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CONCENTRATION OF ARSENIC AND SANITARY CONDITIONS OF GROUNDWATER SOURCES WITHIN IBADAN NORTH-EAST LOCAL GOVERNMENT AREA, IBADAN

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ABSTRACT

This study assessed the concentration of arsenic and sanitary conditions of groundwater sources within Ibadan North-East Local Government Area (IbNE LGA), Ibadan, Nigeria. Water samples were collected from a total of 110 wells and 36 boreholes across high, medium and low density areas within the LGA. Water samples were analyzed for arsenic while sanitary conditions of well and borehole water sources were observed using observational checklist. Data were analyzed using descriptive statistics and Spearman's correlation at p=0.05. The pH values of waters from wells and boreholes for high, medium and low density areas were within the permissible limits of World Health Organisation (WHO) and Standards Organisation of Nigeria (SON). Slightly more than half (50.6%) of the well water sources in the high density area, 43.5% in the medium density and 39.7% in the low density areas, had arsenic concentration exceeding SON's recommended limit while all (100%) of the well water samples in the high, medium and low density areas showed arsenic concentrations within the WHO's guideline value. About thirty-six percent (35.7%) of the borehole water sources in the high density area, 17.9% in the medium density, and 25.4% in the low density areas had arsenic concentration exceeding the SON's recommended limit. All (100%) of the borehole water samples in low, medium and high density areas showed arsenic concentrations within the WHO's guideline value. A significant negative correlation existed between the pH of well water and arsenic concentration in both the high and medium density areas. Observation revealed that well water sources had evidence of waterlogged, wastewater around the source particularly in the high and medium density areas. All the well and borehole water sources had arsenic concentration within WHO's limit while some exceeded SON's limit. Also, some water wells were exposed to sources of pollution. Regular monitoring and hygienic maintenance of wells and boreholes is necessary to prevent arsenic pollution of the potable water sources.

Keywords: Groundwater, Arsenic concentration, Sanitary condition

1 INTRODUCTION

Groundwater serves as one of the primary sources of potable water for millions of people worldwide, particularly in rural and semi-urban areas. It is being exploited extensively in many parts of the world with a massive increase in extraction in the past few decades due to the availability of new and cheaper drilling and pumping technologies [1]. However, the quality of groundwater can be compromised by a range of contaminants, which pose significant risks to public health and the environment. Among these, arsenic (As) contamination has emerged as one of the most serious global water quality concerns. For example, [2] reported that contaminants such as As has become a serious issue of concern in view of its toxicity to humans particularly in underground water sources. Arsenic, a naturally occurring toxic element, is often present in groundwater in areas with certain geological formations [3]. However, human activities such as mining, agricultural practices, and industrial processes can spiral its levels upward, and consequently exacerbate its risks to public health [4. 5].

In some parts of the world, high As concentrations (>10 ppb) have been reported in groundwater sources [6, 7]. Approximately 57 million people drink As-contaminated groundwater with concentrations exceeding the recommended standard for drinking water [8]. This has resulted in a massive epidemic of As-related toxicities in Bangladesh [9, 10], Cambodia [11], China [12], India [13], Taiwan [14] and Vietnam [15]. Furthermore, studies in sub-Saharan Africa has highlighted the presence of arsenic concentrations exceeding safe limits, with implications for public health and the need for effective mitigation strategies [16, 17, 18, 19]. However, a review article [20] reported elevated arsenic concentrations in Nigerian aquifers and highlighted potential treatment options.

Nevertheless, urban environments present a unique risk matrix where geogenic and anthropogenic arsenic sources intersect with poor sanitary infrastructure, often without adequate monitoring and regulation. In many developing countries, particularly in urban centers across sub-Saharan Africa, wells and boreholes are constructed and used without prior hydrochemical assessment or regular water quality monitoring [21]. Sanitary conditions surrounding groundwater sources often influence water quality. Open defecation, unlined latrines, proximity of septic tanks, surface runoff, and indiscriminate waste disposal contribute to microbial and chemical contamination, compounding the risk posed by arsenic and other pollutants [7]. These unsanitary conditions can facilitate the mobilization of arsenic in aquifers by altering redox conditions and increasing organic load [16].

Despite growing awareness, there remains a lack of detailed, localized data on arsenic concentrations and sanitary risks in many metropolitan areas, particularly in low- and middle-income countries. This limits evidence-based policy interventions and public health planning. Moreover, it is essential to understand the spatial distribution of arsenic in relation to sanitary conditions in order to identify high-risk areas and implement targeted mitigation strategies. Therefore, this study was conducted to assess the concentration of arsenic in groundwater sources and evaluate the surrounding sanitary conditions within Ibadan North-East Local Government Area, Ibadan, Nigeria.

