Assessment of groundwater quality: Physicochemical and bacteriological evidence from boreholes in Sangayan Diriya village, northeast Nigeria

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ABSTRACT

The poor geology of Sangayan Diriya village has barred residents from getting access to water from the groundwater in their homes from time immemorial. This study was aimed at assessing the quality of boreholes sunk in close proximity to River Diriya wherein eight water samples were aseptically collected from the two available boreholes; borehole A (BA1, BA2, BA3 and BA4) and borehole B (BB1, BB2, BB3 and BB4). Standard procedures were employed for determining physicochemical properties, while pour plate method and most probable number (MPN) were used to estimate total viable bacterial counts and coliform count in the water collected, respectively. Results were compared with World Health Organization (WHO) guidelines and Nigerian Standard for Drinking Water Quality (NSDWQ) permissible standards. Results indicated pH, temperature, total hardness, turbidity, electrical conductivity (EC), sulphate, nitrate, alkalinity, calcium, magnesium and nitrate conformed to regulated standards, but mean phosphate concentration (1.79 mg/L) was above WHO allowable limit. However, out of the six heavy metals estimated in the water samples, i.e., Cadmium, Iron, Copper, Arsenic, Lead and Chromium, mean Iron concentration (1.16 mg/L) and mean Arsenic concentration (0.37 mg/L) were above allowable limits. The highest total viable bacterial count (6.3×10^4 CFU/mL) was recorded in BA2. Using the MPN method, BA4 recorded the highest coliform count (14 MPN/100 mL) while BB2 recorded the lowest coliform count (7 MPN/100 mL) each above WHO allowable limit. The findings in this study indicated that the water samples did not meet regulated standards and should be subjected to suitable treatment before drinking.

Keywords: Boreholes; Total viable bacterial count; Physicochemical; Coliform count; Water and Nigeria
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INTRODUCTION

Supply of water and ensuring its accessibility to all and sundry is the sixth goal captured in the sustainable development goals and targets set to ensure the actualization of a sustainable environment (Edbert *et al*., 2017). In Nigeria, dependence on the available water source for drinking and other needs has become a norm for people of rural and remote communities (Amoo *et al*., 2021). In Nigeria, 86% of the population lacks access to a securely accomplished potable water source as the supply of municipal water supply is inaccessible or not regular, particularly in communities and towns that have little population (United Nations Children's Fund, 2021). According to Centers for Disease Control and Infection (2021), one of the goals of United Nations' sustainable development is to ensure that 2.2 billion people in the world over have unflinching access to securely managed water and sanitation by 2030. Unfortunately, several documented reports obtainable from the literature have shown that most Africans that are currently living in distant villages coupled with those living in big cities do not have access to potable water (Bilen Kassie, 2018; Amoo *et al*., 2021).

Groundwater exploration for the provision of potable water for mankind use is inevitable (Bisiriyu *et al.,* 2020). Interestingly, about 2.5 billion people globally depend mostly on groundwater resources with a view to meeting their rudimentary water needs on a daily basis [United Nations Educational, Scientific and Cultural Organization (UNESCO), 2012]. Potential groundwater pollutants like fertilizer leachate emanating from most specifically communities known for large scale agricultural practice and discharge of waste from pit latrines which is mostly caused by incessant flooding can substantially initiate damaging pollution of groundwater thereby marring its potability (Adeleye *et al.,* 2020).

Residents of Sangayan Diriya village in Bauchi state, Nigeria, have had to put up with the absence of pipe-borne water, hand-dug wells and boreholes in their households from time immemorial till date for water supply. The poor geology of this village has practically deprived the villagers from having access to water from groundwater, thereby prompting the boring of two boreholes in close proximity to River Diriya, which are few miles away from the heart of the village. They solely get serviced by water hawkers who stock their jerry cans with water from the boreholes in carts and push all the way and sell to the residents. Water is pumped into the jerry cans with the aid of generators that are operated by designated persons. Many authors have established the utmost need to conduct water quality assessment with a view to ensuring its safety for human consumption (Amoo *et al.,* 2018; Hadish Bekuretsion *et al.,* 2018; Hassan *et al*., 2018; Onuorah *et al*., 2018; Onuorah *et al*., 2019; Adeleye *et al*., 2020). Study villagers depend on two boreholes to meet their daily water needs. No information exists on the safety status of the water derived from these boreholes, and therefore this study was conducted to determine the physicochemical and bacteriological status of the water sampled from these boreholes with a view to checking its potability for human consumption.

