 697 km^2 area, which has an estimated population of 209,204. Wamakko Local Government Area is described by the presence of hills, sandy savannah, in addition to numerous rivers, streams and dams. The annual rainfall is about 50 mm with the highest peak in August. The predominant tribe in Wamakko is Hausa. The residents are mainly farmers and fishermen (Kabiru *et al.,* 2013).

2.2. Sample Collection

A total number of 15 samples were collected from different selected locations in the study area. The samples were collected from various sources such as boreholes, water taps and wells in April 2024.

2.3. Physicochemical analysis of Groundwater obtained from Wamakko, L.G.A, Sokoto State

The groundwater samples were for *p*H, Dissolved solids, Turbidity, BOD, Phosphate, Nitrate, Salinity, COD, Coliform count, Bacteria count, Sulphate, and Hardness (APHA, 2012).

2.4. Microbiological Analyses of Groundwater Obtained from Wamakko, L.G.A, Sokoto State

2.4.1 Determination of Total Aerobic Bacteria Count (TABC):

The total Aerobic bacterial count of the groundwater samples was determined using the spread-plate technique on plate count agar. A 10-fold serial dilution was performed on the fifteen (15) groundwater samples. Then 0.1ml aliquots of diluent samples were plated on plate count agar in triplicates. According to Asionye *et al.*, (2023) bacterial colonies within the 30-300 numbers expressed as CFU/ml.

2.4.2 Determination of Coliforms Using the Most Probable Number:

Most Probable Number (MPN) technique was used to ascertain the presence and concentration of coliforms in the groundwater samples (Ugbaja and Otokunefor, 2015). The 5-test tube approach was used while the total coliform count was incubated at 37.5^{o}C the fecal coliform was incubated at 44.5^{o}C after the incubation the completed and confirmatory evaluations were observed for the samples (Bashir *et al.,* 2018).

2.4.3 Determination of Enteric Pathogens in Groundwater:

The *Salmonella* sp and *Shigella* sp. in the water samples were enumerated depending on their location in Wamakko, L.G.A, Sokoto State. The spread-plate technique was employed on the prepared and solidified *Salmonella-Shigella* agar. Water samples were prepared by 10-fold serial dilutions with 1ml of water into 9mls Selenite F-broth (Oxoid) purchased from a local vendor Jochem Limited in Choba, Rivers State as diluents. About 0.1ml of appropriate dilutions were spread on selenite-f broth *Salmonella–Shigella* Agar. The Petri dishes carrying the already spread inoculum from the enrichment were incubated at 37ºC for 48 hours—the colonies of the test organisms that appeared on the medium after incubation were presented below. Thiosulphate Citrate Bile Salt agar (TCBS) is an enrichment broth and selective medium for *Vibrio* spp. About 0.1ml of the incubated sample was aseptically pipetted on TCBS medium. The inoculum was spread with a sterile bent glass rod and incubated in an inverted form at 37ºC. After 24 hours, the plates were observed for the formation of visible colonies.

2.4.4 Identification of Bacterial Isolates

The 24-hr culture plates were sub-cultured on a freshly prepared nutrient agar and allowed to incubate for 18 hours, the isolate was also preserved on a slant for further analysis. A battery of biochemical tests was carried out to identify the organisms based on the dichotomous keys and the reactions from the test. The Bergys' manual of determinative bacteriology was used in the identification of the organism tested (Effiong *et al*., 2022).

