Journal of Multidisciplinary Engineering Science and Technology (JMEST)
ISSN: 2458-9403
Vol. 9 Issue 7, July - 2022

Evaluation Of Borehole Water Quality In Bole District, Ghana

Borehole Water Quality Evaluation

Patrick Aaniamenga Bowan
Senior Lecturer, Department of Civil Engineering, Faculty of Engineering, Dr. Hilla Limann Technical University
(formerly Wa Polytechnic)
P. O. Box 553, Wa, Upper Region, Ghana
E-mail: p.a.bowan@dhltu.edu.gh

***Abstract* — Groundwater, which is usually extracted through boreholes, is the most reliable source of drinking water in many developing countries such as Ghana. This study evaluated borehole drinking water quality in the Bole district in the Savannah Region of Ghana. The evaluation was based on the laboratory analysis of sampled borehole water and comparing the results of the sampled water to the World Health Organization's (WHO's) recommendation for drinking water quality. The laboratory analysis was focused on the physicochemical and bacteriological quality of the borehole water sampled from three purposively selected communities. The results showed that the bacteriological parameters analyzed, *E. Coli* and total coliform, for all the three residential areas were far above the WHO's recommendation for drinking water of 0.00 count/100ml, which is an indication of the contamination of the water in the boreholes sampled. However, the physicochemical quality analysis showed that all the chosen parameters were within the WHO's recommendation for drinking water, except for temperature and potassium. The study recommends a sanitary survey in the district to determine the sources of contamination of the borehole water.**

Keywords* — *Physicochemical quality; Bacteriological quality; Borehole water, Bole District, Ghana

I. INTRODUCTION

Groundwater is the most reliable source of drinking water in arid to semi-arid countries. However, groundwater is usually polluted by natural and anthropogenic activities, which makes groundwater unsafe and unfit for human use without treatment [1], [2]. Contaminated groundwater is found in a range of aquifers of unconsolidated sediment to bedrocks. In addition, groundwater can become contaminated when excreta disposal systems are improperly designed, located, constructed, or maintained. Another source of groundwater contamination is leachate from landfill sites and open dump sites, particularly in developing countries, where open dumps are common [3].

Consequently, the sources of groundwater pollution are categorized into two major types: point source pollution and non-point source pollution [4], [5]. Point source pollution, which includes municipal sewage treatment plants and industrial plants, intense evaporation in shallow aquifers, degradation of water sources in areas located in geothermal/volcanic fields, and rock oxidation, is a single discernible localized source [6]. However, the non-point source pollution, which includes diffuse sources such as land use, land-use changes, chemical reactions of elements in the air or the water and pollutants from runoff from agricultural areas draining into the groundwater, is characterized by multiple discharge points [7]. Therefore, a point source is relatively easy to identify, quantify and control, whereas a non-point source is difficult to monitor and control because the pollution cannot easily be traced to a single point of discharge.

Pollution occurrence usually depends on the level of contaminant transport. Contaminants can be transported through filtration, sorption, chemical processes, microbiological decomposition and dilution [8], [9]. Thus, groundwater pollution may cause ecosystem imbalance and severe sickness, which may lead to death. Prevention of groundwater pollution is more appropriate than remediation [10]. Such preventive measures include proper waste disposal, monitoring of hazardous materials, conducting environmental audits periodically and intensifying health education, while remediation includes stream stripping, oxygen sparing, bioremediation, chemical oxidation and thermal treatment [11], [12]. In addition, most pollution of groundwater is anthropocentric and can be prevented through intensive health education.

The provision of safe drinking water can help to reduce or eliminate preventable deaths, such as those emanating from waterborne diseases, and improve the quality of life for low-income households around the world. According to the World Health Organization (WHO) (2022), globally, at least 2 billion people use a drinking water source contaminated with faeces and that microbial contamination of drinking water as a result of contamination with faeces poses the greatest risk to drinking-water safety. WHO further observes that some 829 000 people are estimated to die each year from diarrhea as a result of unsafe drinking water, sanitation and hand hygiene, yet diarrhea is largely preventable, and the deaths of 297 000 children aged under 5 years could be avoided each year if these risk factors were addressed.