MATERIALS AND METHODS

Study area

Sangayan Diriya village, which is in Ningi Local Government Area of Bauchi State, Nigeria, is geographically situated on Longitude 10°59'22.22" N and Latitude 9°34'8.57" E (Figure 1). According to the head of the village, it has a population of approximately two hundred thousand people. Residents are predominantly farmers. Collection of water samples from the two boreholes sunk very close to River Diriya was done in mid-June 2021 (once), early, mid and late April 2022 (three times).

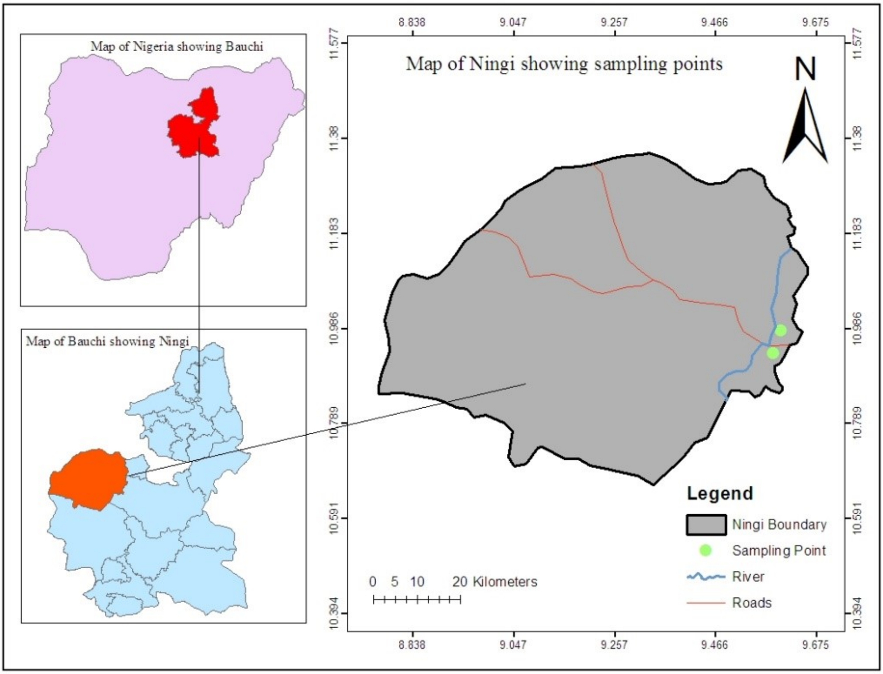

Figure 1. Map of Nigeria showing the water sampling points close to River Diriya.

Collection of water samples

Simple judgmental sampling method was adopted to collect water samples four times from each of the two available boreholes (sampling points); borehole A (BA1, BA2, BA3 and BA4) and borehole B (BB1, BB2, BB3 and BB4) that are in close proximity to River Diriya. During each water collection, for the purpose of the various physicochemical analyses, 2 litres of water were collected from each borehole with two well-labelled new plastic bottles that were first rinsed with de-ionized water followed with the water from the two sampling points before the final water sample collection was done (United State Food and Drug Administration, 2018; Adeleye *et al.*, 2020; Bisiriyu *et al.*, 2020). For the bacteriological assay, 3 litres of water were collected from each borehole with two well-labelled sterilized plastic bottles. Subsequently, the samples were instantly transported in a cooler containing ice cubes for onward analyses in the laboratory of the Department of Biotechnology, Federal University Dutse, Nigeria.

Determination of physicochemical properties of the water samples

Water sampled from the two boreholes (BA1, BA2, BA3, BA4, BB1, BB2, BB3 and BB4) was subjected to a series of physicochemical analyses. Following the procedures reported by American Water Works Association (AWWA) (2017) and Okareh *et al.* (2018), pH was determined with the aid of pocket pro pH tester (HACH, United States of America), the temperature was measured by employing high-accuracy thermometer (THOMAS, India), total hardness was estimated by using digital water hardness meter PGM-1080G, turbidity was measured using 2100Q portable turbidimeter (HACH, United States of America), electrical conductivity (EC) was determined through the use of HQ430D laboratory single input multi-parameter meter (HACH, United States of America), sulphate was estimated using ion chromatographic method whereas nitrate was determined using spectrophotometric method (HACH DR/2010 Spectrophotometer, United States of America). Moreover, alkalinity (as $CaCO_3$), calcium, magnesium, phosphate and nitrate were determined following the procedures established before (AWWA, 2017).