2 MATERIALS AND METHODS

2.1 Study area

Ibadan North-East Local Government Area (LGA) is one of the 11 LGAs that constitute Ibadan Metropolis in Oyo State, South-western Nigeria. It is located within the urban core of Ibadan city and serves as one of the most densely settled areas of the metropolis. The administrative headquarters of the LGA is located at Iwo Road, a major commercial and transportation hub in Ibadan. The LGA lies approximately within the geographical coordinates of 7°23′N–7°27′N latitude and 3°54′E–3°58′E longitude and covers an area of about 18 km^2. It shares boundaries with other metropolitan LGAs, including Ibadan North, Ibadan South-East, and Ibadan North-West. According to the 2006 National Population Census, the LGA had a population of about 330,399 people [22], although current population estimates are considerably higher due to urban expansion, migration, and population growth. The estimated population of the LGA is about 525,723 people at 2.3% growth rate [23]. Ibadan North-East is part of the larger Yoruba cultural region and occupies a strategic position within South-western Nigeria due to Ibadan's role as a major commercial, educational, and administrative center. The principal inhabitants are the Yoruba people, as well as various communities (notably Igbo, Hausa, Edo, and Ibibio) from other parts of the country.

2.2 Study design and study location

The study adopts cross-sectional design that utilized observational checklist and laboratory analytical approaches for data collection. Samples from groundwater sources – hand-dug well and boreholes within Ibadan metropolis – were collected and analyzed. The city was classified, using population density, into three: high, medium and Low density areas; water sources within the classified areas were selected by simple random sampling. Samples were collected from a total of 110 well and 36 borehole water sources (Table 1). Also, information on the age, depth and sanitary conditions of the infrastructure were collected using a set of structured observational checklist. However, depth of all the selected boreholes water sources could not be ascertained.

Table 1: Summary of water sample collected

Sampling area	Water Source		Total
	Well	Borehole	
Low density	17	21	38
Medium density	42	8	50
High density	51	7	58
Total	110	36	

2.3 Sampling techniques

Polytetrafluoroethylene (PTFE) bottles of 100 ml capacity were used to collect samples for arsenic analysis. The samples were fixed with concentrated nitric acid to prevent the metals from adsorbing to the walls of the containers. Two-litre capacity plastic kegs were used to collect water samples for physicochemical parameters (pH, TDS, Nitrate, etc.) determination. Samples were collected according to recommended standard methods described by the American Public Health Association [24]. Samples were collected in triplicates from all the sampling points. The sample bottles were tightly stoppered after each collection and transported under 4^{o}C to the laboratory for physico-chemical and arsenic analysis.

The investigators were able to carry out this study through appropriate community entry, sensitization and mobilization exercise. During the planning stage, the researchers approached both the Department of Community Development Inspectorate (CDI) and Environmental Health Unit in the Department of Health at the LGA. Information pieces about the Community Development Associations (CDAs) and other relevant associations were collected and the community was entered through the leader who usually represents them at the LG Council meetings. Entry into the community was made through the CDA and in conjunction with LG staff in the CDI office. Contacts were made with the chairman of the Community Development Association and good working relationship was established. All the contacts were made with formal letters to obtain permission to carry out the work in the community after which the study's objectives were explained. Furthermore, a sensitization talk on the themes and objectives of the study was given at one of the CDA meetings ensuring that the participants understood all aspects of the study.

2.4 Laboratory analysis

The pH of the samples was measured using a calibrated pH meter (Jenway pH meter) while turbidity (expressed as NTU) was determined using HACH DR/2000 spectrophotometer at wavelength of 450 nm. Conductivity and total dissolved solids were determined using Jenway 470 TDS-Conductivity meter (UK). All reagents used for analysis were prepared from Analar grade chemicals. Appropriate reagent blanks were prepared for each analysis to ensure Quality Control and Quality Assurance. All analyses were carried out in triplicates [24]. The result was compared with World Health Organization's (WHO) drinking water quality guideline and Standard Organisation of Nigeria's (SON) standard for potable water Characteristics (Table 1).