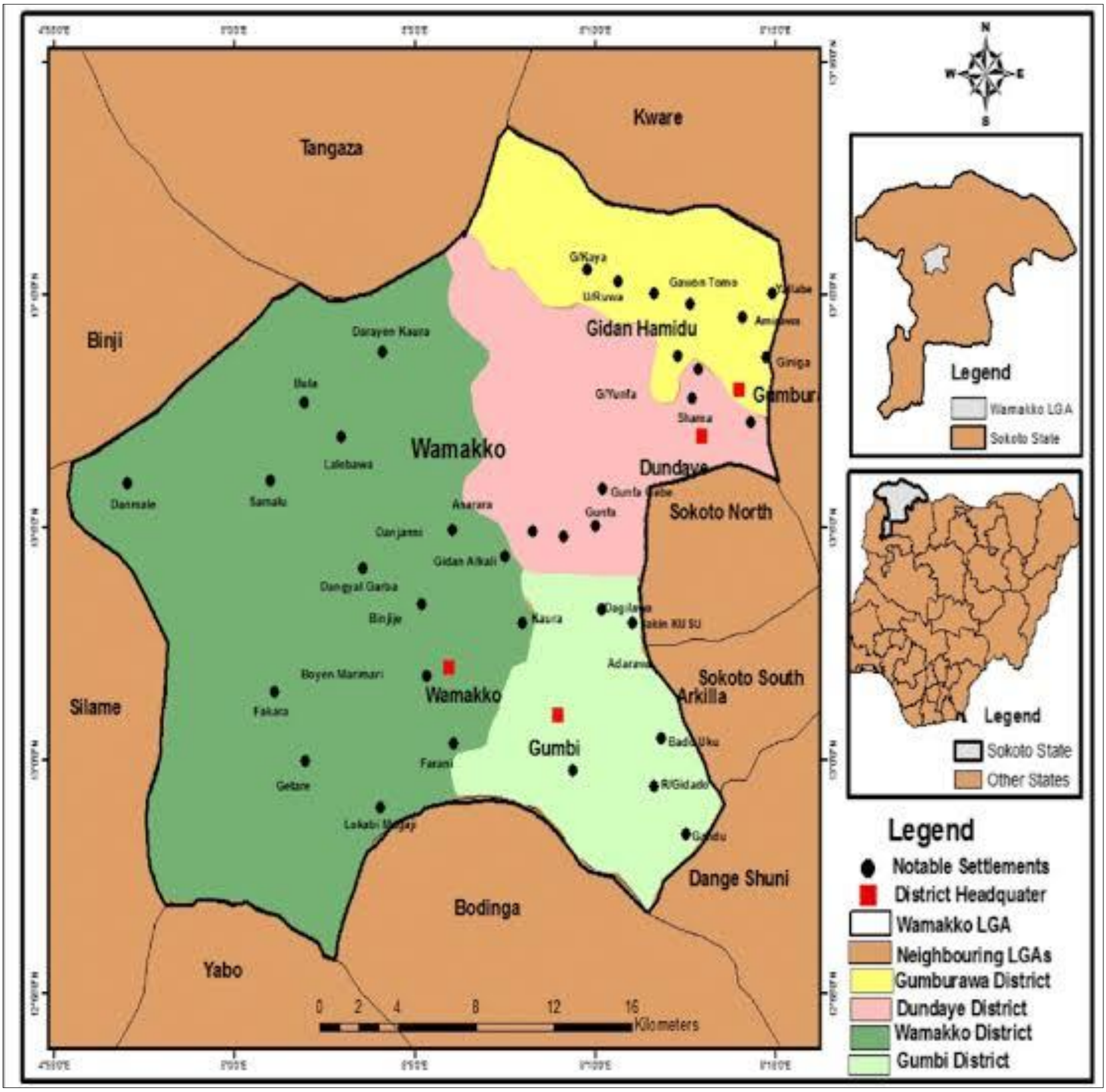

Fig. 1: Map showing the study area and the sample collection points in Wamakko LGA