Estimation of heavy metals in the water samples

Heavy metals were estimated using the procedure outlined by APHA (1995); Cadmium (Cd), Iron (Fe), Copper (Cu), Arsenic (As), Lead (Pb), and Chromium (Cr) contents were estimated using Atomic Absorption Spectrophotometer AA500.

Enumeration of total viable count

The presence of total heterotrophic bacteria in the sampled water was detected through pour plating as outlined elsewhere (AWWA, 2017). This was done by making serial dilution of the sampled water (10^{-1} to 10^{-6}). However, dilution factors of 10^{-4} and 10^{-6} were transferred into 0.1% buffered peptone water (Oxoid Ltd., United Kingdom) and a duplicate of 1 mL aliquot was inoculated into 10 mL sterilized molten Plate Count Agar (HiMedia Laboratories Pvt. Ltd., India) into sterilized bottles. Subsequently, it was comprehensively variegated and dispensed into sterile Petri dishes. The Petri dishes were later subjected to incubation at 37 °C for 24 hours. After incubation, resultant bacterial colonies were counted using an electric colony counter.

Presumptive test for determination of total and faecal coliforms

Total coliform and faecal coliform present in the water samples were determined through the methods reported by WHO (2012). In each of the tests, 3-tube assay of the Most Probable Number (MPN) technique and sterilized MacConkey broth (Oxoid Ltd., United Kingdom) were employed. This was done by dispensing 50 mL of sampled water into an already sterilized test tube having 50 mL of sterilized double strength MacConkey broth. Again, 10 mL of sampled water was aseptically put in five (5) sterilized test tubes having 10 mL single strength MacConkey broth and 1 mL of sampled water was dispensed into five (5) test tubes having 5 mL of sterilized single strength MacConkey broth. Sterilized Durham tubes were inserted into all the test tubes with a view to looking out for possible bubbles indicating gas formation. Successively, the test tubes were subjected to incubation at 37 °C for 24 hours (total coliform) while test tubes meant for examining faecal coliforms were incubated at 44 °C for 48 hours. The colour of the broth in the test tubes was equally checked for a possible change from reddish purple to yellow indicating a positive result for acid production. The exact MPN values were then determined correspondingly on MPN table (Olutiola *et al.*, 2000).

Confirmed test for the determination of total and faecal coliforms

A confirmed test was done following WHO's (2012) procedure. The test was conducted by transferring a loopful of bacterial culture from test tubes recording positive results in the presumptive test into petri dishes having sterilized Violent Red Bile Agar (Oxoid Ltd., United Kingdom) and test tubes having sterilized peptone water. The petri dishes and test tubes were then subjected to incubation at 37 °C for 24 hours (total coliform) and 44 °C for 48 hours (faecal coliform). Production of gas and indole in the peptone water were looked out for and documented as a positive result for *Escherichia coli* presence whereas growth of pink colonies that harboured metallic sheen, bleaching in the center of Violent Red Bile Agar established the presence of coliforms after respective incubation periods.

Completed test for the determination of total and faecal coliforms

The completed test was done as outlined by WHO (2012). The test was conducted by aseptically streaking positive results that emanated from the confirmed test on sterilized Eosin Methylene Blue Agar (Oxoid Ltd., United Kingdom) to generate discrete colonies. The Petri dishes were then subjected to incubation at 37 °C for 24 hours. The growth of green metallic sheen colonies on Eosin Methylene Blue Agar plates was documented as a completed test for coliforms in the water samples.

Further identification of bacterial isolates

Helmenstine's procedure (2019) was followed with a view to Gram staining the bacterial isolates. Having Gram stained the bacterial isolates, series of biochemical tests were done as shown before (Barrow and Feltham, 1993). Voges-Proskauer, gelatin, triple sugar iron, catalase, mannitol, oxidation fermentation, indole, citrate, urease, nitrate reduction, lactose, glucose and methyl red were conducted according to the procedures detailed earlier with a view to confirming the identity of the bacterial isolates (Microbiology Info, 2022).