This paper assesses borehole water quality in Bole in the Savannah Region of Ghana, with a focus on the physicochemical and bacteriological quality of borehole water in three selected communities in Bole, namely: Bole West (Bole Hospital area), Bole North (Top Hill area), and Bole South (Refugee Camp area). Groundwater occurrence in the Bole district is largely influenced by rainfall, topography, overburden thickness, and geology [14]. Aquifers are discrete, localized and discontinuous and groundwater flow is controlled by fracture intensity and the degree of interconnections. Groundwater movement and its properties are unique regarding its place of occurrence in Northern Ghana, as Northern Ghana has three major hydrological provinces, namely, archaean crystal province, metamorphosed sedimentary province, and deccan trap province [15]. Groundwater occurs in these provinces under unconfined to semi-confined conditions and under confined conditions in depth [16].

Therefore, this study evaluates borehole water in the Bole district, as a drinking water quality surveillance measure to create awareness of the public health implications of the results of the study, and make the findings catalyse subsequent research in the study area and other places, to improve borehole drinking water quality.

IIMATERIALS AND METHODS

Bole district is one of the seven districts in the Savannah region of Ghana, with an estimated land area of 9,631 km². It is located between latitude 9°02'02.4"N and longitude 2°29'06.0"W. Water samples were purposively taken from boreholes located in three places in the district, namely, Bole West (Bole Hospital area), Bole North (Top Hill area), and Bole South (Refugee Camp area). All the samples were collected in December 2020. In all three locations, the residents used the borehole water for domestic purposes such as drinking, bathing, cooking, washing, and other purposes. The bacterial load of the samples was determined using standard microbiological methods, with the analysis of the samples focused on Escherichia coli (*E. Coli*) and total coliform. *E. coli* is a member of the family Enterobacteriaceae, and is characterized by the possession of the enzymes β-galactosidase and β-glucuronidase, and grows at 44 – 45°C on complex media, ferments lactose and mannitol with the production of acid and gas, and produces indole from tryptophan [17], [18]. On the other hand, coliform organisms have long been recognized as a suitable microbial indicator of drinking-water quality, largely because they are easy to detect and enumerate in water [19]. The term “coliform organisms” refers to Gram-negative, rod-shaped bacteria capable of growth in the presence of bile salts or other surface-active agents with similar growth-inhibiting properties and able to ferment lactose at 35 – 37°C with the production of acid, gas, and aldehyde within 24–48 hours [20].

Furthermore, the analysis of the borehole water was also focused on physicochemical parameters. The physicochemical quality is very important in drinking water quality analysis, as they determine the acceptability of water by consumers and some of the parameters have health implications. The selected physicochemical parameters and their analytical method are indicated in Table 1.

Table 1: Selected physicochemical parameters

Parameter	Unit	Analytical Method
Temperature	^{o} C	Using a thermometer
pH		Electrochemical method using the pH Meter
Turbidity	NTU	Nephelometric meter
Colour	TCU/Hazen	Spectrophotometric method
Conductivity	(μmhos/cm)	Probe and meter
Total dissolved solids	mg/l	Total dissolved solids Meter Method
Total hardness	mg/l	Colorimetric titration with an EDTA solution
Calcium hardness	mg/l	Titrimetric (T10 Ca Hard)
Magnesium hardness	mg/l	Titrimetric
Alkalinity	mg/l	Using sulfuric acid with a digital titrator
Chloride	mg/l	Iodometric method
Nitrite	mg/l	Visible spectrophotometer
Nitrates	mg/l	Calorimetric (spectroscopy method)
Ammonia (Nitrogen)	mg/l	Spectrophotometric IPB method
Fluoride	mg/l	An ion-selective electrode
Iron	mg/l	Color-changing test
Zinc	mg/l	Atomic absorption spectrophotometry
Copper (Total)	mg/l	Most probable number (MPN) method
Potassium	mg/l	Automatic ultraviolet absorptiometric method
Aluminium	mg/l	Deferoxamine infusion test
Sulphate	mg/l	Turbidimetric method
Lead	mg/l	Flame atomic absorption spectrometry (FAAS)
Manganese	mg/l	Spectrophotometric method
Mercury	mg/l	Atomic fluorescence spectrophotometer
Arsenic	mg/l	ICP-mass spectrometry (ICP-MS)
Bicarbonate	mg/l	Titration
Carbonate	mg/l	Titration