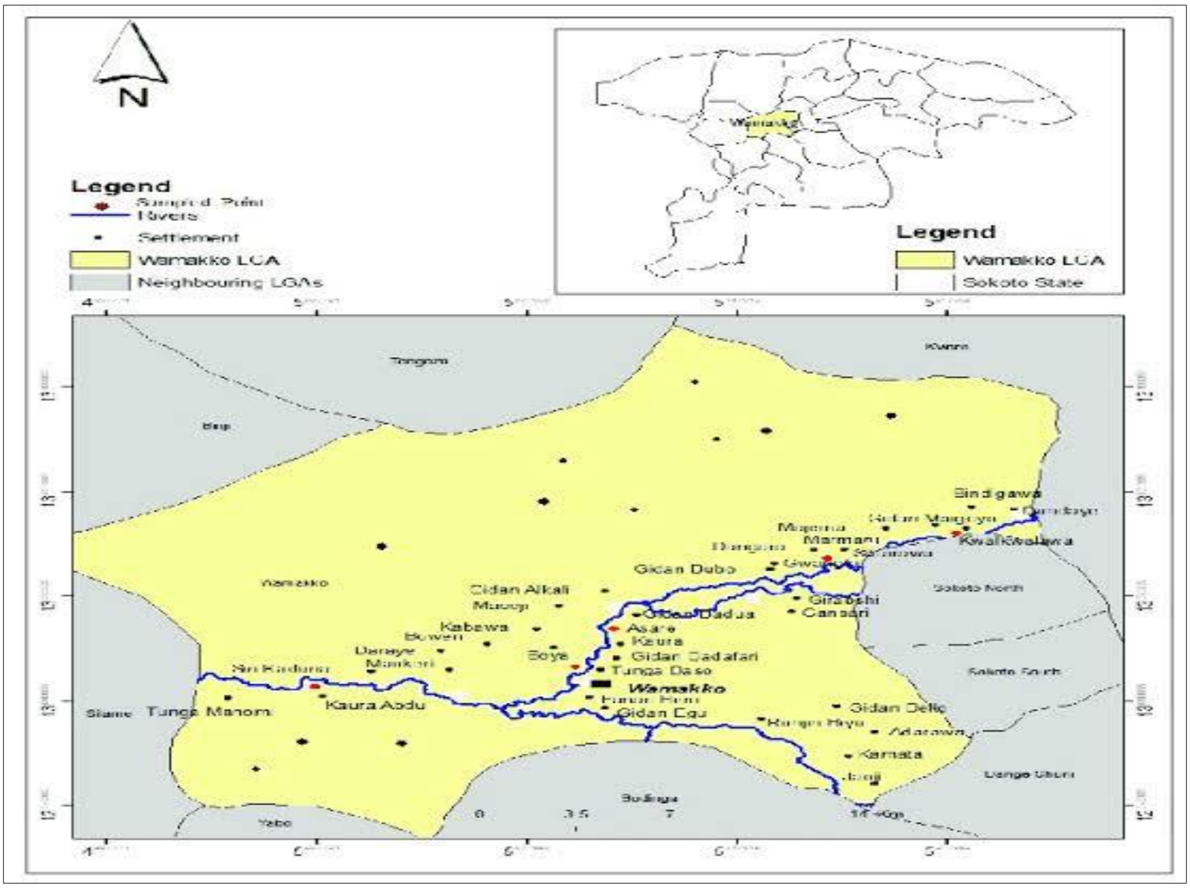

Fig. 2: Map of Wamakko LGA in Sokoto State, Nigeria

2.5 Statistical Analysis

The data obtained from the physicochemical analysis was analyzed using ANOVA and Pearson Correlation analyses on Statistical Package for Social Sciences (SPSS) version 25 using p-value < 0.05. The correlational analysis was performed to ascertain the association between the parameters using p< 0.05

3.0. RESULTS

3.1. Physicochemical Composition of Groundwater Obtained from Wamakko LGA, Sokoto State, Nigeria

The *p*H of the groundwater source sites was identified to range from 6.77±0.01^{c} to 7.90±0.04. Groundwater obtained from the sampling points 3, 4, 7, 10 and 14 was not significantly different at p<0.05. It can be inferred that the *p*H of the samples was within the same range suggesting a close association between the condition of the groundwater sources. The samples obtained from sampling points 1, 2 and 8 were also significantly different from the previously mentioned sampling points but statically observed to show no significant differences as indicated by the superscripts. The *p*H of the groundwater sample obtained from sampling point 6 was identified to be 5.27±0.06. The *p*H of the sample was way below the recommended limits of NIS, NAFDAC, SON and WHO intervention limits. The sampling points for most of the groundwater sources were observed to have *p*H values within the intervention limits. Total Dissolved Solids (TDS) of the groundwater samples obtained from the Wamakko LGA of Sokoto State, Nigeria. The concentration values of TDS for the water samples ranged from 57.6mg/L to 529.96 mg/L while samples obtained from sampling point 7 had the lowest concentration values; the values obtained for total dissolved solids for the groundwater in Wamakko LGA in Sokoto State were significantly different as described by the superscripts. The groundwater obtained from point 11 had the highest concentration value of 529.96±0.22 mg/L the values were slightly higher than the WHO intervention limits for groundwater. The salinity of the groundwater samples obtained from Wamakko ranged from 0.02±0.01 to 0.5±0.01%. The samples obtained from points 2 and 8 were not significantly different, the same applied to samples obtained from points 4 and 9 were also insignificant at p<0.05. The other samples were observed to be statistically significant across the sample lots. Similarly, the sample obtained from point 5 was 0.18% this was slightly more significant compared to the WHO intervention limits.

The turbidity of the groundwater samples was observed to range between 0.001±0.00 to 3.28±0.18 NTU. There was no statistically significant difference between results obtained for the sampling points 5, 6, 8 -14. This was clearly shown by the superscripts assigned to the results in Table 1. The results showed statistical significance when compared with the samples obtained from Wamakko LGA. The sample obtained from point 2 showed it was turbid with a turbidity index of 3.28±0.18 NTU. The results were closer or associated with the WHO intervention limits for groundwater. The water samples obtained from points 6 and 8 were adjudged "clear"; although the other samples were observed to fall within the international and local interventions for groundwater. The hardness of the groundwater samples obtained from Wamakko LGA ranged from 16.10±0.08 to 157.56±3.62 mg/L. The samples obtained from 2 and 9 were not statistically significant at p < 0.05. The entire sample lot showed indications of statistical significance as demonstrated by the superscripts in Table 1. The samples reported for points 3, 5, 6 and 14 exceeded the groundwater/drinking water intervention limits. The water sample obtained for point 14 was observed to be hard with a concentration value of 157.56±3.62 mg/L. The WHO standard/ intervention limit for groundwater is 100 mg/L this has also shown that samples obtained from points 1, 11 and 4 were lower than the intervention limits.