2.5 Data Analysis

Table 2: World Health Organization's (WHO) Guideline, Standard Organisation of Nigeria's (SON) standard for Potable Water Characteristics

Parameters (Units)	WHO's Limits	SON's Limits
pH	6.5-8.5	6.5-8.5
Total dissolved solids (mg/L)	500	500
Turbidity (NTU)	5.0	5.0
Arsenic concentration (mg/L)	0.05	0.01

Source: [25. 26]

Data were analyzed using Statistical Package for Social Sciences (SPSS) Windows Version 22. The mean and the corresponding standard deviation were used to summarize the characteristics of the water while the results were compared with Standards Organisation of Nigeria (SON) for drinking water and World Health Organization's (WHO) Guidelines for drinking water quality (Table 2). Association between water source characteristics (Age, Depth) and arsenic concentration was determined using Spearman's correlation coefficient at 5% level of significance.

3 RESULTS

3.1 Characteristics of the groundwater sources

Table 3 presents the characteristics of the groundwater sources. The mean ages of the well water sources were 19.0±4.8 years, 16.8±5.2 years, and 21.6±6.1 years in low, medium and high density areas, respectively. Ages of the boreholes were 11.7±1.6 years, 13.3±3.5 years, and 9.7± 1.9 years in low, medium and high density areas, respectively. Depth (meter) of the wells in low, medium and high density areas were 9.9±1.7; 8.6±3.4; and 9.2±2.6, respectively. While depth of the boreholes could not be ascertained for the purpose of the study, they were reported to vary between 55m to 75m in the area.

Table 3: Characteristics of Groundwater Sources

Features	**Water Source**	
	Well	Borehole
Age (years)		
Low density	19.0±4.8	11.7±1.6
Medium density	16.8±5.2	13.3±3.5
High density	21.6±6.1	9.7±1.9
Depth (metres)		
Low density	9.9±1.8	++
Medium density	8.6±3.4	++
High density	9.2±2.6	++

++ = Reported depth vary between 55m to 75m.

3.2 Physicochemical quality of water samples

Physicochemical quality of the groundwater sources is shown in Table 4. The mean values for pH, Total dissolved solids (mg/L), Conductivity (µS/cm), Turbidity (NTU), Alkalinity (mg/L) and Chloride (mg/L) for both well and borehole water sources in low, medium and high density, respectively, were within the recommended limits by WHO and SON for potable water quality. However, the mean values for Total hardness (mg/L) for well water sources in low (142.7±2.8), medium (114.0±34.0) and high density areas (137.7±6.8), respectively, were higher than the limits (100mg/L) recommended by WHO. However, the values were within the concentration (150mg/L) recommended by SON. Total hardness (mg/L) values for borehole water sources in low (94.2±3.8), medium (83.7±4.1) and high density areas (97.7±8.6), respectively, were below the limits recommended by WHO (100mg/L) and SON (150mg/L).

Table 4: Physicochemical characteristics of water

Characteristics (Unit)	**LD**	**MD**	**HD**	**WHO**	**SON**
	Mean±SD	Mean±SD	Mean±SD		
Well water source					
pH	7.2±0.4	7.1±0.3	7.7±1.0	6.5-8.5	6.5-8.5
Total dissolved solids (mg/L)	286.0±15.5	483.0±37.8	143.0±0.2	500	500
Conductivity (µS/cm)	266.0±0.0	289.5±0.5	292.0±7.0	1000	1000
Turbidity (NTU)	2.7±0.4	1.4±0.2	1.8±0.5	5	5
Temperature (^oC)	25.3±0.8	25.3±0.2	26.3±1.3	-	-
Alkalinity (mg/L)	14.0±2.0	8.0±0.0	12.0±0.0	100	-

Total hardness (mg/L)	142.7±2.8	114.0±34.0	137.7±6.8	100	150
Chloride (mg/L)	3.3±1.5	7.0±3.0	5.6±2.2	250	-
Borehole water source					
pH	6.9±0.7	7.6±0.9	6.7±1.3	6.5-8.5	6.5-8.5
Total dissolved solids (mg/L)	312±13.7	239.0±17.9	198.0±10.2	500	500
Conductivity (µS/cm)	387.0±20.4	309.8±14.5	426.0±27.3	1000	1000
Turbidity (NTU)	1.4±0.2	2.1±0.3	1.7±0.3	5	5
Temperature (^oC)	26.5±1.6	25.9±2.1	27.2±1.9	-	-
Alkalinity (mg/L)	29.1±3.2	38.2±5.3	42.9±6.1	100	-
Total hardness (mg/L)	94.2±3.8	83.7±4.1	97.7±8.6	100	150
Chloride (mg/L)	13.7±2.3	27.7±3.7	21.9±2.8	250	-

