Open Access Library Journal
2019, Volume 6, e5734
ISSN Online: 2333-9721
ISSN Print: 2333-9705

Groundwater Biological Quality in Abuja FCT: Myths and Realities of Point and Non-Point Pollution of Fractured Rock Aquifers

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How to cite this paper: Akoachere, R.A., Eyong, A.T., Ngassam, M.P., Akoachere, J.-F.K., Okpara, S.O., Yaya, O.O. and Mbaabe, F.A. (2019) Groundwater Biological Quality in Abuja FCT: Myths and Realities of Point and Non-Point Pollution of Fractured Rock Aquifers. *Open Access Library Journal*, **6**: e5734.
https://doi.org/10.4236/oalib.1105734

Received: August 26, 2019
Accepted: September 16, 2019
Published: September 19, 2019

Abstract

The quality of groundwater is three fold: physical, chemical and biological. For water to be fit for human consumption, it must have satisfied all three quality aspects. Therefore, the groundwater biological quality of Abuja FCT can never be over emphasized since the wellbeing of the citizens of the capital territory, seat of the government of Nigeria, is of strategic importance. There are myths and realities about the biological quality of groundwater in fractured rock aquifers which must be clarified. Groundwater plays a very important role in the development of Abuja, Nigeria's Capital as many private, government, and households establishments depend solely on hand-dug wells and boreholes for their daily water needs. This study evaluates the biological quality using total bacterial density (TBD), total coliform (TC), coliform bacteria (CB), faecal coliform (FC), total bacteria count (TBC), and salmonella species (SS) as biological pollution indicators. From physicochemical parameters: pH ranged from, 4.8 - 7.9; EC, 13.4 - 1634 μS/cm; Temperature, 26˚C - 36.1˚C and TDS, 17.42 - 1094.78 mg/L. Groundwater of Abuja FCT is not suitable for drinking as the species had the following concentration and percentages above the permissible limits for drinking water: TC (0 - 1280) 51.06%, FC (0 - 170) 19.15%, TBD (0 - 86.6) 98.94%, TBC (0 - 5120) 95.74%, CB (0 - 438) 74.47% and SS (0 - 223) 69.15%. Groundwater from Abuja FCT Granite-Gneiss fractured rock aquiferous formation is unfit for human consumption and an added danger to humans since it is usually assumed to be safe. Groundwater from Granite-Gneiss fractured rock aquifers could be the source of endemic outbreaks of waterborne diseases such as *E. coli*, Cholera, Gastroenteritis, Typhoid and Diarrhea; as such all groundwater from the aquiferous formations in Abuja FCT should be treated before consumption and use. Source protection strategies as well as monitoring are recommended although it may not serve the purpose for which it is intended since the potential for pollution is point and non-point sourced.

Subject Areas

Environmental Sciences, Hydrology

Keywords

Groundwater, Biological Quality, Abuja FCT, Point-Non-Point-Pollution, Fractured-Rock-Aquifers

1. Introduction

The quality of water (groundwater) is three fold: physical, chemical and biological. For water to be fit for human consumption, it must satisfy all three quality aspects. Groundwater when biologically contaminated results in serious health related problems and consequences. Groundwater has been recognized as playing a very important role in the development of Abuja FCT, Nigeria's Capital as many private, government, and households establishments depend solely on hand-dug wells and boreholes for their daily water needs [1]. Therefore, the groundwater biological quality of Abuja FCT can never be over emphasized, since the wellbeing of the citizens of the capital territory, seat of the government of Nigeria, is of strategic importance. There are myths and realities of the biological quality of groundwater in fractured rock aquifers which must be clarified. The Federal Capital Territory (FCT) Abuja, is bounded between 8˚45'N-9˚40'N and 6˚50'E-8˚55'E and covering an area of about 8000 km^2 was conceived with adequate allocation of resources, to be a model city of urbanization in sub-Saharan Africa. Before the birth of the FCT, Abuja and environs had been plagued with varying intensities of water shortages and crisis at the local government scale. As the Capital City emerged, the rate of influx of population outstripped the capacity to provide utilities, exacerbating the water crisis to a higher scale, mainly due to the following:

1) Natural causes stemming from the hydrogeology and the hydrology (Basement fractured rock and weathered regolith aquiferous formations and the moderate rainfall regime).

2) Inadequate exploration/exploitation and unsustainable management practices amplified by shortfalls associated with lack of equipment and technological knowhow for monitoring and characterizing the groundwater reserves [1].

Groundwater represents an important source of drinking water in Abuja FCT and its quality is currently threatened by a combination of factors: over-abstraction, chemical and microbiological contamination.

Due to growing populations and expanding land use, sources of pathogen contaminated wastes steadily increase thereby raising the potential pollution of groundwater with infectious biological agents in Abuja FCT. The quality of many source waters depends upon geology, soil type, natural vegetation, and climate and run-off characteristics. Disruption of natural geology and heavy rainfall can dramatically affect water quality. Wild animals and birds can also be natural sources of zoonotic pathogens [2].

The microbial analysis of water used for drinking purposes helps in the understanding of risk associated with pathogenic microorganisms; these microorganisms have natural habitat of the intestines of man and/or warm blooded animals [3].

Bacteriological contamination of groundwater is associated with water borne diseases such as viral hepatitis, schistosomiasis and cholera [4]. The microbial quality of water is very important because it is directly related to the presence and concentration of disease causing microorganisms which include some bacteria, fungi, protists and viruses [5]. The contamination of water with fecal material, domestic and industrial waste may result in increased risk of disease transmission to individuals who use the water. Diarrhoeas which are caused by poor sanitation and by contaminated water are part of diseases in developing countries [6].

Indicator microbes like coliform bacteria are widely used to validate the degree of cleanliness, detect and estimate levels of contamination, and the potential presence of microorganisms. The greatest risk to public health from microbes in groundwater is associated with consumption of groundwater contaminated with human and animal excreta, although other sources of exposure may also be significant. In rural areas, drinking water is generally supplied by groundwater through individual or community wells/boreholes [7]. Indicator bacteria give the overall microbial status of the water [8].

The study aims at determining the biological quality of groundwater of Abuja FCT, compare them with the Nigerian Industrial standard for drinking water quality and world health organization WHO guidelines.

1.1. Location

The study area lies between 8.92N-9.20N and 7.25E-7.60E in Abuja Federal Capital Territory (FCT) as in **Figure 1**. It is bounded in the east by Nasarawa State, north by Kaduna State, west by Niger State and south by Kogi State.

1.2. Physiology

The topography of Abuja is undulating with hills and inselbergs that rise northwestwards to a maximum of 1060 m above sea level. There are extensive plains found between hills in the study area. The Zuma rock stands out clearly on its own as the most conspicuous Inselberg at the boundary of the Abuja with

Niger State. The lowest elevations are in the southwestern flood plains of the River Gurara, about 76 m above sea level. The rivers rise from the hills in the northeast and flow to the southwest. The area is drained by many rivers in and around Abuja including Rivers Gwagwalada and Usmanu while Rivers Wupa, Wosika and other smaller seasonal southerly-flowing streams form the tributaries and drain the study area. The drainage pattern generally varies from trellis to dendritic. The major rivers join at Nyimbo village to form a tributary of River Niger in the south. These rivers depend on rainfall for their recharge. As such, their stages are high in rainy season and decrease drastically during the dry season.