The concentration of phosphates in the groundwater was observed to range from $0.16±0.01^a$ to $5.21±0.12^h$ mg/L. The concentration of phosphates in the groundwater samples varied significantly across the entire sample lot as seen by the superscripts assigned to the concentration values. The results for points 13, 9 and 11 exceeded the WHO, NIS and NAFDAC standards for groundwater. The sample obtained from point 11 was observed to have a concentration value of 5.21±0.12 mg/L which was higher than the WHO limits of 0-3 mg/L, similarly, the samples obtained from sampling points 9 and 13 were also slightly higher than the regulatory standards for groundwater. The level of nitrate in the groundwater observed during the study ranged from 1.99±0.01 to 4.14±0.21 mg/L. The samples from points 4 and 5 had the highest and lowest concentrations of nitrates in the groundwater obtained from Wamakko LGA, in Sokoto with 4.14 mg/L and 1.99 mg/L respectively. The concentration of nitrates in samples expressed a high level of statistical significance at p-value < 0.05 for the results obtained during the study. The samples obtained for points 5 and 12 did not express any statistical significance at p<0.05.

3.2 Correlational Analysis of the Physicochemical Parameters of the Groundwater in Wamakko L.G.A, Sokoto State

The result presented in Table 2. Shows the correlational associations of the groundwater parameters in Wamakko L.G.A, Sokoto, Nigeria. The study demonstrated that there is a significant association between the *p*H of the groundwater and the Total dissolved solids at r =0.94. Furthermore, there was a positive correlation between sulphate and Total bacterial count at r -values of 0.305 and 0.61 respectively. The study also revealed *p*H had a correlation coefficient of 0.277 and a p-value of 0.153 for nitrate. There was a strong correlation between turbidity and BOD of groundwater at r=0.800, Salinity and hardness of the groundwater with a correlation coefficient of 0.88 at p-value < 0.01.

The result presented in Table 3, showed the Total aerobic Bacterial Count for the groundwater samples. The samples obtained from samples obtained from points 1 and 4 had a bacterial load of $1.1x10^5$CFU/ml while the samples obtained from point 14 had a bacterial load of 1.3 $x10^4$ CFU/ml indicating that the bioload of the water samples was grossly higher than the WHO-regulatory limits. The results presented in Table 3, show that points 1 and 4 had a high coliform count of 140 and 70 CFU/100ml respectively. The samples obtained from point 6 were observed to have a fecal coliform count of 6 MPN/100ml and 40MPN/100ml for total coliform. The microbial diversity ascertained by the biochemical evaluation showed that the bacterial flora obtained from point 14 were *Pseudomonas*, *Salmonella* sp., *E. coli* and *Enterobacter* sp. The predominant isolates obtained from point 1 were *Proteus* sp., *Klebsiella* sp., *Citrobacter* sp. and *Pseudomonas* sp. The isolates from point 4 had a concentration of microbes of health significance *E. coli, Salmonella sp.* and *Enterobacter* sp.

Table 1.0: Permissible Limits and Standards for Groundwater/Drinking water

Parameter	NIS/NAFDAC/SON (mg/L)	WHO
*P*h	6.5-8.5	6.5-8.5
TDS	500	500
Salinity	500	1500
Turbidity	0-5NTU	0-5 NTU
Hardness	100	100
Phosphate	0-3	0-3
Nitrate	50	10
Sulphate	100	200
TBC	0	0

Table 1: Physicochemical composition of groundwater samples obtained from Wamakko LGA, Sokoto State