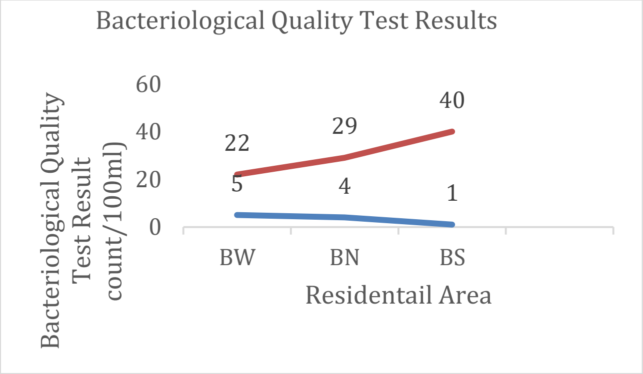
The water samples were analysed and assessed using standard sampling and laboratory analysis. The nozzle of each borehole was flamed with lit cotton wool soaked in 98% alcohol for about 2 minutes to achieve sterility. The borehole water samples were collected from the sources using sterilized glass bottles after pumping water out for 2 minutes to flush out stagnant water in the pipes. All the water samples were collected into $500\,ml$ sterilized plastic bottles. The bottles were sterilized by washing with 5% nitric acid and then rinsing several times with distilled water. This was carried out to ensure that the sampling bottles were free from all forms of possible contaminants. The samples were then kept in an ice container and transferred to the Ghana Water Company Limited's (GWCL) laboratory in Wa in the Upper West Region for analysis. The analysis of the samples collected was done by comparing the tested values of the chosen parameters to the WHO's standards for drinking water quality.

III RESULTS AND DISCUSSION

The importance of drinking water quality analysis cannot be overemphasized, as the quality of drinking water is a major determinant of the health of consumers. Therefore, periodic control measures, such as drinking water quality analysis, are necessary to ensure drinking water is always safe for consumption. Nonetheless, in many rural communities in Ghana, where boreholes are the major source of drinking water, the quality of the borehole water is rarely checked. Thus, this study evaluated borehole water quality in three selected communities in the Bole in the Savannah region of Ghana, intending to provide data that might be useful to policymakers and water service providers. The study was focused on the bacteriological and physicochemical quality of the sampled borehole water.

A. *Bacteriological Quality Analysis*

The essence of bacteriological quality analysis of water is to determine the presence or otherwise of disease-causing bacteria in water. The potential for water-borne diseases arises when water is polluted with faecal matter, as polluted water may contain pathogenic faecal bacteria, viruses, or other micro-organisms [21], [22]. Consequently, Cairncross (2017) observes that it would be far too complex to try to detect all of these on a routine basis, and in any case, many of the pathogens may only be present in very small numbers or not at all and that it is therefore normal practice to look for 'indicator bacteria'. Thus, bacteriological quality analysis of sampled borehole water was focused on *E. Coli* and total coliform. The test results as indicated in Figure 1 showed that the *E. Coli* and total coliform for all the water sampled in the three residential areas were far above the WHO's recommendation for drinking water of 0.00 $count/100ml$ (not detected). However, there was variation in the values of these parameters in the sampled water from the three residential areas. Whereas, water sampled from the borehole at the Bole hospital area in Bole West (BW) produced the highest *E. Coli* value of $5\,ml$, water sampled at 'Refugee Camp' in Bole South (BS) produced the least *E. Coli* of $1\,ml$. For the total coliform values obtained from the test, water sampled in a borehole at 'Refugee Camp' in BS produced the highest total coliform value of $40\,ml$, whilst water sampled from the borehole in BW produced the lowest total coliform value of $22\,ml$.