1.3. Climate

The area has its highest temperature of about 36˚C during the dry season, November to March. During the rainy season April to October, the temperature drops to a maximum of 24˚C [9]. The annual rainfall ranges from 1100 mm to 1600 mm [10]. Two types of vegetation occur; the forest predominantly of woody plants thorn bushes and trees in which grasses are virtually absent comprise mainly of secondary forest, which is continuously degraded for subsistence farming and habitation and the savanna herbs and shrubs, the study area being in Guinean Savanna Vegetation Zone of Nigeria.

1.4. Geology

The geology of the study area has been described by many workers, including [3] [9] [11]. The study area is underlain by Precambrian rocks of the Nigerian Basement Complex which cover about 85% of the land surface and cretaceous sedimentary rocks belonging to the Bida Basin which cover the remaining 15% as in **Figure 2**.

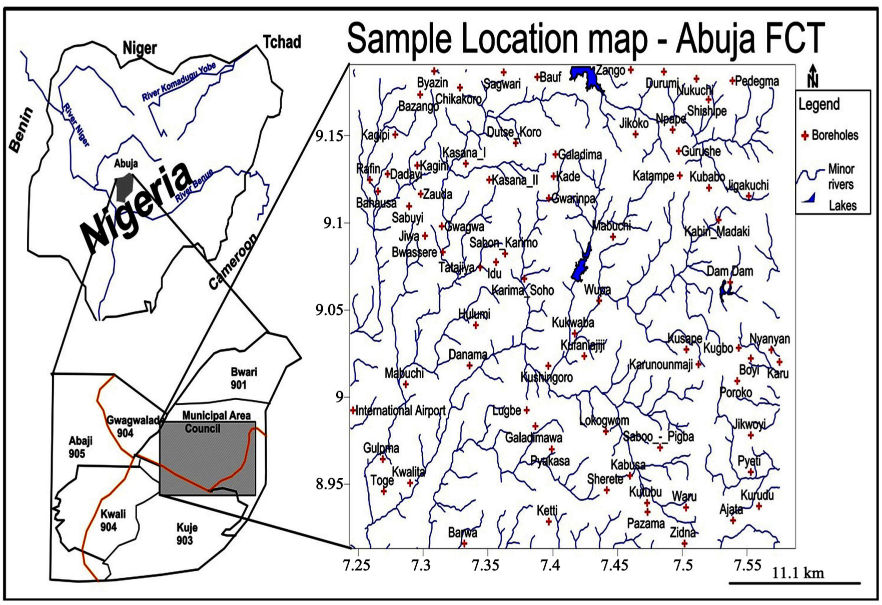

Figure 1. Location of the study area showing field tested and sampling points.

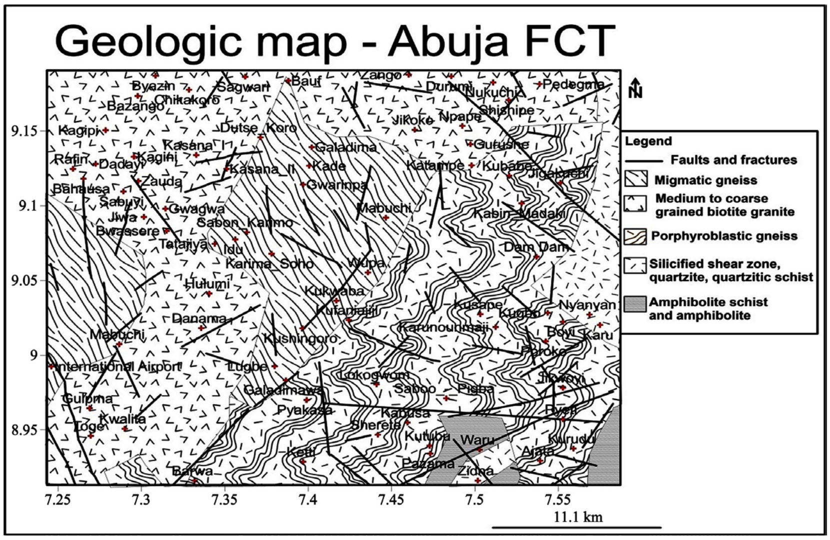

Figure 2. Geologic map of the study area.

1.5. Hydrogeology

The aquiferous formations in Abuja FCT are mostly Granite-Gneiss fractured rock and their regolith.

In Granite-Gneiss-type rocks, single weathering and erosional processes induce similar geological structures. From field observations, borehole lithostratigraphic sections and by comparing various case studies in similar terrain, a modified hydro-geological conceptual model of migmatite/gneiss-type fractured rock aquifers in Africa postulated by [1] has been adopted in Abuja FCT.

In this model, precipitation infiltrates through the sandy regolith and groundwater flows through:

1) Weathered basement regolith

2) Fractured/fissured basement

3) Deep large regional fractures with a larger fraction flow volumes.

Groundwater is stored in:

1) The weathered basement or regolith in the inter-particulate pore spaces and relics of fractures. Though here storage is directly impacted by seasonal variations of precipitation

2) The fracture/fissure insular network infrastructure of unconnected joints, fissures and fractures

3) The fracture/fissure interconnected network infrastructure which also serves as the major conduit/channel for storage and flow of groundwater.

The weathered regolith, the local fractures and the regional fracture network form a single continuous hydraulic unit making a single weathered basement fractured-rock aquifer.

2. Materials and Methods

Field Mapping, Measurements and Sampling

Ninety-four (94) groundwater samples were collected from productive boreholes in the study area after a geological traverse field mapping exercise and borehole water field testing for physico-chemical parameters as shown in **Table 1**, following standard sampling protocols [12]. Boreholes for tests and measurements were selected based on three criteria:

Table 1. Location of water samples for microbial analysis and physico-chemical measurements.