Sample Code	*p*H	TDS (mg/L)	Salinity (%)	Turbidity (NTU)	Hardness (mg/L)	BOD (mg/L)	COD (mg/L)	PO_4 (mg/L)	NO_3 (mg/L)	SO_4 (mg/L)	TBC (x10^4 CFU/ml)
1	7.45 ± 0.28^{d}	122.8 ± 0.01^{d}	0.06 ± 0.01^{b}	0.69 ± 0.01^{b}	44.3 ± 0.28^{d}	10.36 ± 0.09^{c}	13.40 ± 0.04^{de}	0.28 ± 0.02^{bc}	3.49 ± 0.01^{e}	10.22 ± 0.04^{g}	11.2 ± 0.1^{g}
2	7.42 ± 0.01^{d}	341.5 ± 12.02^{j}	0.03 ± 0.01^{a}	3.28 ± 0.18^{d}	18.12 ± 0.16^{a}	21.78 ± 0.48^{h}	25.26 ± 0.19^{j}	0.16 ± 0.01^{a}	3.10 ± 0.14^{d}	11.85 ± 0.07^{h}	1.91 ± 0.01^{a}
3	6.77 ± 0.01^{c}	404.2 ± 1.47^{m}	0.22 ± 0.01^{e}	0.84 ± 0.01^{c}	128.76 ± 1.05^{i}	14.08 ± 0.028^{f}	18.33 ± 0.01^{h}	0.18 ± 0.02^{ab}	2.97 ± 0.03^{d}	13.93 ± 0.04^{i}	8.35 ± 0.10^{e}
4	6.92 ± 0.01^{c}	57.6 ± 2.18^{b}	0.08 ± 0.0^{b}	0.95 ± 0.00^{c}	49.7 ± 0.64^{e}	9.24 ± 0.00^{b}	12.96 ± 0.04^{d}	0.35 ± 0.03^{cd}	4.14 ± 0.21^{g}	5.79 ± 0.05^{b}	11.5 ± 0.70^{a}
5	6.41 ± 0.01^{b}	367.6 ± 5.03^{k}	0.3 ± 0.01^{f}	0.11 ± 0.01^{a}	105.56 ± 0.78^{h}	5.48 ± 0.03^{a}	6.29 ± 0.01^{a}	0.45 ± 0.01^{d}	1.99 ± 0.01^{a}	6.82 ± 0.01^{c}	5.25 ± 0.21^{c}
6	5.27 ± 0.06^{a}	278.6 ± 2.22^{h}	0.18 ± 0.02^{d}	0.001 ± 0.00^{a}	101.06 ± 1.49^{g}	9.24 ± 0.01^{b}	12.14 ± 0.06^{b}	0.29 ± 0.00^{bc}	2.6 ± 0.03^{c}	7.87 ± 0.05^{d}	7.35 ± 0.21^{d}
7	6.68 ± 0.31^{c}	42.40 ± 0.71^{a}	0.27 ± 0.03^{f}	0.83 ± 0.04^{c}	108.06 ± 1.50^{h}	15.96 ± 0.22^{g}	21.04 ± 0.72^{i}	0.69 ± 0.02^{e}	2.93 ± 0.07^{d}	8.65 ± 0.07^{e}	1.11 ± 0.01^{a}
8	7.66 ± 0.01^{def}	142.1 ± 1.12^{e}	0.02 ± 0.01^{a}	0.001 ± 0.00^{a}	21.75 ± 1.06^{b}	12.38 ± 0.09^{i}	14.07 ± 0.06^{ef}	0.38 ± 0.02^{cd}	3.98 ± 0.03^{fg}	8.45 ± 0.10^{e}	1.0 ± 0.00^{b}
9	7.90 ± 0.04^{f}	92.2 ± 1.29^{c}	0.09 ± 0.01^{b}	0.04 ± 0.01^{a}	16.10 ± 0.08^{a}	9.21 ± 0.04^{b}	12.03 ± 0.13^{b}	3.71 ± 0.03^{g}	3.04 ± 0.08^{d}	26.67 ± 0.66^{k}	4.5 ± 0.70^{a}
10	6.68 ± 0.04^{c}	157.66 ± 3.47^{f}	0.19 ± 0.01^{de}	0.10 ± 0.01^{a}	43.05 ± 0.15^{d}	9.9 ± 0.30^{bd}	12.65 ± 0.05^{cd}	1.25 ± 0.07^{f}	2.36 ± 0.08^{b}	23.10 ± 0.57^{j}	1.45 ± 0.1^{0}
11	7.84 ± 0.08^{f}	529.96 ± 0.22^{n}	0.13 ± 0.01^{c}	0.025 ± 0.01^{a}	24.56 ± 0.8^{bc}	11.65 ± 0.65^{d}	14.81 ± 0.45^{f}	5.21 ± 0.12^{h}	3.84 ± 0.08^{f}	9.96 ± 0.22^{g}	9.3 ± 0.42^{f}
12	7.52 ± 0.04^{de}	238.56 ± 0.76^{g}	0.09 ± 0.01^{b}	0.00 ± 0.00^{a}	26.10 ± 0.28^{c}	11.09 ± 0.15^{d}	14.20 ± 0.43^{f}	0.31 ± 0.01^{cdf}	2.1 ± 0.03^{a}	3.72 ± 0.01^{a}	4.17 ± 0.09^{b}
13	7.77 ± 0.06^{ef}	299.65 ± 0.92^{i}	0.20 ± 0.01^{de}	0.08 ± 0.01^{a}	79.33 ± 3.29^{f}	11.85 ± 0.37^{d}	15.84 ± 0.81^{g}	3.7 ± 0.04^{cd}	2.35 ± 0.10^{b}	9.35 ± 0.35^{f}	1.02 ± 0.03^{a}
14	6.81 ± 0.04^{c}	338.06 ± 2.9^{1}	0.5 ± 0.01^{g}	0.07 ± 0.01^{a}	157.56 ± 3.62^{j}	9.18 ± 0.62^{b}	11.78 ± 0.06^{b}	0.33 ± 0.01^{cd}	3.88 ± 0.06^{f}	5.31 ± 0.02^{b}	1.3 ± 0.01^{g}

Results= Mean ±SD, TDS=Total Dissolved Solids, BOD=Biochemical Oxygen demand, COD= Chemical Oxygen Demand, PO_4=Phosphates, NO_3=Nitrates, SO_4=Sulphates, TBC= Total Bacterial Count, CFU/ml= Colony Forming Units per milliliters. Numerical data with similar superscripts are considered significant while ones with dissimilar superscripts are considered insignificant.