BW = Bole West (Bole Hospital Area), BN = Bole North (Hill Top Area), and BS = Bole South (Refugee Camp Area)

Figure 1: Bacteriological Quality Test Results

The high values of the bacteriological quality test results obtained for all the samples are a clear indication that the borehole water for all three residential areas was contaminated. The contamination of borehole water (groundwater) in this manner usually emanates from poorly constructed excreta disposal systems. During the fieldwork, the researcher observed that there were septic tanks and Kumasi Ventilated Pit Latrines (KVIPs) in use in all the residential areas in which the borehole water was sampled. Even though the researcher did not assess the efficiency of these excreta disposal systems, they could be the sources of the contamination of the borehole water in the three residential areas. Nonetheless, Cairncross (2017) observes that bacterial concentration in unchlorinated water supplies, such as borehole water is very variable; after two days of incubation, a sample collected on a sunny day may show few or no bacterial, however, bacterial contamination may be many times greater after heavy rain. Therefore, a low bacterial count can give a false sense of security, whereas a sanitary survey could determine the possible source of contamination [24], [25].

B. *Physicochemical Quality Analysis*

Table 2 shows the physicochemical quality test results for the borehole water sampled in the three residential areas. All the chosen parameters for the analysis were within the WHO's guidelines for drinking water except for temperature and potassium. The temperature recorded at the sampling points was 27.40 ◦C for all three residential areas. Though this temperature is slightly above the WHO's recommendation of drinking water temperature of less than or equal 25 ◦C, the high temperatures usually recorded in Northern Ghana, particularly during the harmattan period (from November to March) could be the cause of the high temperature of all the water sampled in the three residential areas. The water samples were collected in December 2020 in the afternoon, during which the temperature in Bole ranged from 9 ◦C in the morning to 30 ◦C in the afternoon.

In addition, the values recorded for potassium for the water sampled in all three residential areas were above the WHO's recommendation for drinking water of $3\ mg/l$, as water sampled from BS produced the highest value of $12\ mg/l$, whereas water sampled from both BW and BN produced $9\ mg/l$. Even though adverse health effects of high potassium in drinking water are unlikely in healthy individuals [26], [27], its presence in borehole water may indicate groundwater quality issues or other problems with the borehole [28], [29]. According to Segun and Raimi (2021), an increase in potassium in water should initiate an inspection of the borehole and the testing of coliform bacteria. Thus, the high potassium in all the water sampled from the three residential areas correlates with the test results for total coliform for the three residential areas, which indicated that the total coliform for all the water sampled in the three residential areas was far above the WHO's recommendation for drinking water. This calls for an investigation to determine the source of the high potassium and total coliform in the borehole water for the water sampled in the three residential areas.