Data presentation

Results obtained from the physicochemical properties, heavy metal estimation, total viable bacterial counts and most probable number (MPN) values of the water were consecutively summarized in tables. Means and standard deviations calculated from the physicochemical parameters and heavy metal estimation were equally depicted in a tabular form. Data generated were subsequently compared with NSDWQ and WHO regulated standards.

RESULTS AND DISCUSSION

Results showing the physicochemical attributes of the sampled water are depicted in Table 1. It can be deduced from therein that temperature ranged between 29 and 33 °C (Table 1).

This temperature range is ambient enough for the growing waterborne bacteria as it is in line with NSDWQ recommended temperature for potable water (Nigerian Industrial Standard, 2007). Total hardness, alkalinity and turbidity of the sampled water ranged from 17.12 to 45.00 mg/L, 30 to 80 mg/L and 1.33 to 2.22 mg/L respectively (Table 1). Interestingly, it can be seen in Table 2 that the mean temperature value (31.38 °C) of the water sampled from the two boreholes agrees with temperature ranges reported before from studies regarding assessment of borehole water quality in their respective study areas (Bamigboye and Amina, 2018; Adeleye *et al.*, 2020; Amoo *et al.*, 2021).

Table 1. Physicochemical properties and concentrations of heavy metals estimated from the sampled water in the two boreholes.

Parameter	BA1	BA2	BA3	BA4	BB1	BB2	BB3	BB4
Temperature (˚C)	31	29	30	31.5	33	32	31.5	33
pH	7.76	7.04	7.14	7.39	7.54	7.50	7.32	7.44
Total hardness (mg/L)	45.00	20.03	27.46	31.32	17.12	22.14	23.05	19.18
Calcium (mg/L)	12.79	11.32	12.56	12.67	3.75	4.52	4.16	3.50
Magnesium (mg/L)	3.17	3.02	3.22	3.16	1.21	1.27	1.31	1.26
Sulphate (mg/L)	0.20	0.25	0.23	0.26	0.30	0.24	0.22	0.25
Nitrate (mg/L)	2.50	2.32	2.45	2.16	1.98	2.03	2.18	2.11
Phosphate (mg/L)	0.82	1.22	1.09	1.18	2.60	2.45	2.38	2.56
Ak ($CaCO_3$) (mg/L)	80	78	77	79	30	32	36	33
EC (µS/mL)	229	230	227	226	226	228	226	231
Turbidity (NTU)	2.22	1.79	1.98	2.07	1.33	1.36	2.01	1.49
Cadmium (mg/L)	0.003	0.029	0.025	0.004	0.004	0.003	0.004	0.029
Iron (mg/L)	1.24	1.26	1.22	1.23	1.07	1.09	1.06	1.08
Copper (mg/L)	0.03	0.03	0.02	0.03	0.04	0.03	0.03	0.04
Arsenic (mg/L)	0.43	0.41	0.40	0.42	0.32	0.33	0.31	0.30
Lead (mg/L)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Chromium (mg/L)	0.01	0.01	0.02	0.01	0.01	0.01	0.02	0.01

Note: BA= Borehole A; BB= Borehole B; Ak= Alkalinity; EC= Electrical conductivity

The mean pH value (7.39) recorded in the water samples was in the range of the acceptable limits of NSDWQ and WHO (Table 2). A pH range (6.7-7.8) within the mean pH value recorded in this study has been reported by Bamigboye and Amina (2018) in their study area. However, apart from the mean phosphate concentration (1.79 mg/L) which was above WHO allowable limit (0.1 mg/L), the mean concentrations of calcium (8.16 mg/L), sulphate (0.24 mg/L), magnesium (2.20 mg/L), nitrate (2.22 mg/L), EC (227.88 µS/mL), total hardness (25.66 mg/L), alkalinity (55.62 mg/L) and turbidity value (1.78 NTU) fell below NSDWQ and WHO permissible limits (Table 2). The detection of phosphate which was above WHO permissible limit in this study could be due to percolation of domestic sewage and agricultural fertilizer into the aquifers of the study area. Results generated from the estimation of possible heavy metals; Cd, Fe, Cu, As, Pb and Cr contents in the sampled water depicted in Table 1 indicate that Cd concentrations ranged between 0.025 and 0.004 mg/L while Cr concentrations ranged from 0.01 to 0.02 mg/L. It can be observed that the mean concentrations of Cd (0.01 mg/L), As (0.37 mg/L) and Fe (1.16 mg/L) obtained in the sampled water were above the allowable limits set by NSDWQ and WHO (Table 2). However, the mean concentrations of the remaining heavy metals (Cu, Pb and Cr) estimated in the sampling points were below and conformed to regulated standards (Table 2).

