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Publications

Open Access
ONLINE ISSN: 2992-5819
PRINT ISSN: 2992-6149

NEWPORT INTERNATIONAL JOURNAL OF SCIENTIFIC AND EXPERIMENTAL SCIENCES (NIJSES)
Volume 3 Issue 3 2023

Evaluation of the bacteriological characteristics of selected borehole water Samples in Agbor, Delta State, Nigeria

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ABSTRACT

Drinkable water is one that is free from pathogens, low in compounds that are acutely toxic and havegreat long-term effects on human health. Bacteriological load ofsome borehole water samples in Agbor, Delta State were carried out to determine its potability fordrinking and domestic purposes. Sixty water samples from fifteen boreholes were sampled in June and July, 2022 (rainy season); and January and February, 2023 (dry season). The total bacterial count and coliformswere determined by tenfold serial dilution and membrane filtration techniques respectively. Seven bacterial species namely *Escherichia coli*, *Pseudomonas fluorescens*, *Pseudomonas aeruginosa*, *Klebsiella aerogenes*, *Proteus mirabilis* strain LYRY45, *Proteus mirabilis* strain AMJ230, and *Salmonella enterica* were isolated. The presence of coliforms above WHO acceptable limits indicated that the borehole water samples are not fit for human consumption. The water samples were more contaminated in rainy season than in the dry season with the isolation of more organisms during the rainy season. The bacterium that had the highest frequency of occurrence in rainy season was *Klebsiella aerogenes* (19.60%), while *Proteus mirabilis* strain AMJ 230 had the least frequency of occurrence (10.66%).*Salmonella enterica* had the highest frequency of occurrence (27.32%) in dry season, while *Pseudomonas fluorescens* had the least frequency of occurrence (6.48%).

Keywords: Bacteriological, borehole, water, Agbor, Delta State and Nigeria

INTRODUCTION

Water is vital to many life processes and they could also serve as route through which disease- causing pathogens can be transmitted. It can also contain heavy metals and other chemical substances that may adversely affect human health. Ensuring good quality of drinking water is a basic factor for guaranteeing public health [1]. Potable water is that whichis odourless, colourless, practically tasteless and free from physical, chemical and biological contaminants [2]. Water is exploited by man for several commercial, agricultural,domestic and industrial usages; and the usage of water for any activity usually depends on the cleanness of the water. The quality of water is determined by its physical, chemical and microbiological characteristics [3]. The paucity of water supply in Nigeria has forced residents to depend on shallow dug boreholes as the sources of water for drinking and domestic purposes [3]. Groundwater sources are commonly vulnerable to pollution, which may degrade their quality. Generally, groundwater quality varies from place to place, and this sometimes depends on seasonalchanges [4]; [5]. The quality of water also depends on thetypes of soils, rocks and surfaces through which it moves beneath the earth. Access to potable drinking water is a major public health issue in many parts of the world especially in most developing economies (Nigeria inclusive) where water hygiene and sanitation may still be poor. The people living in these countries usually get their primary source of water from boreholes, surface waters such as streams, ponds, rivers and the open skies when it rains. Population growth coupled with increased industrialization, livestock farming and urbanization have led to frequent contamination of rivers [6]. Due to the inability of some governments to meetthe ever-increasing water demand of their populace, most people often resort to groundwater sources such as boreholes as