Table 2: Physicochemical Quality Test Results

Parameter	WHO Guidelines (Cotruvo, 2017)	BW	BN	BS
Temperature (°C)	≤ 25 ◦C	27.40	27.40	27.40
pH	6.50 – 8.50	7.00	7.50	6.90
Turbidity (NTU)	0.00 – 1.00	0.50	0.80	1.25
Colour (TCU/Hazen)	15	5.00	5.00	5.00
Conductivity (µmhos/cm)	-	98.00	125.00	112
Total dissolved solids $(mg\ /\ l)$	<600.00	13.00	12.00	12
Total hardness $(mg\ /\ l)$	500.00	42.00	39.00	42
Calcium hardness $(mg\ /\ l)$	-	23.00	23.00	27
Magnesium hardness $(mg\ /\ l)$	-	19.00	16.00	31.20
Alkalinity (mg/l)	30.00 – 400.00	100.00	110.00	98.00
Chloride (mg/l)	250.00	0.00	0.00	0.00
Nitrite $(mg\ /\ l)$	3.00	0.00	0.00	0.00
Nitrates $(mg\ /\ l)$	50.00	0.00	0.00	0.00
Ammonia (Nitrogen) $(mg\ /\ l)$	1.50	0.00	0.00	0.00
Fluoride $(mg\ /\ l)$	1.50	0.12	0.10	0.04
Iron $(mg\ /\ l)$	0.3	0.03	0.01	0.01
Zinc $(mg\ /\ l)$	3.00	0.01	0.01	0.01
Copper (Total) $(mg\ /\ l)$	2.00	0.00	0.00	0.00
Potassium $(mg\ /\ l)$	3.00	9.00	9.00	12.00
Aluminium $(mg\ /\ l)$	2.00	0.00	0.00	0.00
Sulphate $(mg\ /\ l)$	250.00	0.00	0.00	0.00
Lead $(mg\ /\ l)$	0.05	0.00	0.00	0.00
Manganese $(mg\ /\ l)$	0.40	0.00	0.00	0.00
Mercury $(mg\ /\ l)$	0.30	0.00	0.00	0.00
Arsenic $(mg\ /\ l)$	0.01	0.00	0.00	0.00
Bicarbonate $(mg\ /\ l)$	-	0.00	0.00	0.00
Carbonate (mg/l)	-	0.00	0.00	0.00

BW = Bole West (Bole Hospital Area), BN = Bole North (Hill Top Area), and BS = Bole South (Refugee Camp Area)

IV.CONCLUSION

The study evaluated borehole water in the Bole district of the Savannah region of Ghana, with a focus on the bacteriological quality and physicochemical quality of borehole water sampled from boreholes located in three residential areas. The results showed that the bacteriological parameters analyzed, *E. Coli* and total coliform, for all the water sampled in the three residential areas were far above the WHO's recommendation for drinking water of $0.00\ count/100ml$ (not detected). However, the physicochemical quality analysis showed that all the chosen parameters were within the WHO's recommendation for drinking water, except for temperature and potassium. The high temperature of the sampled water could be attributed to the general high temperature in the Bole District, particularly during the harmattan season, when the water samples were collected. The high potassium in the sampled water confirms the bacteriological analysis, which indicated the high presence of bacteria and other viruses in the water sampled for the three residential areas. This calls for a sanitary survey of excreta disposal systems, such as septic tanks and KVIPs, which are the potential sources of the high potassium, *E. Coli* and total coliform, in the Bole district to determine the sources of contamination of the borehole drinking water in the Bole district.

ACKNOWLEDGEMENT

The researcher is grateful to Amantana Boadu Fatawu for assisting in the collection of the water samples in Bole and the staff of GWCL in Wa for conducting the laboratory test on the water samples.

COMPETING INTERESTS

The author declare no competing financial interests.

FUNDING

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

REFERENCES

[1]S. Kurwadkar, S. R. Kanel, and A. Nakarmi, “Groundwater pollution: Occurrence, detection, and remediation of organic and inorganic pollutants,” Water Environment Research, vol. 92, no. 10. John Wiley & Sons, Ltd, pp. 1659–1668, Oct. 01, 2020, doi: 10.1002/wer.1415.

[2]T. Sharma, B. S. Bajwa, and I. Kaur, “Contamination of groundwater by potentially toxic elements in groundwater and potential risk to groundwater users in the Bathinda and Faridkot districts of Punjab, India,” Environ. Earth Sci., vol. 80, no. 7, pp. 1–15, Mar. 2021, doi: 10.1007/s12665-021-09560-3.

[3]R. Marshall, J. Levison, B. Parker, and E. McBean, “Septic System Impacts on Source Water: Two Novel Field Tracer Experiments in Fractured Sedimentary Bedrock,” Sustain., vol. 14, no. 4, p. 1959, Feb. 2022, doi: 10.3390/su14041959.

[4]A. Motevalli, S. A. Naghibi, H. Hashemi, R. Berndtsson, B. Pradhan, and V. Gholami, “Inverse method using boosted regression tree and k-nearest neighbor to quantify effects of point and non-point source nitrate pollution in groundwater,” J. Clean. Prod., vol. 228, pp. 1248–1263, Aug. 2019, doi: 10.1016/j.jclepro.2019.04.293.