Key: LD = Low Density; MD=Medium Density; HD=High Density

3.3 Distribution of Arsenic (As) in the water source

Concentrations of Arsenic in the well and borehole water sources in high, medium and low density areas are shown in Table 5. It was found that well water at the high density area had the highest mean arsenic concentration (0.035±0.003mg/L) compared to low density (0.023±0.009mg/L) and medium density area (0.031±0.006mg/L). Slightly more than half (50.6%) of the well water sources in the high density area, 43.5% in the medium density and 39.7% in the low density areas had arsenic concentration exceeding the SON's recommended limit while none (0.0%) of well water in the high, medium and low density areas showed arsenic concentrations exceeding the WHO's guideline value. The mean concentrations of arsenic (mg/L) in borehole water from low, medium and high density area were 0.033±0.001, 0.026±0.002 and 0.029±0.003, respectively. However, 35.7% of the borehole water sources in the high density area, 17.9% in the medium density area and 25.4% in the low density areas had arsenic concentration exceeding the SON's recommended limit. None (0.0%) of the borehole water in low density, medium density and high density areas showed arsenic concentrations exceeding the WHO's guideline value.

Table 5: Distribution of Arsenic (As) in Groundwater Sources

Water sources	No. of water sources surveyed	As concentration Mean±SD (mg/L)	% As Con. exceeding SON's standard	% As Con. exceeding WHO's standard
Wells				
Low density	17	0.023±0.009	39.7%	0%
Medium density	42	0.031±0.006	43.5%	0%
High density	51	0.035±0.003	50.6%	0%
Borehole				
Low density	21	0.033±0.001	25.4%	0%
Medium density	8	0.026±0.002	17.9%	0%
High density	7	0.029±0.003	35.7%	0%

3.4 Correlation between Groundwater Sources (wells and boreholes) Characteristics (Age and pH) and Arsenic Concentration

Table 6 presents the correlation between groundwater sources (wells and boreholes) characteristics (Age and pH) and arsenic concentration. A significant negative correlation existed between the pH of well water and arsenic concentration in both high and medium density areas. Similarly, there was a significant negative correlation between pH of borehole water and arsenic concentration in both high and medium density areas. However, in low density area, age of the well water (r=0.595; p<0.05) and borehole water (r=0.655; p<0.05) had a significant positive correlation with arsenic concentration.

Table 6: Correlation Matrix between Water Sources (Wells and Boreholes) Characteristics (Age and pH) and Arsenic Concentration

	Age	**Depth**	**pH**	**As**
Wells				
High Density				
Age	1.000			
pH	0.312	0.235	1.000	
As	0.198	0.106	-0.716**	1.000
Medium Density				
Age	1.000			
pH	-0.188	-0.211	1.000	
As	0.096	-0.577*	-0.696*	1.000
Low Density				
Age	1.000			
pH	0.134	-0.059	1.000	
As	0.595*	-0.122	-0.101	1.000
Boreholes				
High Density				
Age	1.000			
pH	0.172		1.000	
As	0.194		-0.615*	1.000
Medium Density				
Age	1.000			
pH	-0.098		1.000	
As	-0.102		-0.597**	1.000
Low Density				
Age	1.000			
pH	0.137		1.000	
As	0.655*		-0.039	1.000

*. Correlation is significant at the 0.05 level (2-tailed).; **. Correlation is significant at the 0.01 level (2-tailed).

3.5 Surrounding features of the well and borehole water sources

The surrounding features of the well and borehole water sources were presented in Table 7. It was observed that none (0.0%) of the well and borehole water sources was located close to latrine within 30m in the low density area while two (9.5%) of the borehole water sources were located close to latrine within 30m. Only three (1.6%) of the well water sources in the low density areas had water logged in their surroundings while there was evidence of litter around four (23.5%) of the well water sources in the low density areas. Two (11.8%) of the well water sources in the low density area showed evidence of wastewater around their locations while 15 (88.2%) of the well water in the low density area had appropriate drainage system. None (0.0%) of the borehole water source in the low density area neither had water logged nor showed evidence of litter and wastewater around the source. However, all (100%) of the borehole water sources in the low density area had appropriate drainage system.