8	Name	N	E	SN	Name	N	E	SN	Name	N	E
1	Kwalita	7.2499	8.9540	33	Toge	7.3356	8.9487	64	Galadima	7.3796	9.1674
2	Kwalita	7.2496	8.9532	34	Sherete	7.3337	8.9489	65	Gwagwa	7.3354	9.1017
3	Pazama	7.2547	8.9332	35	Pyakasa	7.3567	8.9686	66	Gwagwa	7.4081	9.1011
4	Zidna	7.2152	8.9134	36	Saboo_Pigba	7.3723	8.9673	67	Gwagwa	7.4081	9.1011
5	Kabusa	7.2941	8.9453	37	Lokogwom	7.3730	8.9700	68	Gwagwa	7.4097	9.1018
6	Kutubu	7.2916	8.9448	38	Galadimawa	7.3738	8.9804	69	Gwarinpa	7.4177	9.1060
7	Gulpma	7.2432	8.9549	39	Kasana_I	7.3677	8.9983	70	Gurushe	7.4670	9.1408
8	Jigakuchi	7.2893	8.9967	40	Jikoko	7.3711	8.9963	71	Zango	7.5200	9.1610
9	Jikoko	7.3193	9.0040	41	Jikwoyi	7.4203	9.0184	72	Zango	7.4915	9.1012
10	Kusape	7.3305	9.0278	42	Dutse_Koro	7.4227	9.0179	73	Jiwa	7.4367	9.0947
11	Kushingoro	7.3504	9.0298	43	Dutse_Koro	7.4427	9.0175	74	Byazin	7.4339	9.0952
12	Hulumi	7.3714	9.0449	44	Kabin_Madaki	7.4224	9.1032	75	Karu	7.5690	9.0291
13	Dam Dam	7.3633	9.0714	45	Zauda	7.3990	9.1249	76	Kugbo	7.5685	9.0292
14	Kubabo	7.3345	9.0766	46	Dadayi	7.3877	9.1288	77	Kugbo	7.5650	9.0281
15	Bahausa	7.2810	9.1093	47	Chikakoro	7.3668	9.1376	78	Kugbo	7.5770	9.0294
16	Kasana_II	7.2877	9.1166	48	Npape	7.3671	9.1375	79	Kugbo	7.5751	9.0328
17	Kurudu	7.2979	9.0993	49	Npape	7.2989	9.1350	80	Kugbo	7.5624	9.0123
18	Sabon_Karimo	7.3083	9.0804	50	Npape	7.3002	9.1350	81	Kugbo	7.3423	9.0064
19	Mabuchi	7.3067	9.0913	51	Npape	7.3002	9.1350	82	Katampe	7.5205	9.0383
20	Mabuchi	7.3133	9.0901	52	Kasana_I	7.3002	9.1350	83	Katampe	7.5205	9.0383
21	Ketti	7.2821	9.0710	53	Kagini	7.2989	9.1320	84	Katampe	7.5194	9.0177
22	Poroko	7.3318	9.0080	54	Kade	7.3008	9.1280	85	Boyi	7.5176	9.0169
23	Karima_Soho	7.3544	9.0711	55	Chikakoro	7.3161	9.1430	86	Ajata	7.4882	9.0029
24	Idu	7.4479	9.0817	56	Kagipi	7.3209	9.1532	87	Barwa	7.4683	9.0846
25	Wupa	7.4102	9.0633	57	Bazango	7.3200	9.1520	88	Sabuyi	7.4809	9.0991
26	Danama	7.4108	9.0239	58	Shishipe	7.3257	9.1704	89	Durumi	7.4809	9.0991
27	Pazama	7.3972	8.9920	59	Pedegma	7.3277	9.1766	90	Rafin	7.4870	9.1026
28	Pazama	7.3944	8.9994	60	Bauf	7.3261	9.1773	91	Rafin	7.4826	9.1009
29	Intl. Airport	7.4025	8.9904	61	Sagwari	7.3326	9.1802	92	Rafin	7.4887	9.1020
30	Kufaniajiji	7.4269	8.9917	62	Nukuchi	7.3382	9.1735	93	Rafin	7.4744	9.0757
31	Kukwaba	7.3049	8.9377	63	Galadima	7.3735	9.1392	94	Rafin	7.4792	9.0658
32	Waru	7.3265	8.9415								

1) Availability of data

2) Being functional and in use

3) Not deeper than our water level indicator 50 m and Sonar bottom sounder 61 m.

The following groundwater and borehole physical parameters were measured in-situ in the field using calibrated field instruments; Hanna HI 98127 (pH), HI 98304 (EC), HI 96304 (TDS), HI 9147 (DO), Groundwater temperature and electrical conductivity in boreholes was profiled real-time using Solinst levelogger for Static Water Level measurements as shown in Table 2. Geolocation and elevation measurements of boreholes were done using a Global Positioning System (GPS) Garmin 60 CSx.

The methodologies used are based on the following protocols:

[13] used for the enumeration of coliform bacteria, total coliform and fecal coliform. The Standard Test for membrane filtration, subsequent culture on differential agar media and calculation of number of target organisms in the samples, [14] for the enumeration of Salmonella species and [15] to specify the total bacterial count and total bacterial density.

The interpretation is based on [16] [17] [18] [19].

Data from the geological traverse field mapping, field tests, field measurements and laboratory analysis were placed on MS Excel spreadsheets, and then mounted unto various GIS and software platforms, Surfer V12, Grapher, and Global mapper 11 where they were vigorously queried as shown in Table 2.

Table 2. Field equipment, specifications and functions.

Equipment/Softwares	Specifications	Functions
GPS	Garmin GPSMAP 60CSx	To measure longitude, latitude and elevation of wells
EC Meter	Hanna HI 98304/HI98303	To measure Electrical Conductivity of water.
pH Meter	Hanna HI 98127/HI98107	To measure pH of water.
Water level indicator	Solinst Model 102M	To indicate static water levels of water in wells
Measuring Tape	Weighted measuring tape	Measurement of well diameter and depth.
Digital Thermometer	Extech 39240 (−50˚C to 200˚C)	To measure temperature of water
Total Dissolved Solid meter	Hanna HI 96301 with ATC	To measure Total dissolved solids in water
Water sampler	Gallenkampf 1000 ml	To collect well water sample from well
Sample bottles	Polystyrene 500 ml	To hold sample for onward transmission to laboratory
Global Mapper	Version 15	GIS Geolocation of wells
Surfer Golden Software	Version 12	GIS plotting contours for spatial distribution
AqQA/Aquachem	Version 1.5	For the analysis/interpretation of water chemistry

3. Results and Discussion

The summary statistics of physicochemical parameters of groundwater in Abuja: Temperature, pH, EC and TDS were evaluated in **Table 3** and microbiological classification of groundwater in Abuja FCT in **Table 4** for 94 boreholes.

3.1. Digital Elevation Model

Abuja has an undulating relief of hills and valleys. The land surface is covered by top soil in most areas as in **Figure 3**. The topography of the Abuja is varied with the lowest elevations in the extreme southwest at the floodplains of the River Gurara, about 76 m above sea level and it rises irregularly northwestwards to a height of 760 m above sea level. There are numerous hills that occur in the area but the Zuma rock stands out clearly on its own as the most conspicuous Inselberg at the boundary of the Abuja with Niger State.

3.2. Water Level Fluctuations

Groundwater levels range from 3 - 12.5 m. High water levels are at Kwalita, Galadimawa, Wupa, Pigba, Kurundu and Pyeti whereas low values are at Pedegma, Nukuchi, Durumi and Zango as seen **Figure 4**. The shallow depth to water levels which in some areas could increase surface runoff into boreholes and thus increase the number of microorganisms in the water. These low depths to water could also be prone to pollution if the wells are not appropriately constructed and protected.

Table 3. Basic statistics of the physicochemical found in groundwater, min, max, mean and standard deviation.

Parameter	Min	Max	Mean	Std
T (˚C)	26.0	36.1	31.35	2.19
PH	4.8	7.9	6.04	0.67
EC (μS/cm)	13.4	1634	265.21	281.26
TDS (mg/L)	17.42	1094.78	178.88	187.74

Table 4. Microbial classification of groundwater in Abuja using [18] and [17] guidelines.