[5]Y. Xia et al., “Recent advances in control technologies for non-point source pollution with nitrogen and phosphorous from agricultural runoff: current practices and future prospects,” Applied Biological Chemistry, vol. 63, no. 1. Springer, pp. 1–13, Dec. 01, 2020, doi: 10.1186/s13765-020-0493-6.

[6]M. Van Damme et al., “Industrial and agricultural ammonia point sources exposed,” Nature, vol. 564, no. 7734, pp. 99–103, Dec. 2018, doi: 10.1038/s41586-018-0747-1.

[7]L. Zou, Y. Liu, Y. Wang, and X. Hu, “Assessment and analysis of agricultural non-point source pollution loads in China: 1978–2017,” J. Environ. Manage., vol. 263, p. 110400, Jun. 2020, doi: 10.1016/j.jenvman.2020.110400.

[8]A. Azaroff, M. Monperrus, C. Miossec, C. Gassie, and R. Guyoneaud, “Microbial degradation of hydrophobic emerging contaminants from marine sediment slurries (Capbreton Canyon) to pure bacterial strain,” J. Hazard. Mater., vol. 402, p. 123477, Jan. 2021, doi: 10.1016/j.jhazmat.2020.123477.

[9]J. S. Calderon, M. E. Verbyla, M. Gil, F. Pinongcos, A. M. Kinoshita, and N. Mladenov, “Persistence of Fecal Indicators and Microbial Source Tracking Markers in Water Flushed from Riverbank Soils,” Water. Air. Soil Pollut., vol. 233, no. 3, pp. 1–13, Mar. 2022, doi: 10.1007/s11270-022-05542-8.

[10]V. Masindi and S. Foteinis, “Groundwater contamination in sub-Saharan Africa: Implications for groundwater protection in developing countries,” Clean. Eng. Technol., vol. 2, p. 100038, Jun. 2021, doi: 10.1016/j.clet.2020.100038.

[11]A. Hussain et al., “In-situ, Ex-situ, and nano-remediation strategies to treat polluted soil, water, and air – A review,” Chemosphere, vol. 289. Pergamon, p. 133252, Feb. 01, 2022, doi: 10.1016/j.chemosphere.2021.133252.

[12]S. Kuppusamy, N. R. Maddela, M. Megharaj, and K. Venkateswarlu, “Case Studies on Remediation of Sites Contaminated with Total Petroleum Hydrocarbons,” in Total Petroleum Hydrocarbons, Springer, Cham, 2020, pp. 225–256.

[13]World Health Organization, “Drinking-water,” 2022. https://www.who.int/news-room/fact-sheets/detail/drinking-water (accessed May 17, 2022).

[14]M. D. Cahalan and A. M. Milewski, “Sinkhole formation mechanisms and geostatistical-based prediction analysis in a mantled karst terrain,” Catena, vol. 165, pp. 333–344, Jun. 2018, doi: 10.1016/j.catena.2018.02.010.

[15]P. Mageshkumar, A. Subbaiyan, E. Lakshmanan, and P. Thirumoorthy, “Application of geospatial techniques in delineating groundwater potential zones: a case study from South India,” Arab. J. Geosci., vol. 12, no. 5, pp. 1–15, Feb. 2019, doi: 10.1007/s12517-019-4289-0.

[16]S. P. S. Ray and A. Ray, “Major ground water development issues in South Asia: An overview,” in Ground Water Development - Issues and Sustainable Solutions, Springer, Singapore, 2018, pp. 3–11.

[17]A. Samie, Escherichia coli: Recent Advances on Physiology, Pathogenesis and . - Google Books. 2017.

[18]B. A. Shaikhan, K. Güven, F. M. Bekler, Ö. Acer, R. G. Güven, and K. Güven, “A highly inducible β-galactosidase from enterobacter sp,” J. Serbian Chem. Soc., vol. 85, no. 5, pp. 609–622, May 2020, doi: 10.2298/JSC190711141S.