In the medium density area, six (14.3%) of the well water and three (37.5%) of the borehole water sources were located close to latrine within 30m distance. Three (7.1%) of the well water sources and one (12.5%) of the borehole water sources were located close to septic tank within 15m distance. Moreover, eight (19%) well water sources showed evidence of water logging, six (14.3%) showed evidence of litter, 35 (83.3%) showed wastewater around the source while four (9.5%) had appropriate drainage system. Three (37.5%) borehole water sources showed evidence of water logging; three (37.5%), litter; two (25.5%), wastewater around the source; and six (75%), appropriate drainage system in the medium density area. On evidences of animal enclosure within 30m distance to ground water, three (7.1%) well water sources and two (25%) borehole sources in the medium density areas were identified. Five (11.9%) well water sources and two (25%) borehole water sources were located at a lower slope environment.

Furthermore, in the high density area, ten (19.6%) of the well water sources and two (28.6%) of the borehole water sources were located close to latrine within 30m distance. Thirty-seven (72.5%) of the well water sources and three (42.9%) of the borehole water sources were located close to septic tank within 15m distance. Moreover, twelve (23.5%) well water sources were waterlogged, 37 (72.5%) with evidence of litter, 33 (64.7%) with wastewater around, and ten (19.6%) with appropriate drainage. For the borehole sources, two (28.6%) were waterlogged, one (14.3%) had evidence of litter, six (85.7%) and two (28.6%) had appropriate drainage system in the high density area. In the high density area also, 37 (72.5%) well water sources and two (28.6%) borehole sources had animal enclosure within 30m. Finally, eight (15.7%) well water sources and one (14.3%) borehole sources were located at a lower slope environment.

Table 7: Sanitary Condition of Well and Borehole Water Sources

Surrounding features	DW (%)	BH (%)
Low density		
Latrine within 30m	0 (0.0)	0 (0.0)
Septic tank within 15m	0 (0.0)	2 (9.5)
Waterlogged	3 (17.6)	0 (0.0)
Evidence of litter	4 (23.5)	0 (0.0)
Evidence of wastewater around	2 (11.8)	0 (0.0)
Appropriate drainage system	15 (88.2)	21 (100)
Animal enclosure within 30m	0 (0.0)	0 (0.0)
Lower slope topography	0 (0.0)	0 (0.0)
Medium density		
Latrine within 30m	6 (14.3)	3 (37.5)
Septic tank within 15m	3 (7.1)	1 (12.5)
Waterlogged	8 (19.0)	3 (37.5)
Evidence of litter	6 (14.3)	3 (37.5)
Evidence of wastewater around	35 (83.3)	2 (25.0)
Had appropriate drainage system	4 (9.5)	6 (75.0)
Animal enclosure within 30m	3 (7.1)	2 (25.0)
Lower slope topography	5 11.9)	2 (25.0)
High density		
Latrine within 30m	10 (19.6)	2 (28.6)
Septic tank within 15m	37 (72.5)	3 (42.9)
Waterlogged	12 (23.5)	2 (28.6)
Evidence of litter	37 (72.5)	1 (14.3)
Evidence of wastewater around	33 (64.7)	6 (85.7)
Had appropriate drainage system	10 (19.6)	2 (28.6)

Animal enclosure within 30m	37 (72.5)	2 (28.6)
Lower slope topography	8 (15.7)	1 (14.3)

4 DISCUSSION

This study assessed the concentration of arsenic and sanitary conditions of groundwater sources within a metropolitan area of Ibadan, Nigeria. It was found that concentration of pH, Total dissolved solids (mg/L), Conductivity (μS/cm), Turbidity (NTU), Alkalinity (mg/L) and Chloride (mg/L) for both well and borehole water sources in low, medium and high density, respectively, were within the recommended limits by WHO and SON for potable water quality. This is an indication that pH of all the groundwaters in this study were at neutral level and could not enhance the dissolution of arsenic from mineral sources into the water. Although, studies have identified lower pH levels as a contributing factor to arsenic contamination in aquifers [27, 28]. However, values for Total hardness (mg/L) for well water sources in low, medium and high density areas, respectively, were higher than the limit (100mg/L) recommended by WHO; the values were within the concentration (150mg/L) recommended by SON. Although, hardness is not directly related to arsenic contamination, areas with harder groundwater may require additional treatment interventions to remove both hardness and arsenic, which could be challenging for local populations who already face difficulties accessing safe water sources [29, 30].