Organism	Range	MAC	No of samples		% Guideline		Reference
	No	(cfu)/100ml)	below	above	below	above	
CB	0 - 438	0	24	70	25.53	74.47	NIS, 2007
F C	0 - 170	0	76	18	80.85	19.15	NIS, 2007
TC	0 - 1280	10	46	48	48.94	51.06	WHO, 2004
SS	0 - 223	0	29	65	30.85	69.15	WHO, 2004
TBC	0 - 5120	0	4	90	4.26	95.74	WHO, 2004
TBD	0 - 86.6	0	1	93	1.06	98.94	WHO, 2004

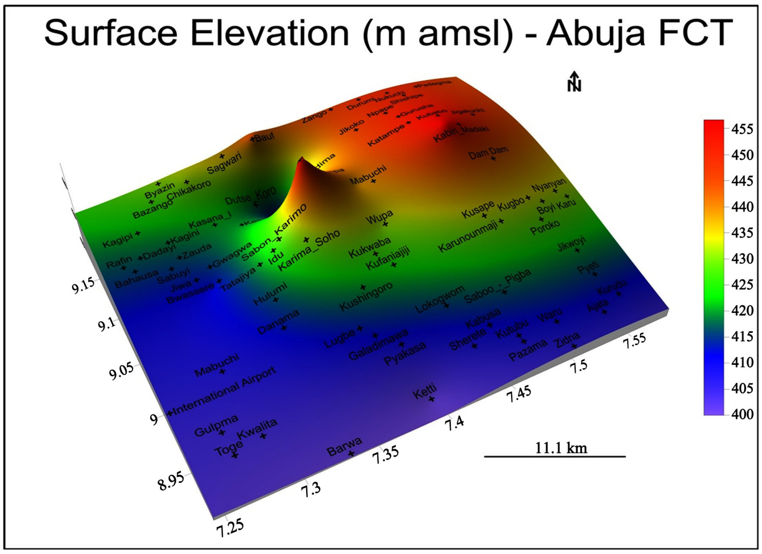

Figure 3. Spatial variation of elevation above mean sea level in Abuja.

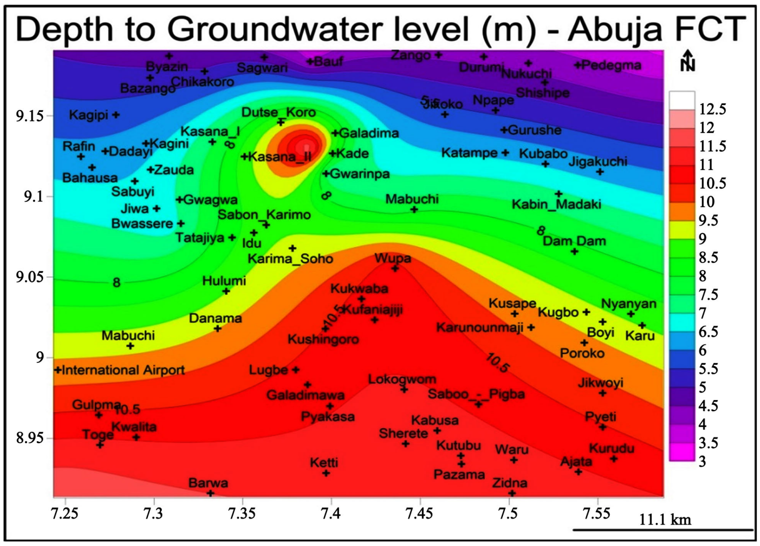

Figure 4. Depth to static water levels of Abuja groundwater. High values are at Kwalita, Galadimawa, Pigba, and Pyeti whereas low values are at Pedegma, Nukuchi and Zango.

3.3. Temperature

The temperatures of groundwater in Abuja range from 26.0˚C - 36.1˚C as shown in Table 3. These groundwater temperatures are close to air temperatures indicative of phreatic aquifers. Some bacteria can be killed at elevated temperatures > 15˚C or higher, thus the temperatures within the study area are suitable for the survival of microorganisms. High temperatures are at Koro, Kade, Galadima, Mabuchi, Kushingoro and Karunounmaji whereas low temperatures are at Kgjini, Jiwa, Dadayi, and Sabuyi as in Figure 5.

3.4. pH

The pH of groundwater samples in the study area ranged from; 4.8 - 7.9 as shown in Table 3. The value of pH of a water sample is recognized as an index of classifying groundwater as acidic < 5.5, slightly acidic 5.5 - 6.5, neutral 6.5 - 7.5, slightly alkaline 7.5 - 8, moderately alkaline 8 - 9 and alkaline > 9. From the above results, it is indicative that water in the study area is acidic to alkaline. High pH values are at Kwalita, Kukwaba, Kufaniajiji whereas low pH values are at Danama, Bazango, Chikakoro, Dutse, Kade, and Galadima as seen in Figure 6.

3.5. Electrical Conductivity

The observed conductance in the study area ranged from 13.4 - 1634 $\mu S/cm$ as shown in Table 3. The measurement of conductivity gives a good indicator of the concentration of dissolved salts in water. In the present study EC values were in the permissible limits as in Figure 7.

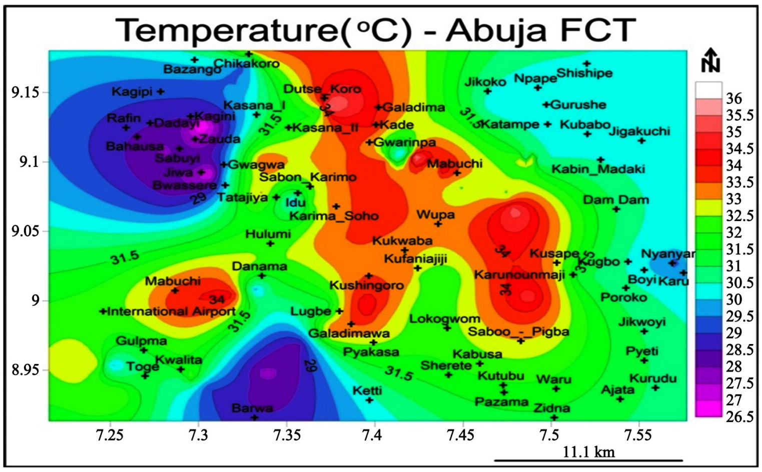

Figure 5. Spatial variation of Temperature in Abuja; Note high temperature values around Mabuchi and Karunounmaji whereas low temperature values are at Jiwa, Dadayi, Sabuyi.

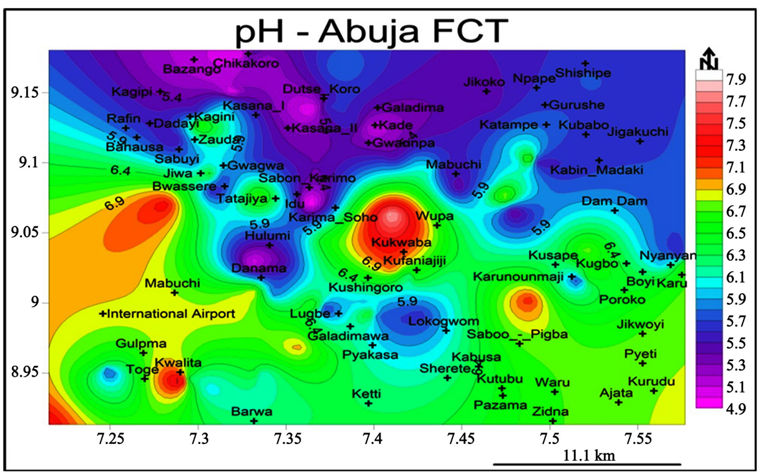

Figure 6. Spatial variation of pH in Abuja; Note high pH values around Kwalita, Kukwaba, Kufaniajiji whereas low pH values are at Danama, Chikakoro, Dutse, Kade, and Galadima.