alternative water source. Borehole water therefore, is a primary source of water in most developing nations; and the chemical, physical and biological constituents of these sources of water is a critical public health issue that needs to be ascertained on periodic basis. Borehole water serves as one of the easily accessed and cheap commercial sources of drinking water for a greater number of the Nigerian populace; and they also infer that the conformation of these sources of water to lay down microbiological standards is of public health interest because of their capacity to spread diseases within a large population. The provision of potable water to both the rural and urban population is necessary to prevent public health hazards such as the emergence and spread of waterborne pathogens [7]; [8]. Agbor in Delta State depends mostly on ground water, its abstraction account for 20% of the total water usage. Currently, demands for groundwater usage have been increasing due to population growth and diminishing opportunities to economically develop potable water supplies [9]. The management of the resource is lagging behind the pace of development, and often, very little sanitary practice is exercised in its exploitation. The current groundwater resources development and supply status is unacceptably low and needs a major transformation [10]. The digging of more boreholes in Agbor brings the need to monitor the issue of water quality that remains a major contender of its supposed existence in abundance essentially its quality is as equally important as its quantity. The quality of water is of vital concern for mankind since it is directly linked with human welfare. According to [11], the quality of public health depends to a greater extent the quality of groundwater. Physicochemical and bacteriological parameters of water indicate the safety of potable water [12] and their analysis is important for public Health and pollution studies [13]. The increase in the prevalence of waterborne diseases across the world is alarming, and Nigeria is not left out since some outbreaks of waterborne diseases have also been reported in this part of the world [14]; [15]. Since borehole water is an important alternative source of potable water to most people in both the rural and urban areas across the world, it is vital to evaluate their physicochemical and microbiological quality since these sources of water are usually at risk of pollution from human and other environmental activities. Thus, this study determined the physical, chemical and bacteriological quality of some selected borehole water sources in Agbor, Delta State owing to the fact that this source of water is commonly patronized in this region. High increase in the outbreak of waterborne diseases such as cholera, and typhoid due to the intake of contaminated water has been repeatedly reported in Agbor, Delta State. The less availability of Environmental and Health impact Assessment (EHIA) and lack of knowledge on proper waste management and sewage disposal by occupants of Agbor have led to siting of boreholes close to contamination areas like septic tanks, refuse dump sites resulting to high occurrence of water related diseases from percolation or infiltration of leachates from such areas into the groundwater.

Aim of the study

The aim of this study was to evaluate the bacteriological characteristics of some selected boreholes in Agbor, Delta State, Nigeria.

MATERIALS AND METHODS

Study area

Agbor is the headquarters of Ika South Local Government Area of Delta State in the South Southern part of Nigeria. Agbor has a population in excess of 250,000 people and a land mass of 685km^2. The geographical coordinates of Agbor are 6.254^{o}C latitude, 6.194^{o}C longitude and 427ft elevation. The topography within two miles of Agbor contains only variations in the elevation with a maximum elevation of 367ft and an average elevation above sea level of 504ft. Agbor lies within the equatorial climate with two distinct seasons, the wet (April to September) and dry (October to March), high humidity of between 24^{o}C to 27^{o}C, which supports the rainforest vegetation. The discovery and exploration of oil in commercial quantity in Ekuku Agbor and environs have earned Agbor the status of oil producing city within the Niger Delta region of Nigeria. Agbor has the blessing of abundant natural water bodies. The people of Agbor are known for commerce and agricultural activities. Agbor hosts amenities such as University of Delta, Delta College of Nursing, 181 Army Amphibious battalion, National Psychiatric Hospital, General Hospital, Area Command of Nigeria Police Force, and the adorable Dein Royal Palace. The Dein of Agbor is the traditional ruler of Agbor Kingdom with over seventy communities [16]. A drive around the borehole locations was undertaken to enable proper capture of the accurate borehole points using the handheld Global Positioning System. The coordinates of the actual positions were acquired and inputted on the Google map. On-screen vectorization of features like towns, roads and boundaries were directly observed and recorded. The features from the Google map were zoomed to a very high resolution where all the features became very clear as represented in the samples map presented in this work. The mapping was carried out in collaboration with Geo-trust Project Services Ltd, a surveying firm in Agbor.