Table 2: Correlational studies on the physicochemical composition of groundwater samples

Correlations												
		*p*H	TDS	Salinity	Turbidity	Hardness	BOD	COD	Phosphate	Nitrate	Sulphate	TBC
*p*H	Pearson Correlation	1	-.013	-.440*	.073	-.616**	.252	.230	.421*	.277	.201	-.100
	Sig. (2-tailed)		.949	.019	.711	.000	.196	.238	.026	.153	.305	.612
TDS	Pearson Correlation		1	.272	.025	.232	.059	.008	.248	-.116	-.203	.083
	Sig. (2-tailed)			.162	.901	.236	.765	.970	.203	.555	.300	.675
Salinity	Pearson Correlation			1	-.301	.880**	-.312	-.274	-.147	-.124	-.202	-.286
	Sig. (2-tailed)				.120	.000	.107	.159	.454	.529	.304	.140
Turbidity	Pearson Correlation				1	-.174	.800**	.759**	-.272	.139	-.003	-.013
	Sig. (2-tailed)					.375	.000	.000	.162	.481	.989	.949
Hardness	Pearson Correlation					1	-.205	-.146	-.406*	-.114	-.323	-.087
	Sig. (2-tailed)						.295	.459	.032	.563	.094	.660
BOD	Pearson Correlation						1	.981**	-.127	.126	.028	-.290
	Sig. (2-tailed)							.000	.520	.524	.889	.135

Correlations

		*p*H	TDS	Salinity	Turbidity	Hardness	BOD	COD	Phosphate	Nitrate	Sulphate	TBC
COD	Pearson Correlation							1	-.117	.126	.030	-.233
	Sig. (2-tailed)								.554	.524	.881	.233
Phosphate	Pearson Correlation								1	.213	.453*	.186
	Sig. (2-tailed)									.277	.016	.343
Nitrate	Pearson Correlation									1	-.133	.306
	Sig. (2-tailed)										.499	.114
Sulphate	Pearson Correlation										1	-.125
	Sig. (2-tailed)											.525
TBC	Pearson Correlation											1
	Sig. (2-tailed)											

*. Correlation is significant at the 0.05 level (2-tailed).

**. Correlation is significant at the 0.01 level (2-tailed).

Table 3: Microbiological Composition of Groundwater obtained from Wamakko L.G.A, Sokoto State

Sample points	Fecal Coliform Composition	Total Coliform Composition	Tentative identity of bacterial species isolated from the Groundwater in Wamakko LGA, Sokoto State
(MPN/100ml)			
1	7	140	*Proteus* sp, *Klebsiella* sp, *Citrobacter* sp and *Pseudomonas* sp
2	4	21	*Salmonella* sp. and *E. coli*
3	2	9	*Streptococcus* and *Proteus* sp.
4	6	70	*E. coli, Salmonella sp.* and *Enterobacter* sp.
5	2	26	*Proteus* sp., *Pseudomonas* sp. and *Staphylococcus* sp.
6	6	40	*Citrobacter* sp. and *Aeromonas* sp.
7	6	27	*Pseudomonas* sp., *Serratia* sp., *Klebsiella* sp. and *Bacillus* sp.
8	8	23	*E. coli* and *Salmonella* sp.
9	2	23	*Salmonella* sp. and *E. coli*
10	26	17	*Salmonella* sp., *Shigella* sp, *Enterobacter* sp. and *E. coli*
11	4	12	*Klebsiella* sp. and *E. coli*
12	9	17	*Bacillus* sp., *Vibrio* sp and *Pseudomonas* sp.
13	8	21	*Proteus* sp., *E. coli* and *Enterobacter* sp.
14	11	50	*Pseudomonas*, *Salmonella* sp., *E. coli* and *Enterobacter* sp.

DISCUSSION

*p*H is an indicator parameter that describes the degree of acidity or alkalinity of any system; the *p*H of water asserts the presence or absence of organics or chemical radicals of health concern in the water. The *p*H of the groundwater observed in Wamakko during the study showed that the concentration value obtained for point 1 was 7.45±0.28 while the ones obtained at point 3 had *p*H 6.77. The samples obtained from 6 had a *p*H of 5.27±0.06 which was objectionable and below regulatory standards. The sampling point 13 was also identified to possess a *p*H of 7.77 these ranges of concentration values were within the WHO standards for potable water which is *p*H 6.5-8.5. In a related study. The work of Okunola *et al*., (2018) identified that association between the physicochemical composition of groundwater sources in Ota and posited that geophysical parameters of the sachet water factories played a key in the quality of the groundwater samples This corroborated the report of Ocheli *et al*., (2022) reported a *p*H of 6.6 for groundwater; in their opinion, electrical conductivity played a major role in groundwater quality. The result obtained for the study agreed strongly with the report of Garba *et al*., (2018) whose study on the groundwater in Dutse metropolitan city of Jigawa State had a *p*H range between 6.5 to 7.5. Palamuleni and Akoth (2015) explained that most microbial conditions can occur at narrow *p*H ranges hence fluctuations can indicate a sensitive flux in the microbiota and its diversity. This also corroborates the report of Traore *et al.,* (2023) whose investigation of the physicochemical qualities of the groundwater obtained from Ouagadougou in Burkina Faso reported a *p*H value may be crucial in the determination of the severity of pollution of water. Adesakin *et al*., (2020) conducted a study on the physicochemical and microbiological indices of groundwater in Zaria; the study is closely related to the present study due to the geology of the study area and further agrees with the findings of the present study as it points out that groundwater with a *p*H lower than 6.5 is regarded to be too acidic for human or microbial consumption as it may result in acidosis it could impair on the fecundity of the microbes. Hence such water may have been impacted by industrial pollutants. They further identified that the soil type and free carbon dioxide; the *p*H of a particular water source can affect the availability and solubility of harmful toxins. The account of Asionye *et al*., (2023) identified the role of industrial activities in Okerenkoko and Gbaramatu Kingdom can impact the *p*H of both surface and groundwater. The water samples impacted by the activities in Gbaramatu had a *p*H of 5.62 which was similar to the reported for point 6 which had a *p*H 5.27 which is a strong indication of a water source being impacted by a crucial anthropogenic source.