[19]M. Osmani, S. Mali, B. Hoxha, L. Bekteshi, P. Karamelo, and N. Gega, “Drinking water quality determination through the water pollution indicators, Elbasan district,” Thalassia Salentina, vol. 41, no. 0, pp. 3–10, 2019, doi: 10.1285/i15910725v41p3.

[20]M. Moniruzzaman and M. A. Rahaman, “Examine the Water Quality of Pond Sand Filter (PSF): A Study on Khontakata Examine the Water Quality of Pond Sand Filter (PSF): A Study on Khontakata

Union of Sarankhola Upazila , Bangladesh,” no. January 2019, 2017, Accessed: Aug. 23, 2021. [Online]. Available: https://www.researchgate.net/publication/330506844.

[21]C. García-Aljaro, A. R. Blanch, C. Campos, J. Jofre, and F. Lucena, “Pathogens, faecal indicators and human-specific microbial source-tracking markers in sewage,” Journal of Applied Microbiology, vol. 126, no. 3. John Wiley & Sons, Ltd, pp. 701–717, Mar. 01, 2019, doi: 10.1111/jam.14112.

[22]N. Sasakova et al., “Pollution of Surface and Ground Water by Sources Related to Agricultural Activities,” Front. Sustain. Food Syst., vol. 2, p. 42, Jul. 2018, doi: 10.3389/fsufs.2018.00042.

[23]S. Cairncross, “Bacteriological testing of water,” Water, Eng. Dev. Cent. (WEDC), Loughbrgh. Univ., pp. 1–12, 2017.

[24]E. Kelly, R. Cronk, M. Fisher, and J. Bartram, “Sanitary inspection, microbial water quality analysis, and water safety in handpumps in rural sub-Saharan Africa,” npj Clean Water, vol. 4, no. 1, pp. 1–7, Jan. 2021, doi: 10.1038/s41545-020-00093-z.

[25]A. Cassivi, E. Tilley, E. O. D. Waygood, and C. Dorea, “Household practices in accessing drinking water and post collection contamination: A seasonal cohort study in Malawi,” Water Res., vol. 189, p. 116607, Feb. 2021, doi: 10.1016/j.watres.2020.116607.

[26]A. G. Godswill, I. V. Somtochukwu, A. O. Ikechukwu, and E. C. Kate, “Health Benefits of Micronutrients (Vitamins and Minerals) and their Associated Deficiency Diseases: A Systematic Review,” Int. J. Food Sci., vol. 3, no. 1, pp. 1–32, Jan. 2020, doi: 10.47604/ijf.1024.

[27]M. Kumari and A. Kumar, “Human health risk assessment of antibiotics in binary mixtures for finished drinking water,” Chemosphere, vol. 240, p. 124864, Feb. 2020, doi: 10.1016/j.chemosphere.2019.124864.

[28]E. E. Ezenwaji and I. D. Ezenweani, “Spatial analysis of groundwater quality in Warri Urban, Nigeria,” Sustain. Water Resour. Manag., vol. 5, no. 2, pp. 873–882, Jul. 2019, doi: 10.1007/s40899-018-0264-2.

[29]A. B. Bantin, H. Wang, and X. Jun, “Analysis and control of the physicochemical quality of groundwater in the chari baguirmi region in chad,” Water (Switzerland), vol. 12, no. 10, p. 2826, Oct. 2020, doi: 10.3390/w12102826.

[30]A. A. Segun and M. O. Raimi, “When Water Turns Deadly: Investigating Source Identification and Quality of Drinking Water in Piwoyi Community of Federal Capital Territory, Abuja Nigeria.,” Trends J. Sci. Res., vol. 1, no. 1, pp. 38–58, Aug. 2021, doi: 10.31586/ojc.2021.010105.

[31]J. A. Cotruvo, “2017 Who guidelines for drinking water quality: first addendum to the fourth edition,” J. Am. Water Works Assoc., vol. 109, no. 7, pp. 44–51, Jul. 2017, doi: 10.5942/jawwa.2017.109.0087.