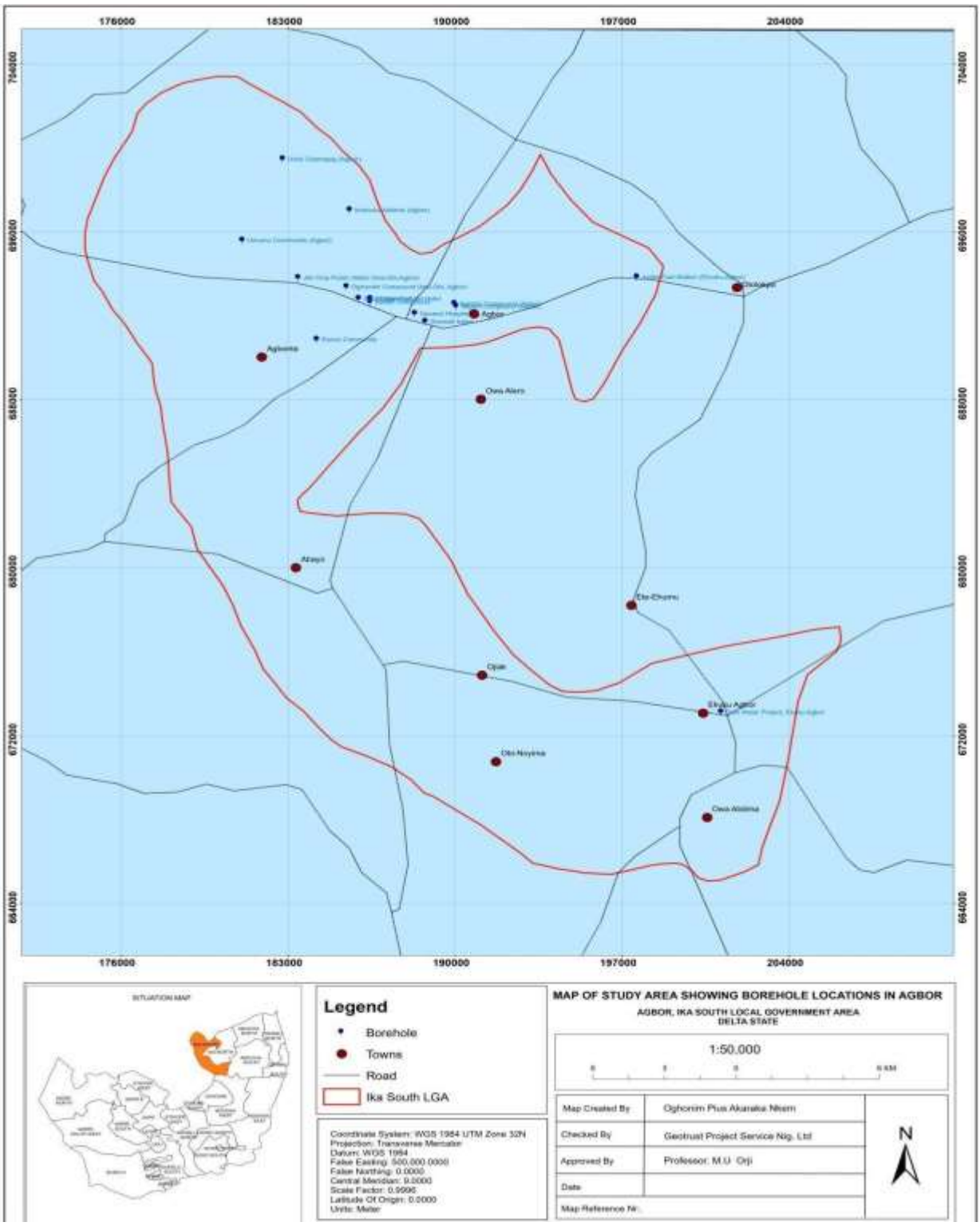

Fig. 1: Map of the study area, 2023. **Source: Geo-trust Project Services Ltd.**

Sample collection for bacteriological analysis

All the sampled points were selected randomly within Agbor, Delta State. Sixty (60) samples wereaseptically collected from 15 different boreholes between June and July, 2022 (rainy season); January and February, 2023 (dry season). The selected borehole waters were those used for drinking and for other domestic purposes. These water samples were collected in the morning period (7am – 9am). During the rainy season, fifteen samples were collected in June, analyzed and recorded, this was repeated in July and average of the values was taken, making it a total of thirty samples. This was also done in the dry season period to give a total of sixty samples for both seasons. Samples for physicochemical analysis were collected using one-litre plastic containers. The containers were first washed with sterile water and thereafter it was rinsed with water from the respective boreholes three times before collecting the water samples. Samples for the bacteriological analysis were aseptically collected in sterilized one-litre plastic container (which was sterilized by rinsing with 70% ethanol and then with sterile water and thereafter with the respective water sample three times before collection). The water was left to rush for 2 minutes (This allows the nozzle of the tap to be flushed and any stagnant water in the service pipe to be discharged). A piece of cotton-wool soaked in ethanol and lighter was used to decontaminate the faucet of the borehole before collection. The collected samples were kept at 4°C in the cooler box

Bacteriological analysis

Bacterial isolation was done as described by [17]. The media used were preparedaccording to manufacturer's instruction. The glass wares such as Petri dishes, conical flasks, test tubes, beakers and Bijou bottles were thoroughly washed and sterilized in a hot air oven at 160^0C for an hour. The inoculating loop was sterilized by flaming in the Bunsen burner until it turns red hot. Similarly, microbial load on the working surfaces were reduced by the application of disinfectant solution (70% ethanol).