Total dissolved solids (TDS) of groundwater samples are indicators of water quality and concentration of solutes for the groundwater samples obtained from the study to a large extent could be said to be higher than the standards for drinking/potable water. The one obtained for point 3 was 404.2 mg/L while for point 11 was 529 mg/L. In most cases TDS level <1000mg/L is recommended for drinking water. Sarker *et al.,* (2020) had a higher TDS concentration from the study they conducted at Bangladesh metropolis. Higher TDS concentration values are indicative of geochemical disturbance and seawater intrusion. Most of the groundwater with high TDS have poor organoleptic properties and may also be objectionable for drinking or cooking but may be using for lavatory, sanitary or irrigation purposes. The samples obtained from the point 11 may contain certain amounts of carcinogenic materials and may also possess.

The TDS of groundwater is a reflection of ionic radicals contained in the water namely carbonates, chlorides, sulphates, phosphates salts of magnesium, calcium, sodium, Iodides etc (Olajire and Imeppeoria, 2001). Total dissolved solids (TDS) of groundwater samples are indicators of water quality and concentration of solutes for the groundwater samples obtained from the study to a large extent could be said to be higher than the standards for drinking/potable water. The one obtained for point 3 was 404.2 mg/L while for point 11 was 529 mg/L. In most cases TDS level <1000mg/L is recommended for drinking water. Sarker *et al*., (2020) had a higher TDS concentration from the study they conducted at Bangladesh metropolis. Higher TDS concentration values are indicative of geochemical disturbance and seawater intrusion. Most of the groundwater with high TDS have poor organoleptic properties and may also be objectionable for drinking or cooking but may be using for lavatory, sanitary or irrigation purposes. The samples obtained from the point 11 may contain certain amounts of carcinogenic materials and may also be poorly drilled well. According to Wali *et al.,* (2019) reported low TDS concentrations have been reported elsewhere in Sokoto Basin (along the Sokoto-Gusau road). Groundwater sources in Kebbi State have low TDS—28–79 mg/L which also corroborated the standpoint of this current study. A groundwater is considered "hard" due to the sum of calcium and magnesium hardness of the water. This is also expressed as the inability to form lather or foam with soap, thereby leading to high economic losses. The acceptable indices for total hardness for standard for potable ranges from 20-400mg/L. The geochemistry is the reason for the hardness of water; which eventually will involve the leaching, seepages and runoffs. This present study revealed that samples obtained from 5-7 and 14 were slightly high but lower than the standard intervention limits for drinking or potable water as the hardness ranged from 101 mg/L to 157.6mg/L. These values obtained were in agreement with the report of Falowo and Otuaga (2022) whose investigation reported a hardness concentration of groundwater of 92mg/L in a study conducted in Igoba area of Ondo State. They also agreed that soil chemistry affects the hardness of water.

Turbidity is a crucial component of groundwater quality as it serves as a linker to the presence of organics which may be laden with microbes of diverse populations. According to Isa *et al*., (2013), the parent rock activities or other geological and anthropogenic activities including decay activity may also impair and increase the concentration of the turbid material in the groundwater. WHO limits for the acceptability of groundwater suggest that 0-5 NTU is permissible. Samples obtained from sampling point 2 were slightly high with a concentration of 3.28 NTU (Nephlometric turbidity units). The other samples obtained from Wamakko, Sokoto were within the standard reference point for acceptable water.

Phosphate and nitrates are indicators of presence of organics and limiting nutrients of human origin. Samples obtained from sampling points 9 and 13 were observed to have a concentration value of 3.71 mg/L for phosphates while samples obtained from point 2 were observed the lowest concentration of phosphate with a concentration of 0.16 mg/L and the highest was for point 11 which had 5.21mg/L. These findings were in agreement with the report of Layade and Ogunkoya (2017) the concentration of nitrate in groundwater they obtained from Isolu, Ogun State had a higher concentration of nitrate. Nitrate-in-water is the cause of Methaneglobinaemia or Blue Baby Syndeome which is a disease of infants within 6 months of age. Nitrate can also impact on the quality of water as one of the causes of the eutrophication or aging of water.