Arsenic contamination in groundwater typically arises from natural sources, such as the dissolution of arsenic-bearing minerals like arsenopyrite, or from anthropogenic activities, including mining, industrial discharges, and the use of arsenic-based pesticides [29, 31, 32, 33]. Data from the study revealed that well water at the high density area had the highest arsenic concentration compared to low density and medium density area. While several proportions of the well water sources in the high, medium and low density areas had arsenic concentration exceeding the SON's recommended limit, none of the well water sources in the high, medium and low density areas showed arsenic concentrations exceeding the WHO's guideline value. Low proportion of the borehole water sources in the high density area, medium density and low density areas had arsenic concentration exceeding the SON's recommended limit. None of the borehole water sources in low density, medium density and high density areas showed arsenic concentrations exceeding the WHO's guideline value.

The heterogeneous distribution of arsenic in well and borehole water sources could be attributed to several factors, including the depth of the wells, the geological characteristics of the aquifers, and local hydrological conditions [34, 35, 36]. Overexploitation and evaporation may also have caused the discrepancy of the results, as stated by [37]. In areas where groundwater is sourced from shallow wells, arsenic levels tend to be higher due to the more direct influence of surface contamination and the reduced filtration capacity of upper aquifers. This is supported by a report in which the elevated arsenic concentrations were detected in shallow tube wells [38]. In contrast, deeper aquifers may show lower arsenic concentrations. However, this is not always guaranteed, particularly in regions where geochemical conditions favor the mobilization of arsenic from mineral deposits [39].

This study found a statistically significant negative correlation between the pH of well water and arsenic concentration in both the high and medium density areas. Likewise, there was a significant negative correlation between pH of borehole water and arsenic concentration in both the high and medium density areas. This indicates that reduction in pH values of both well water and borehole water sources led to the increase in the concentration of arsenic in these groundwater sources. This is contrary to the report of Alam *et al*., [40], that there was a positive correlation between the pH and arsenic concentration in groundwater, which indicated that arsenic mobilization is favorable at high pH. However, studies had identified lower pH levels as a contributing factor to arsenic contamination in aquifers [27, 28].

Sanitary conditions play a significant role in determining the level of contamination in groundwater resources. In areas with poor sanitation practices such as inadequate sewage treatment, waste disposal, and sewage system infrastructure, the risk of contaminating groundwater with harmful pathogens and chemicals, including arsenic, increases. The result of the study on the effects of solid waste on groundwater, conducted by Livinus and Yakubu, [41] showed that solid waste at dump sites generate leachate which percolate into the subsurface thus polluting the groundwater. The contaminants detected were heavy metals which included arsenic, in high concentrations This study observed that very few well and borehole water sources were located close to latrine within 30m in low density, medium density and high density area. Data revealed that some well water sources in the low density area showed evidence of wastewater around their locations; however, all the borehole water sources in the low density area had appropriate drainage system.

According to the study also, the well water sources showed evidence of water logging and wastewater around the source, particularly in the high and medium density areas. Inadequate waste disposal practices in these regions will increase the anthropogenic contributions to arsenic levels in groundwater, as reported by [41]. Data also revealed that there were evidences of animal enclosure within 30m distance to well water in high and medium density areas. Some well water sources and borehole water sources were located at a lower slope environment. Large percentage of the well water sources and borehole water sources in high and medium density areas were located close to septic tank within 15m distance. These water sources are prone to contamination through the mixing of sewage/wastewater with potable water supplies.

5 CONCLUSION

This study underscores the complex interplay between arsenic contamination, physiochemical characteristics of groundwater, and sanitary conditions. Total hardness (mg/L) for well water sources in low, medium and high density areas, respectively, were higher than the limit (100mg/L) recommended by WHO. There were high levels of arsenic in some of the studied groundwater sources, and this is a potential risk to public health. Large proportion of groundwater in the studied high and medium density areas had arsenic concentration that exceeded the recommended limits by SON, although arsenic concentration in well and borehole water sources in high and medium and low density areas were within the WHO's recommended limit. This study found a significant negative correlation between the pH of the groundwater (well and borehole) and arsenic concentration in the high and medium density areas. The study also revealed that well water showed evidence of water logging and wastewater around the source, particularly in the high and medium density areas. This finding calls for urgent public health interventions such as regular monitoring, water treatment solutions, and public education about the risks of consuming contaminated water.

STATEMENTS ON COMPLIANCE WITH ETHICAL STANDARDS

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Disclosure of conflict of interest

The authors declare no conflicts of interest regarding this manuscript.

Author Contributions

Study conception and design was carried out by M. Adejumo. Material preparation and data collection were performed by B. I. Yusuf and M. Adejumo. M. Adejumo performed the data analysis, prepared the draft while all the authors read and approved the final manuscript.

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