Determination of total bacterial count

The borehole water samples were homogenized by shaking them for 25 times, beside a bunsen burner. The total viable count (total plate count) was determined using the pour plate technique, cultured in triplicates. One (1) ml of the samples was aseptically transferred into the Petri plates. The plates were labelled before inoculation and the culture medium was Nutrient Agar. The medium was prepared according to the manufacturer's instruction and sterilized by autoclaving at 121^0C for 15 minutes at 15psi and then allowed to cool to 45^0C before dispensing twenty millilitersinto sterile Petri-dishes and allowed to solidify, inverted to prevent condensation droppings from the lid into the agar and incubated in the incubator at 37^0C for 24 hours. A control was equally prepared without adding the sample. The bacterial colonies ranging from 30 to 300 were countedand expressed in colony forming unit per ml (CFU/ml). The bacterial isolates were counted and sub-cultured on a freshly prepared nutrient agar for characterization and identification.

Examination of total and faecal coliform by membrane filtration method

The membrane filtration was carried out as described by [17]. A sterile filtration apparatus was placed in position and connected to a vacuum pump. The apparatus was rinsed by passing small amount of sterile water and the water sample through the funnel and applying pressure through the vacuum pump. The water samples were thoroughly mixed by shaking for 25 times beside a Bunsen flame and one hundred milliliters of the water samples were measured and dispensed into the funnel and slowly filtered through the membrane filter consisting of a cellulosecompound with a uniform pore diameter of 0.2 µm by applying pressure through the vacuum pump. After filtration, the membrane filter containing the bacteria was carefully unscrewed and picked up using sterile forceps and placed upright in a Petri-plate ensuring that there were no air bubbles trapped under the membrane paper, incubated at 37^0C with a selective and differential culture medium, characteristic colonies of total coliforms/ faecal coliforms that developed were counted directly. The sterile funnel was carefully and accurately replaced on the filter base and then screwed for another filtration. Eosine methylene blue agar at 44.5^0C incubation for 24 hours was used for faecal coliforms, while Mac Conkey agar medium at 37^0C incubation for 48 hours was used for total coliforms.

Total coliform count

MacConkey agar was weighed and prepared based on the manufacturer's instruction (Appendix iii). It was sterilized in an autoclave at 15psi (121°C) for 15 minutes, allowed to cool and aseptically dispensed into Petri dishes. The membrane filter paper containing the bacteria was carefully placed with the grid-side uppermost on the MacConkey agar. Duplicate plates were prepared and labeled for each water sample. Incubation was carried out in an inverted position at 37°C for 48 hours. The presence of pink to red colonies after 24 hours were suspected of rapid lactose fermenters while light pink and colourless colonies after 48 hours were suspected of slow and non-lactose fermenters respectively. The coliform colonies that developed were counted and result recorded. Each different colony was sub-cultured and stored on a sterile nutrient agar slant for characterization and identification using Gram stain and biochemical tests.

Faecal coliform count

Eosin Methylene Blue (EMB) agar was weighed and prepared based on the manufacturer's instruction (Appendix iii). It was sterilized in an autoclave at 15psi (121°C) for 15 minutes, allowed to cool and aseptically dispensed into petri dishes. The membrane filter paper containing the bacteria was carefully placed with the grid-side uppermost on the Eosin methylene blue (EMB)agar. Duplicate plates were prepared and labeled for the water samples. Incubation was carried outin an inverted position at 44.5°C for 24 hours. The presence of green metallic sheens was suspectedof *Escherichia coli.* The faecal coliform bacteria that developed were counted and the result recorded. Each colony was sub-cultured and stored on a sterile nutrient agar slant for characterization and identification using Gram stain and biochemical tests.

Detection of *Salmonella species*

Salmonella-Shigella agar was weighed and prepared based on the manufacturer's instruction (Appendix iii). Two hundred and fifty (250) milliliters of sterile water was dispensed into the weighed medium, homogenized, heated using a Bunsen flame, cooled, aseptically dispensed into the petri dishes and allowed to gel. The membrane filter paper containing the bacteria was carefullyplaced with the grid-side uppermost on the prepared Salmonella-Shigella agar. Duplicate plates were prepared and labeled for the water samples. Incubation was carried out in an inverted positionat 37°C for 24 hours. The presence of colourless colonies with black centers were suspected to be*Salmonella* species. The colonies that developed were counted and the result recorded. Each different colony was sub-cultured and stored on a sterile nutrient agar slant for characterization and identification using Gram stain and biochemical tests.