Water and its uses play a significant role in the transmission of diseases. Thus, making it one of the oldest diseases carrying fomites for diseases of health concern. This is because water can serve both industrial and domestic purposes. Every potable water available to man should be monitored routinely for microbiological compliance with standards. Groundwater sources are prone to contamination; and serve diverse purposes by both classes of the socio-economic divide. Borehole water represents a major resource for water and the microbiological indices of the water remain an indispensable index for potability. The WHO standards for aerobic microbial counts were observed during the study, the report of Bashir *et al*., (2018) reported a microbial population of 3.7 x10^6 to 1.0x 10^2 CFU/ml. These were in tandem with Asionye *et al*., (2023) whose study identified a microbial population of 3.0x10^4CFU/ml for the groundwater in Gbaramatu kingdom of Delta State. The findings of Garba *et al.,* (2018) reported a total aerobic count of about 5.8x10^3CFU/ml in their study of the groundwater supplies in Jigawa State. These findings corroborated the result obtained in Wamakko, Sokoto State, Nigeria as the report obtained at point 7 was1.11x10^4 CFU/ml. The report Envuladu *et al.,* (2012) opines that the contamination of borehole water was common in rural communities. This was due to a lack of proper technical "know-how" and the nature of sanitary activities. Similarly, Donuma *et al*., (2023) identified that leaching may play a significant in the pollution of municipal water supply systems in several parts of the world today. Indiscriminate waste disposal mechanism is suggested to be a leading cause of disease transmission for both organic and inorganic pollutants. The fecal coliform composition of the groundwater obtained from Wamakko, Sokoto State, ranged from 2-26MPN/100ml while total coliform ranged from 9-140 MPN/100ml. These findings were in tandem with the previous report of Bashir *et al*., (2018) reported a coliform value of 16 MPN/100ml as it corroborates our report. This further agrees with the Sarker *et al*., (2020) report that the fecal coliform of 30 CFU/ml in groundwater was obtained from Bangladesh. The investigation carried out by Adesakin *et al*., (2020) further identified the potable water resources in Zaria were grossly tainted by priority coliforms making them unacceptable and unwholesome for consumption and use for domestic purposes. However, Okunola *et al*., (2018) identified the potential variation in the population of coliforms.

The bacterial flora associated with the groundwater in Wamakko L.G.A, Sokoto L.G.A were as follows namely *Aeromonas* sp., *Bacillus* sp. *Proteus* sp, *Klebsiella* sp, *Citrobacter* sp., *Streptococcus* sp. *Pseudomonas* sp. *E. coli, Salmonella* sp. and *Enterobacter* sp. *Vibrio* sp., and *Shigella* sp., This was in tandem with the work of Asionye *et al*., (2023) whose report identified the following bacterial flora associated with the borehole and surface water samples were *Bacillus* sp., *Escherichia* sp., *Staphylococcus* sp., *Streptococcus* sp., *Shigella* sp., *Proteus* sp., *Pseudomonas* sp., *Klebsiella* sp., *Vibrio* sp. and *Micrococcus* sp. *Escherichia coli* is an indicator of fecal pollution. *Shigella* and *Salmonella* are enteric organisms responsible for Shigellosis and Salmonellosis. Furthermore Eboh *et al*., (2017) corroborated our study which the organisms namely *Escherichia* sp., *Enterobacter* sp., *Alcaligenes* sp., *Klebsiella* sp., *Staphylococcus* sp., *Bacillus* sp., *Proteus* sp., *Micrococcus* sp., *Serratia* sp., *Acinetobacter* sp., *Alcaligenes* sp. and *Pseudomonas* sp. were obtained from groundwater at Ukwuani LGA in Delta State. A previous study by Allamin *et al.,* (2015) identified a high concentration of fecal coliforms in groundwater in the Kaduna metropolis. *Escherichia* coli, *Salmonella* sp., *Vibrio,* and *Enterobacter faecalis* have been implicated in cases of gastroenteritis. *Salmonella* sp. can lead to either typhoidal or non-typhoidal salmonellosis with varying degrees of fatalities. Basic source-tracking approaches can indicate the possible trajectory for the contamination of the groundwater.

4.0 CONCLUSION AND RECOMMENDATIONS

The physicochemical and microbiological indices of groundwater in Wamakko, Sokoto, Nigeria are clear indicators of its wholesomeness and fitness for consumption. These parameters were observed and a number of them did show that the water as a source of potable water as they fell short of local and international standards and interventions. The microbiological indices of the groundwater were grossly below standards. The study also showed that the groundwater was impacted by several anthropogenic factors which also impacted the physicochemical qualities of the groundwater/ borehole water samples. The groundwater sources were said to be unfit for drinking because of their poor microbiological qualities. There is a need for Governmental agencies to set up a Risk-based study to identify possibly remote causes denting the quality of the groundwater.

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