3.6. Total Dissolved Solids

The values range from 17.42 - 1094.78 mg/L with the highest value observed at Kuru, Gwagwa, Kurundu, and Barwa whereas low values are at Nyana, Dam Dam, Jikoko, Galadima, Kade, Mabuchi, and Jikoko as seen Figure 8. TDS represents the amount of inorganic substances. High TDS is commonly offensive to taste. A higher concentration of TDS usually serves as no health threat to humans until the values exceed 10,000 mg/L.

3.7. Dissolved Oxygen

Several biological and inorganic processes taking place in the subsurface may consume dissolved oxygen and deplete the DO levels. The water samples collected in the study area had DO between 0 and 10 mg/L and a spatial variation as in Figure 9. Low DO levels can be attributed to heterotrophic biological respiration.

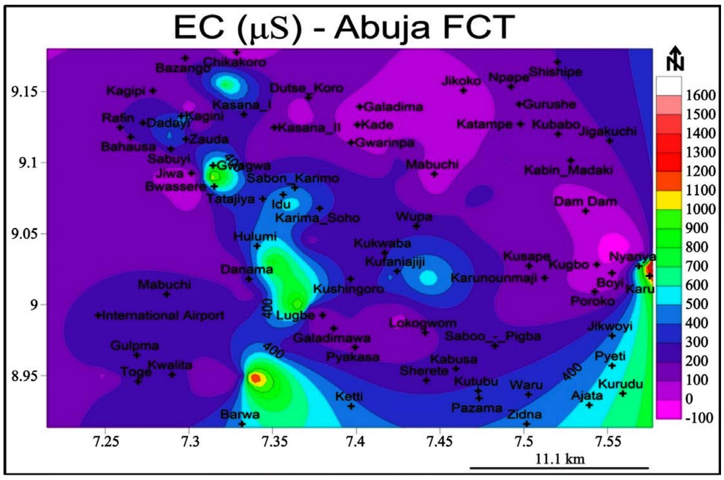

Figure 7. Spatial variation of Electrical Conductivity (μS/cm) in Abuja; EC is maximum at Kuru, Gwagwa, Kurundu, and Barwa whereas low values are at Jikoko, Kade, Mabuchi, and Jikoko.

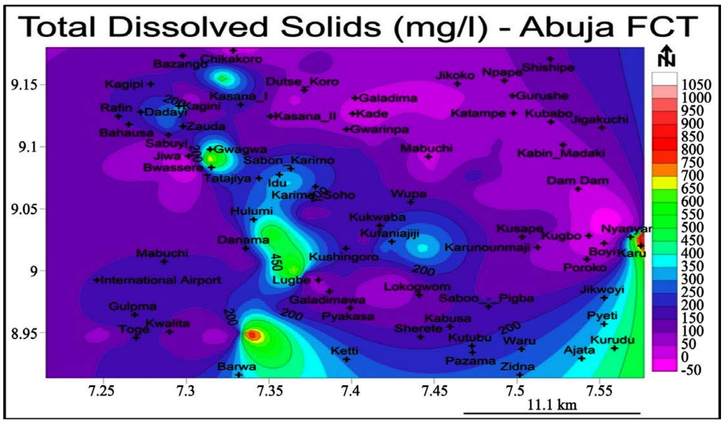

Figure 8. Spatial variation of Total dissolved solids (mg/L) in Abuja; TDS is maximum at Kuru, Kurundu, and Barwa whereas low values are at Nyana, Galadima, Kade, Mabuchi, and Jikoko.

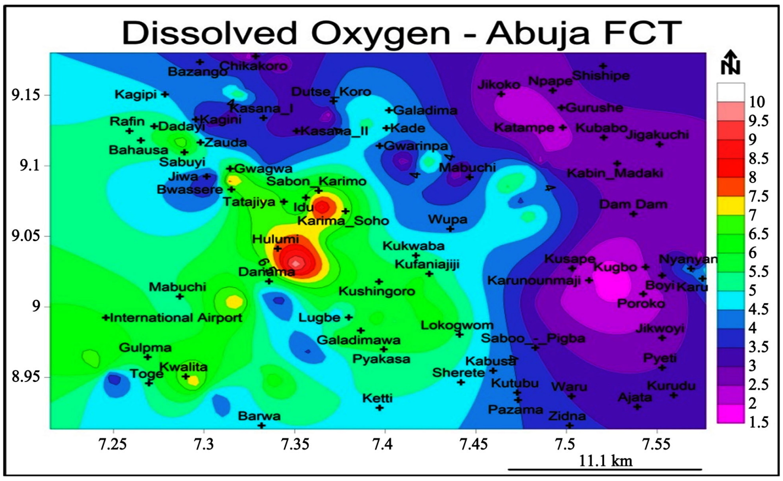

Figure 9. Spatial variation of dissolved oxygen (mg/L) in Abuja; DO is maximum at Danama, Hulumi, Kama Soho and Sabon Karimo whereas low values are at Gurushe, Kugbo and Poroko.

3.8. Total Bacterial Count (TBC)

Total bacterial count is used to estimate the total amount of bacteria in groundwater and indicates the overall microbial status of the water [8]. Total bacterial count ranges from 0 - 5120 as in **Figure 10**. These values are far above the maximum permissible limits of NIS and WHO.

4. Total Coliforms

As qualitative indicators, total coliforms provide information on the portability of groundwater and the environmental condition of the groundwater resource [20]. Total coliforms range from 0 - 1280 as in **Figure 11**. Their presence indicates that the groundwater may be contaminated by human or animal wastes [21]. Fresh human and animal faeces contain between 10^2 and 10^4 coliforms per gram than other bacteria [22]. These high total coliform values are indicative of disease-causing microbes (pathogens) in groundwater and can cause diarrhea, cramps, nausea, headaches, or other symptoms. These pathogens may pose a special health risk for infants, young children, and people with severely compromised immune systems [2].

4.1. Faecal Coliform

Faecal coliform are a bacteria species belonging to the total coliform group. This bacterium is found in the faces of warm-blooded animals, but, unlike total coliforms, they are not present naturally in the environment [23]. Faecal coliforms range from 0 - 170 as in **Figure 12**. This result indicates that the water is grossly polluted by potentially harmful microorganisms. These pathogens may be of faecal origin and water that contains them is not suitable for drinking and/or cleaning purposes and could cause epidemics of water borne diseases to the population.