Table 2. Comparison of overall sample mean values of physicochemical properties and concentrations of heavy metals recorded in the sampled water with allowable standards.

Parameter	Overall Mean	SD	NSDWQ	WHO
Temperature (^{0}C)	31.38	1.38	Ambient	NSS
pH	7.39	0.23	$\geq$ 6.5 to $\leq$ 8.5	$\geq$7 to $\leq$9.2
Total Hardness (mg/L)	25.66	9.06	150	150 to 500
Calcium (mg/L)	8.16	4.50	75	300
Magnesium (mg/L)	2.20	1.01	20	300
Sulphate (mg/L)	0.24	0.03	100	500
Nitrate (mg/L)	2.22	0.19	50	50
Phosphate (mg/L)	1.79	0.77	100	0.1
Ak (as $CaCO_3$) (mg/L)	55.62	24.52	NSS	200
EC (µS/mL)	227.88	1.96	1000	1000
Turbidity (NTU)	1.78	0.35	5	5
Cadmium (mg/L)	0.01	0.013	0.003	0.003
Iron (mg/L)	1.16	0.088	0.3	0.3
Copper (mg/L)	0.03	0.006	1	2
Arsenic (mg/L)	0.37	0.055	0.01	0.01
Lead (mg/L)	0.00	0.00	0.01	0.01
Chromium (mg/L)	0.01	0.005	0.05	0.05

Note: SD= Standard deviation; WHO= World Health Organization; NSDWQ= Nigerian Standard for Drinking Water Quality; Ak= Alkalinity; EC= Electrical conductivity

The detection of As beyond allowable limit in the assayed water samples can be attributed to excessive usage of pesticides by the villagers on their agricultural land (WHO, 2018). This author and Izah and Srivastav (2015) further reiterated that the presence of As above allowable limit in groundwater is a common phenomenon in northern Nigeria and some other countries in the world. These authors reported that long time exposure to As can trigger cancer and skin diseases. Long time exposure to Cd inherently consumed in drinking water can lead to bone, kidney, blood and liver damage (Water Quality Association, 2022). According to Tomsič *et al.* (2019), the concentration of Fe in drinking water is expected to be naturally low. Remarkably, it has been reported by Minnesota Department of Health (2019) that the presence of Fe in drinking does not cause any health problem. However, in line with the finding in this current study, the detection of Fe beyond the allowable limit in groundwater was reported before (Amadi *et al.,* 2017). These authors attributed this trend to iron-containing rocks undergoing the process of weathering, thereby infiltrating the groundwater. However, Pb was not detected in the sampled water indicating that the water source was not exposed to the influence of lead pollution (Table 2). A similar observation has been reported before (Bisiriyu *et al.*, 2020). Results recorded from the estimation of the total viable bacterial counts (TVBCs) of the sampled water are summarized in Table 3. It can be deduced that BA2 had the highest TVBC (6.3×10^4 CFU/mL). However, the lowest TVBC (1.3×10^6 CFU/mL) was recorded in BA3 (Table 3). According to SMS Environmental (2019), the need to subject water to

TVBC test is paramount as it enables estimation of the total population of viable discrete microorganisms available in any conventional volume of water sample.

Table 3. Total viable bacterial count and MPN values recorded in the sampled water.

Sample	TVBC (CFU/mL) X 10^4	TVBC (CFU/mL) X 10^6	Ratio	MPN/100mL
BA1	5.8	1.8	1:2:3	12
BA2	6.3	2.4	1:2:2	10
BA3	5.2	1.3	1:3:1	11
BA4	6.1	1.9	1:3:2	14
BB1	3.5	1.9	1:2:3	12
BB2	4.4	2.2	1:1:2	7
BB3	4.2	2.1	1:2:2	10
BB4	3.8	2.0	1:3:1	11

Note: TVBC= Total viable bacterial count; CFU= Colony forming unit. MPN table presented by Olutiola *et al.* (2000) was adopted for the generation of the MPN values hereon

Sudden microbial growth regarding TVBC levels in water might be occasionally and concomitantly linked with faecal contamination and this goes a long way in knowing the possible health risks that can be associated with the consumption of such water (WHO, 2003). The detection of TVBCs in this study corroborates a previous report on the presence of heterotrophic plate count in the water assayed (Huo *et al.*, 2021).