Detection of *Pseudomonas species*

Cetrimide agar was weighed and prepared based on the manufacturer's instruction (Appendix iii).It was sterilized in an autoclave at 15psi (121°C) for 15 minutes, allowed to cool and aseptically dispensed into Petri dishes. The membrane filter paper containing the bacteria was carefully placedwith the grid-side uppermost on the cetrimide agar. Duplicate plates were prepared and labeled forthe water samples. Incubation was carried out in an inverted position at 37°C for 24 hours. The presence of green discrete colonies on the agar were suspected to be *Pseudomonas* species. The colonies that developed were counted and result recorded. Each different colony was sub-culturedand stored on a sterile nutrient agar slant for characterization and identification using Gram stain and biochemical tests.

Data Analysis

Data analysis was done using a two-way analysis of variance (ANOVA) to determine the disparitybetween the physicochemical and bacteriological parameter during both seasons.

RESULTS

The bacteriological characteristics of the borehole water samples during both seasons

The average values of the bacteriological parameters investigated in the borehole water during therainy season were shown in Tables 1 and 2. Total bacterial count ranged between 45-84cfu/ml,faecal coliform count ranged from 0-8cfu/100ml, *Pseudomonas fluorescens* count ranged from 0-7cfu/100ml, *Pseudomonas aeruginosa* count ranged from 0-7cfu/100ml, while total coliformcount ranged from 7-19cfu/100ml. The average values of the bacteriological parameter investigated in the borehole water samples during the dry season were shown in Tables 1 and 3. Total bacterial count ranged from 35- 69cfu/ml, faecal coliform count is from 0-5cfu/100ml, *Pseudomonas fluorecens* count is from 0- 3cfu/100ml, *Pseudomonas aeruginosa* count ranged between 0-4cfu/100ml, while total coliform count ranged from 5-15cfu/100ml. The occurrence of the bacterial isolates in the borehole water samples during the rainy and dry season is shown in Tables 2 and 3. The Occurrence of the bacterial isolates in the borehole water samples during both rainy and dry season were analyzed using two-way analysis of variance at Alpha level of 0.05 which showed that there was a significant difference ($p < 0.0298$) between the various drinking water samples inboth rainy and dry season.

Table 1: Mean and logarithm of total bacterial counts from borehole water samples for rainy and dry season

Borehole location	Mean (10^{-2}) (Rainy)	Log (10^{-2}) (Rainy)	Mean (10^{-2}) (Dry)	Log (10^{-2}) (Dry)
Oghonim	45	3.65	41	3.61
Aziken	61	3.78	55	3.74
Agholor	50	3.69	43	3.63
Aliagwu	56	3.74	51	3.70
Dein	60	3.77	49	3.69
Golden Cocktail	77	3.88	60	3.77
Police	62	3.79	58	3.76
Ewuru	60	3.77	47	3.67
Jim Ovia	72	3.85	66	3.81
Omumu	84	3.92	69	3.83
Uvbe Ozanogogo	65	3.81	48	3.68
Idumukwu	63	3.80	50	3.69
Central Hospital	47	3.67	44	3.64
Lucky Irabor	68	3.83	47	3.67
Jodes	74	3.86	35	3.54
W.H.O (2006)	**100**	-	**100**	-

Table 2: Occurrence of the bacterial isolates in the borehole water samples during the rainy season

Borehole location	*Escherichia coli* (cfu/100ml)	*Pseudomonas fluorescens* (cfu/100ml)	*Pseudomonas aeruginosa* (cfu/100ml)	Total coliform (cfu/100ml)
Oghonim	3	1	4	9
Aziken	7	0	6	13
Agholor	1	3	4	10
Aliagwu	2	4	2	12
Dein	0	6	0	17
Golden Cocktail	4	5	6	15
Police	0	7	3	14
Ewuru	3	4	1	13
Jim Ovia	2	1	7	17
Omumu	8	3	2	19
Uvbe Ozanogog	5	1	5	17
Idumukwu	1	0	3	11
Central Hospital	0	2	2	7
Lucky Irabor	2	1	5	16
Jodes	8	0	5	18