4.2. Coliform Bacteria

Coliform bacteria are a group of enteric bacteria that includes E. coli and Enterobacteria species. They are Gram negative, facultative anaerobic, non-sporing rods that may be motile or not. They are generally not harmful themselves; they indicate the possible presence of pathogenic bacteria, viruses and protozoans [24]. Coliform bacteria range from 0 - 438 as seen in Figure 13. The presence of

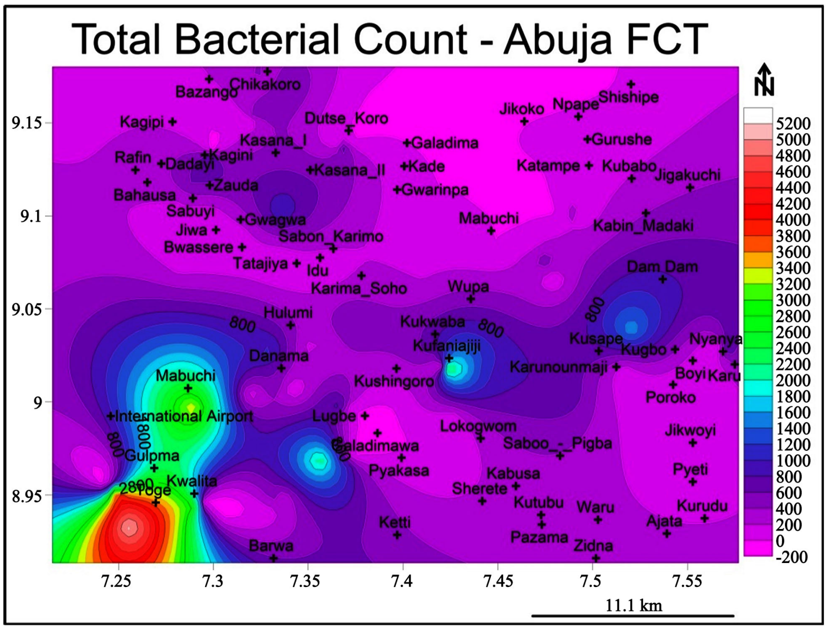

Figure 10. Spatial variation of total bacteria count in Abuja; TBC is maximum at Toge, and Mabuchi whereas low values are at Duste Kuro, Galadima, Pyeti, Jikwoyi and Kurundu.

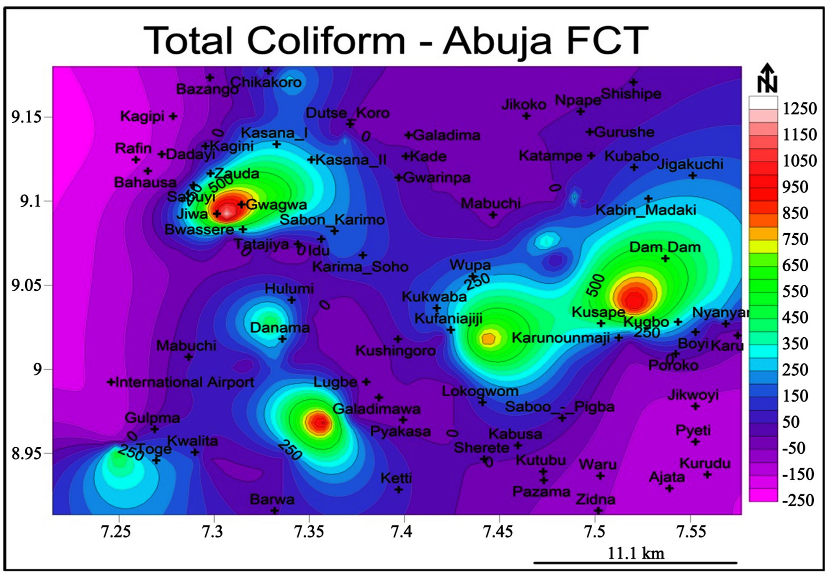

Figure 11. Spatial variation of total bacteria count in Abuja; TBC is maximum at Gwagwa, Dam Dam, and Kusape whereas low values are at Duste Kuro, Pyeti, Bahausa, Kagipi and Kurundu.

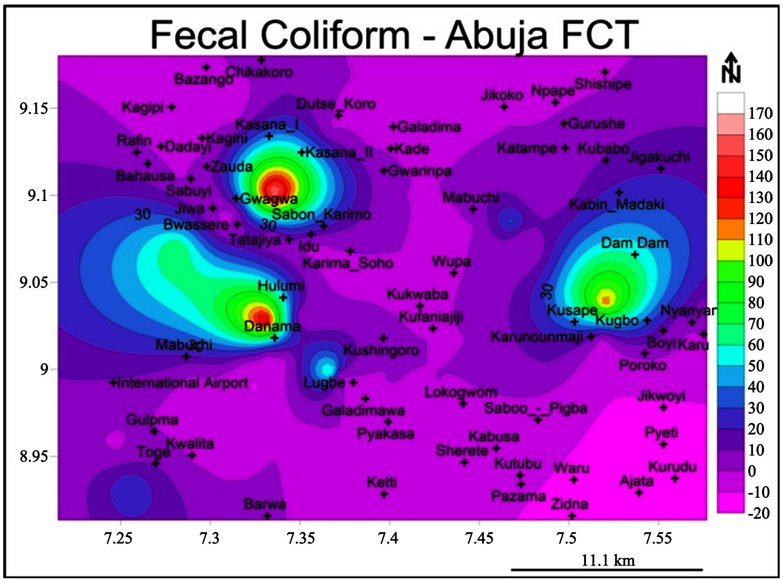

Figure 12. Spatial variation of Fecal coliform in Abuja; TBC is maximum Dam Dam, Danama, and Kusape whereas low values are at Duste Kuro, Pyeti, Jikwoyi, Rafin, Kagipi and Kurundu.

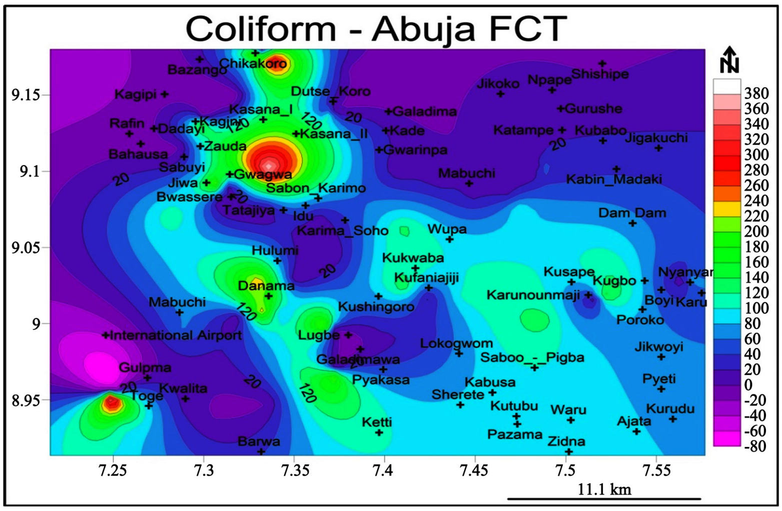

Figure 13. Spatial variation of Coliform bacteria in Abuja; TBC is maximum Gwagwa, Zeuda, Kugbo, Danama, and Kusape whereas low values are at Duste, Pyeti, Jikwoyi, and Kurundu.

coliform bacteria in drinking water increases the risk of contracting a water-borne illness. The presence of these coliform bacteria could be as a result of the following; a missing or defective well cap, contaminant seepage through the well casing, contaminant seeping along the outside of the well casing and well flooding. According to Cheesbrough classification, 23.4% of the samples are acceptable for drinking whereas 76.6% are unacceptable for drinking indicating that the water is polluted by potentially harmful microorganisms as shown in Table 5. These pathogens may be of faecal origin and water that contains them is not suitable for drinking and/or cleaning purposes.