Table 3 quantifies the coliforms that were present in the sampled and assayed water through the adoption of most probable number (MPN) table. It can be observed that BA4 recorded the highest coliform count (14 MPN/100 mL) while BB2 recorded the lowest coliform count (7 MPN/100mL). However, water samples from all the sampling points did not conform to the 0 MPN/100 mL set by WHO (2011), but only the water sampled from BB2 conformed to NSDWQ allowable limit (10 MPN/100 mL) of total coliform in water meant for human consumption. Similar results in the range of total coliform recorded in the borehole water assayed in this study (Garkuwa *et al.*, 2020).

In relation to the ability of total and faecal coliforms that might be growing in the sampled water to produce gas and acid, all the test tubes employed across all the strengths of dilution recorded such (Table 4). These results have indicated that total and faecal coliforms that are indicative of water pollution were present in the water samples. According to Li and Liu (2019), coliforms have got the capability of producing acid and gas when subjected to incubation at the temperatures adopted in this current study. Again, the results obtained in this study on the ability of coliforms to produce gas and acid when found in any water sample are in agreement with other reports that detected total and faecal coliforms in the assayed water samples in their respective study areas (Adeleye *et al.*, 2020; Amoo *et al.*, 2021; Baye Sitotaw *et al.*, 2021).

Table 4. Water assay results obtained from the presumptive test.

Sample	Growth			Acid Production			Gas Production		
	50mL	10mL	1mL	50mL	10mL	1mL	50mL	10mL	1mL
BA1	Yes	Yes	Yes	+	+	+	+	+	+
BA2	Yes	Yes	Yes	+	+	+	+	+	+
BA3	Yes	Yes	Yes	+	+	+	+	+	+
BA4	Yes	Yes	Yes	+	+	+	+	+	+
BB1	Yes	Yes	Yes	+	+	+	+	+	+
BB2	Yes	Yes	Yes	+	+	+	+	+	+
BB3	Yes	Yes	Yes	+	+	+	+	+	+
BB4	Yes	Yes	Yes	+	+	+	+	+	+

Note: + = positive result

However, the bacterial isolates did test positive to methyl red, glucose, mannitol catalase, indole and lactose but tested negative to urease, oxidation fermentation, triple sugar iron, citrate, gelatin, nitrate reduction and voges-proskauer confirming that *Escherichia coli* existed in the assayed water samples. The detection of *Escherichia coli* in all the water samples assayed in this study is a clear indication of recent feacal pollution of the boreholes (Odonkor and Ampofo, 2013; Miner *et al.,* 2016; Baye Sitotaw *et al.*, 2021).

CONCLUSION

Based on the results obtained in this study, even though all other examined physicochemical properties conformed to NSDWQ standards, we can conclude that the sampled water from the two sampling points was not fit for human consumption as the mean concentration of phosphate (1.79 mg/L) in the assayed water samples was above WHO allowable limit while the mean concentrations of Fe (1.16 mg/L), As (0.37 mg/L) and Cd (0.01 mg/L) in the assayed water samples were both above WHO and NSDWQ allowable limits respectively. Even though there is no reported health related issue linked with the presence of excess Fe in drinking water, the presence of As and Cd beyond allowable limits however can potentially, in the long-time lead to the villagers developing skin cancer, bone, kidney, blood and liver related problem owing to their continuous drinking of the water. Again, the numbers of total coliforms detected in the water samples ranging from 7 MPN/100 mL to 14 MPN/100 mL have clearly indicated that it is unfit for human consumption as it was above the permissible limit set by WHO. It is therefore recommended that water derived from the two boreholes should be adequately treated before drinking so as to avert contacting related water borne illnesses attributable to the detected coliforms. Finally, the local government authority should make concerted effort towards constructing a reservoir in a strategic location in the village where water pumped from the boreholes can be channeled and stored for onward and effective distribution to households in lieu of depending on the service of water hawkers.

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Consent for publication
Not applicable.

Competing interests
We, authors of this article, solemnly declare that we have no competing interest.

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