Table 3: Occurrence of the bacterial isolates in the borehole water samples during the dry season

Borehole location	*Escherichia coli* (cfu/100ml)	*Pseudomonas fluorescens* (cfu/100ml)	*Pseudomonas aeruginosa* (cfu/100ml)	Total coliform (cfu/100ml)
Oghonim	3	0	2	5
Aziken	4	0	3	8
Agholor	0	0	4	6
Aliagwu	1	2	1	8
Dein	0	3	0	13
Golden Cocktail	3	1	0	10
Police	0	3	3	11
Ewuru	1	0	1	9
Jim Ovia	0	0	4	13
Omumu	5	3	0	15
Uvbe Ozanogog	2	1	1	14
Idumukwu	0	0	2	11
Central Hospital	0	0	1	7
Lucky Irabor	0	1	3	9
Jodes	3	0	2	14

The average bacteriological characteristics of the borehole water samples during bothseasons compared with WHO (2006) standard

The average values of the bacteriological parameters investigated during rainy and dry seasons compared with the World Health Organization (2006) standard were shown in Table 4. Total bacteria count ranged from 43-77cfu/ml and were within 30-300 WHO (2006) standard, while 73.33% of the values of total coliform count were above the 10cfu/100ml WHO (2006) standard. 80% of the values of faecal coliform (*E. coli*) count were above the 0cfu/100ml WHO (2006) standard, 80% of the *Pseudomonas fluorescens* count were above the WHO (2006) standard of 0cfu/100ml, 93.33% of the *Pseudomonas aeruginosa* count were above the 0cfu/100ml [18] approved limit. The total number of bacteria in the borehole water for both rainy and dry season were analyzed using two way analysis of variance at Alpha level of 0.05 which showed that there was extreme significant difference ($p = 0.0421$) between the various drinking water samples in both rainy and dry season.

Table 4: Comparison of the average values of the bacteriological characteristics with the World Health Organization standard

Borehole location	Total bacterial count	Total coliform count	*Escherichiacoli* count	*Pseudomonas fluorescens* Count	*Pseudomonas aeruginosa* count
Oghonim	43	7	3	1	3
Aziken	58	11	6	0	5
Agholor	47	8	1	2	4
Aliagwu	54	10	2	3	2
Dein	55	15	0	5	0
Golden Cocktail	69	13	4	3	3
Police	60	13	0	5	3
Ewuru	54	11	2	2	1
Jim Ovia	69	15	1	1	6
Omumu	77	17	7	3	1
Uvbe Ozanogog	57	16	4	1	3
Idumukwu	57	11	1	0	3
Central Hospital	46	7	0	1	2
Lucky Irabor	58	18	1	1	4
Jodes	55	16	6	0	4
W.H.O (2006)	**100**	**10**	**0**	**0**	**0**

The distribution of bacteria present in the borehole water samples during both seasons

The distribution of the bacterial isolates in the borehole water samples during the rainy and dry season is shown in Tables 5 and 6. The organisms detected in the samples were marked as beenpositive (+) and those not detected in the samples were marked as negative (-).

Table 5: Distribution of the bacterial isolates in the borehole water samples during the rainy season

Borehole location	*Escherichia coli* (cfu/100ml)	*Pseudomonas fluorescens* (cfu/100ml)	*Pseudomonas aeruginosa* (cfu/100ml)	*Klebsiella aerogenes* (cfu/100ml)	*Proteus mirabilis* strain LYRY45 (cfu/100ml)	*Proteus mirabilis* (cfu/100ml) strain AMJ230	*Salmonella enterica* (cfu/100ml)
Oghonim	+	+	+	+	-	+	+
Aziken	+	-	+	+	+	+	-
Agholor	+	+	+	+	-	-	+
Aliagwu	+	+	+	+	+	+	+
Dein	-	+	-	+	+	+	+
Golden Cocktail	+	+	+	+	-	+	+
Police	-	+	+	+	+	+	+
Ewuru	+	+	+	+	-	-	+
Jim Ovia	+	+	+	-	+	+	+
Omumu	+	+	+	+	+	+	+
Uvbe Ozanogog	+	+	+	+	+	+	-
Idumukwu	+	-	+	+	+	+	+
Central Hospital	-	+	+	-	+	-	+
Lucky Irabor	+	+	+	+	+	+	-
Jodes	+	-	+	+	+	+	+