Table 5. Results of Most Probable Number (MPN) of Coliform Bacteria (CB)/100ml of groundwater samples.

SN	MPN	CB	SN	MPN	CB	SN	MPN	CB	SN	MPN	CB
1	0	A	25	126	U	49	29	U	74	0	A
2	438	U	26	135	U	50	0	A	75	75	U
3	109	U	27	17	U	51	0	A	76	59	U
4	94	U	28	24	U	52	0	A	77	3	U
5	8	U	29	16	U	53	180	U	78	62	U
6	8	U	30	36	U	54	132	U	79	46	U
7	2	U	31	0	A	55	3	U	80	43	U
8	63	U	32	0	A	56	26	U	81	71	U
9	0	A	33	0	A	57	0	A	82	119	U
10	248	U	34	0	A	58	94	U	83	101	U
11	0	A	35	132	U	59	201	U	84	152	U
12	2	U	36	201	U	60	196	U	85	0	A
13	16	U	37	0	A	61	0	A	86	131	U
14	11	U	38	0	A	62	331	U	87	18	U
15	0	A	39	230	U	64	0	A	88	0	A
16	0	A	40	0	A	65	390	U	89	177	U
17	75	U	41	41	U	66	0	A	90	22	U
18	3	U	42	12	U	67	16	U	91	20	U
19	223	U	43	105	U	68	10	U	92	75	U
20	7	U	44	11	U	69	11	U	93	99	U
21	117	U	45	24	U	70	18	U	94	79	U
22	237	U	46	41	U	71	0	A	**A: acceptable**		
23	38	U	47	42	U	72	22	U	**U: unacceptable**		
24	19	U	48	127	U	73	18	U	**CB: Cheesbrough**		

4.3. Salmonella Species

Salmonella species are non-spore-forming, predominantly motile Enterobacteria with cell diameters between about 0.7 and 1.5 µm. Salmonella species values range from 0 - 223 as seen in Figure 14. The isolation of Salmonella species from groundwater samples means that the direct consumption of such water without treatment may be very risky. From this study, the fractured rock aquiferous formations could be contaminated through joint, fissures and fractures by run-off.

Salmonella species causes typhoid fever which can be spread through contaminated water.

4.4. Total Bacterial Density

Total bacterial density range from 0 - 86.5 as seen in Figure 15 and shown in Table 6. Most bacteria are able to tolerate slight temperature and pH changes

[25]. Significant microbial activity in groundwater is found at temperatures of 15˚C or higher [26].

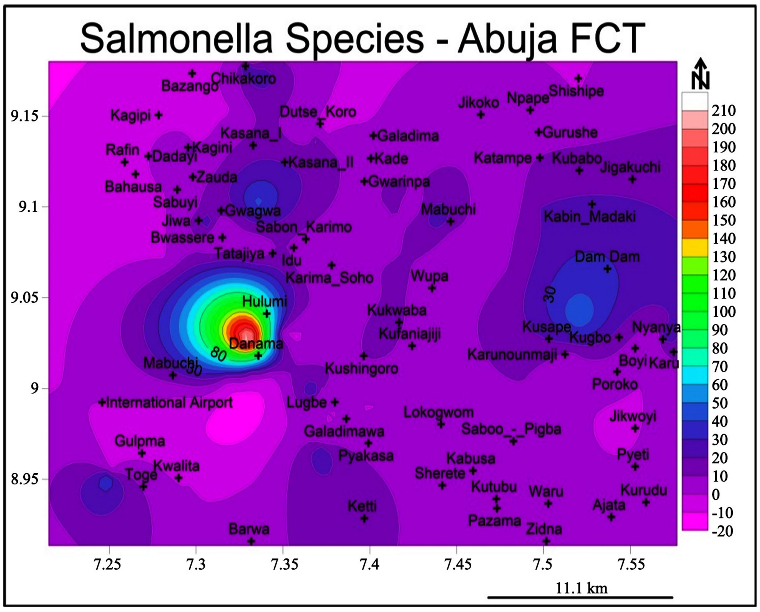

Figure 14. Spatial variation of Salmonella species in Abuja; SS is maximum Danama, and Hulumi whereas low values are at Duste Kuro, Galadima, Pyeti, Jikwoyi and Rafin.

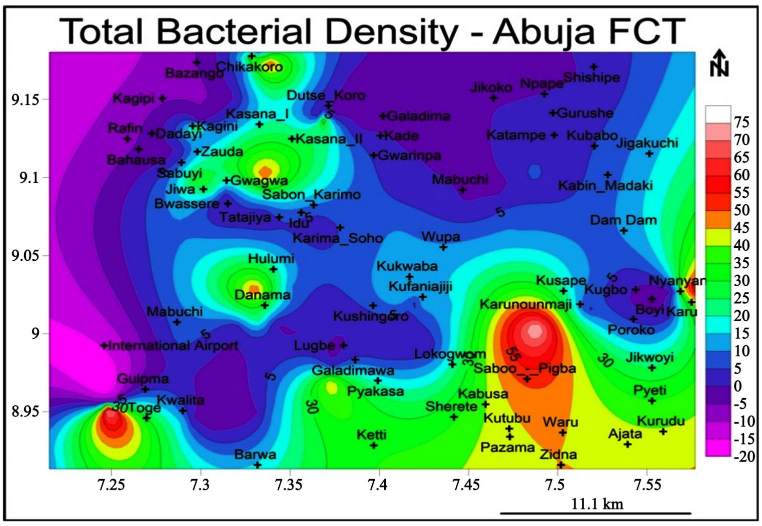

Figure 15. Spatial variation of Total bacterial density in Abuja; TBD is maximum at Pigba, Zidna and Hulumi whereas low values are at Galadimawa, Pyeti, Rafin, Bahausa, Kagipi and Bazango.

Table 6. Abuja FCT groundwater bacteriological risk classification [19].

Risk category	Range	Samples	%
Low risk	1 - 10	34	36.2
Intermediate risk	10 - 100	37	39.4
High risk	100 - 1000	23	24.4

The general belief is that groundwater percolating and infiltrating through aquiferous particulate matrix is relieved of its physical, chemical and biological impurities; is pure and fit for human consumption. And that, deeper boreholes are supposed to contain little or no microorganisms usually removed by extensive filtration as water percolates through the soil [27]. Probably this holds true for some deep multilayered aquifers where the geology does not make it chemically unsafe and is deep enough for most bacteria to live in or sealed top-bottom. For the rest of aquifers, this is nothing but a myth. In most African Granite-Gneiss fractured rock aquiferous (FRA) formations; the regolith is thick in the valleys, thin at the slopes and absent (Bare unweathered or eroded rock surfaces) at the hilltops. As such, the joint, fissure and fracture network that constitute the voids of aquifers are semi-open to open channels since in most cases the weathered regolith retains the fracture features. Coupled with the abundance of mammals (Cattle, sheep, goats, dogs and other wild animals that abound) their droppings will only help in increasing the potential for non-point pollution. The construction of toilets and latrines in these terrains is difficult and in most parts expensive for poor denizens. Faced with this challenge they squat in the bushes or excrete in poorly constructed latrines which then act as point pollution sources of biological contaminant to these aquifers: This is the reality.

This explains the results of the groundwater biological quality in Abuja FCT, those of [28] in Kaduna [29] in Jigawa and [30] in Ethiopia who have all found groundwater in Fractured rock aquifers to be unfit for human consumption by [16] [17] [18].

5. Conclusions

Groundwater from Abuja FCT Granite-Gneiss fractured rock aquiferous formation is unfit for human consumption and a danger to humans since it is usually assumed to be safe.

Groundwater from Granite-Gneiss fractured rock aquifers could be the source of endemic outbreaks of waterborne diseases such as *E. coli*, Cholera, Gastroenteritis, Typhoid and Diarrhea, as such all groundwater from these aquiferous formations in Abuja FCT should be treated before consumption.

Source protection strategies as well as monitoring are recommended although it may not serve the purpose for which it is done since the contamination is point and non-point sourced.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

References

[1] Akoachere, R.A., Yaya, O.O., Egbe, S.E., Eyong, T.A., Nji, B.N. and Tambe, D.B. (2019) GIS-Hydrogeochemical Model of the Yaoundé Fractured Rock Aquifer, Ca-

meroon: Aquifer Setting, Seasonal Variations in Groundwater-Rock Interaction and Water Quality. *Journal of Geoscience and Environment Protection*, **7**, 232-263. https://doi.org/10.4236/gep.2019.75018

[2] USEPA (United States Environmental Protection Agency) (2004). http://www.epa.gov/safe water/mcl.html

[3] Ajibade, A.C. (1976) Proterozoic Crustal Development in the Pan-African Regime of Nigeria. In: Kogbe, C.A., Ed., *Geology of Nigeria*, Rock View Ltd., Jos, 57-63.

[4] Ishaku, H.T., Sahabo, A.A. and Yerima, B.D. (2015) Assessment of Municipal Solid Waste Management Practices in Jimeta-Yola Adamawa State Nigeria. *Journal of Water Resource and Protection*, **2**, 1-7.

[5] Rabiet (2006) Contamination of Water Resources by Wastewater in the Mediterranean Watershed, Providing Majar Elements, Trace and Rare Earth Elements. Th. Doc. Monpelier II.

[6] Akoachere, R.A. and Ngwese, Y.M. (2017) Dug-Well Biological Water Quality in Kumba-Cameroon: GIS Evaluation and Seasonal Variation of a Pollution-Indicator. *Geoinformatics & Geostatistics*: *An Overview*, **5**, 3.

[7] Ashbolt, N.J. (2004) Microbial Contamination of Drinking Water and Disease Outcomes in Developing Regions. *Toxicology*, **198**, 229-238. https://doi.org/10.1016/j.tox.2004.01.030

[8] Aksu, H. and Vural, A. (2004) Evaluation of Microbiological Risks in Drinking Water. *Tesisat*, **98**, 120-131. (In Turkish)

[9] Mc-Curry, P. (1985) The Geology of the Precambrian to Lower Paleozoic Rocks of Northern Nigeria. A Review. In: Kogbe, C.A., Ed., *Geology of Nigeria*, Elizabethan Co., Lagos, 15-39.

[10] Ajibade, A.C. and Wright, J.B. (1988) Structural Relationship in Schist Belts of Northwestern Nigeria. In: Oluyide, P.O., *et al.*, Eds., *Precambrian Geology of Nigeria*, Geological Survey of Nigeria Publication, Kaduna, 103-109.

[11] ISO5667-16 (2017) Water Quality—Part 16: Guidance on Biotesting of Water Samples.

[12] ISO 9308-1 (2014) Water Quality—Part 1: Guidance on Biotesting of Water Samples.

[13] ISO 6579:2002+A1 (2007) Water Quality—Part A1: Guidance on Biotesting of Water Samples.

[14] ISO 4832 (2006) Water Quality—Part A1: Guidance on Biotesting of Water Samples.

[15] Ajibade, A.C. and Woakes, M. (1983) Proterozoic Crustal Development in the Pan-African Regime of Nigeria. In: Kogbe, C.A., Ed., *Geology of Nigeria*, Rock View Ltd., Jos, 57-63.

[16] Cheesbrough, M. (2002) District Laboratory Practice in Tropical Countries Part 2. Cambridge Low Price Edition, 38-39, 62-70, 143-157.

[17] WHO World Health Organization (2011) Guidelines for Drinking-Water Quality. 4th Edition, Volume 1, Recommendations, WHO, Geneva.

[18] (2007) Nigerian Industrial Standard for Drinking Water Quality.

[19] Howard, A.G. (2002) Water Quality Surveillance: A Practical Guide. Loughborough University, Loughborough.

[20] Belousova, A.P. and Proskuriva, I.V. (2008) Principal of Zoning a Territory by the Hazard and Risk of Groundwater Pollution. *Water Resources*, **35**, 108-119. https://doi.org/10.1134/S0097807808010132

[21] ICMSF (International Commission on Microbiological Specifications for Foods) (1998) Microorganisms in Foods. St Edmunds Bury Press, Suffolk, 461-472.

[22] Gleeson, C. and Gray, N. (1997) The Coliform Index and Waterborne Disease. Chapman Hall, London.

[23] Alhou, B. (2007) Impacts of Discharges of Niamey (Niger) on the Water Quality of the River Niger. University Faculties, Notre de la Paix, Namur.

[24] Oyedeji, O., Olutiola, P.O. and Moninuola, M.A. (2010) Microbiological Quality of Packaged Drinking Water Brands Marketed in Ibadan Metropolis and Ile-Ife City in South Western Nigeria. *African Journal of Microbiology Research*, **4**, 96-102.

[25] Nester, E.R., Roberts, C.E., Pearsall, N.N. and McCarthy, B.J. (1978) Microbiology. 2nd Edition, Holt, Rinehart and Winston, New York, 769.

[26] Smith, D.B., Hess, A.F. and Opheim, D. (1989) Control of Distribution System Coliform Regrowth 1009-1029. In: *Proceedings of the AWWA Water Quality Technology Conference*, American Water Works Association, Denver, 1009-1029.

[27] Uzoigwe, C.I. and Agwa, K.O. (2012) Microbiological Quality of Water Collected from Boreholes Sited near Refuse Dumpsites in Port Harcourt, Nigeria. *African Journal of Biotechnology*, **11**, 3135-3139. https://doi.org/10.5897/AJB10.2664

[28] Yabaya, A. and Aliyu, A. (2012) Microbial Quality Assessment of Well Water in Kaduna North Local Government Area. *Journal of Biological Science and Bio-Conservation*, **4**, 1-6.

[29] Bashari, S. (2016) An Assessment of Microbial Water Quality of Shallow Wells for Drinking Purpose in Ringim Town, Jigawa State, Nigeria. *International Journal of Chemical, Environmental & Biological Sciences*, **4**, 33-36.

[30] Genet, G.K. and Desta, H.H. (2017) Bacteriological Quality of Drinking Water from Source to Point of Use among Rural Communities of Farta Woreda in North West, Ethiopia. *African Journal of Microbiology Research*, **11**, 1069-1074. https://doi.org/10.5897/AJMR2017.8571