Key + = Organism isolated

\- = Organism not isolated

Table 6: Distribution of the bacterial isolates in the borehole water samples during the dry season

Borehole location	*Escherichia coli* (cfu/100ml)	*Pseudomonas fluorescens* (cfu/100ml)	*Pseudomonas aeruginosa* (cfu/100ml)	*Klebsiella aerogenes* (cfu/100ml)	*Proteus mirabilis* (cfu/100ml) strain LYRY45	*Proteus mirabilis* (cfu/100ml) strain AMJ230	*Salmonella enterica* (cfu/100ml)
Oghonim	+	-	+	+	-	-	+
Aziken	+	-	+	+	+	+	+
Agholor	-	-	+	-	+	-	+
Aliagwu	+	+	+	+	+	+	+
Dein	-	+	-	+	+	+	+
Golden Cocktail	+	+	-	+	-	-	+
Police	-	+	+	+	+	+	+
Ewuru	+	-	+	+	-	-	+
Jim Ovia	-	-	+	+	+	+	+
Omumu	+	+	-	+	+	-	+
Uvbe Ozanogog	+	+	+	+	+	+	+
Idumukwu	-	-	+	+	+	+	-
Central Hospital	-	-	+	-	-	-	+
Lucky Irabor	-	+	+	+	+	+	-
Jodes	+	-	+	+	+	-	+

Key + = Organism isolated

\- = Organism not isolated

The frequency and percentage occurrence of bacteria in borehole water samples duringboth seasons

Forty-six and twenty-two colonies of *Escherichia coli* were isolated during rainy and dry seasonsfrom the borehole water samples with a percentage frequency of 13.26% and 10.19% respectively. Thirty-eight and 14 colonies of *Pseudomonas fluorescens* were isolated from the borehole water sample during rainy and dry season with a percentage frequency of 10.95% and 6.48% respectively. Fifty-five and 27 colonies of *Pseudomonas aeruginosa* were isolated from the borehole water sample during rainy and dry season with a percentage frequency of 15.85% and 12.5% respectively. Sixty-eight and Fifty-one colonies of *Klebsiella aerogenes* were isolated during rainy and dry seasons from the borehole water samples with a percentage frequency of 19.60% and 23.6% respectively. Forty-three and 27 colonies of *Proteus mirabilis* strain LYRY45 were isolated during rainy and dry seasons from the borehole water samples with a percentage frequency of 12.39% and 12.5% respectively. Thirty-seven and sixteen colonies of *Proteus mirabilis* strain AMJ230 were isolated during rainy and dry seasons from the borehole water samples with a percentage frequency of 10.66% and 7.41% respectively. Sixty and 59 colonies of *Shigella enterica* were isolated during rainy and dry seasons from the borehole water samples witha percentage frequency of 17.29% and 27.32% respectively.

Table 7: Frequency and percentage occurrence of the bacterial isolates for both seasons

Isolates	Total number of isolates for rainy season	Total number of isolates for dry season	Percentage frequency for rainy season	Percentage frequency for dry season
Escherichia coli	46	22	13.26	10.19
Pseudomonas Fluorescens	38	14	10.95	6.48
Pseudomonas aeruginosa	55	27	15.85	12.5
Klebsiella aerogenes	68	51	19.60	23.6
Proteus mirabilis strain LYRY45	43	27	12.39	12.5
Proteus mirabilis strain AMJ230	37	16	10.66	7.41
Salmonella enterica	60	59	17.29	27.32
Total	**347**	**216**	**100**	**100**

DISCUSSION

Groundwater has been considered as a safe source of drinking water. However, nowadays, the quality of drinking water is deteriorating [19]. Groundwater exploitation is generally considered as the only realistic option for meeting dispersed rural and urban water demand. Due to inability of governments to meet the ever-increasing water demand, residents' resort to shallow wells etc as alternative water resources for domestic purposes. The effect of uncontrolled disposal systems and other bad sanitary practices in Agbor can render groundwater unsafe for human, agricultural and recreational use, hence, posing a threat to human life and is therefore against the principle of sustainable development. Therefore, the present study focuses on the seasonal evaluation of the bacteriological parameters of selected borehole water samples in Agbor, Delta State. The analysis of the total bacterial count in the borehole water samples revealed the presence of heterotrophic bacteria in all the water samples. The W.H.O standard for heterotrophic bacteria in potable water states that the total heterotrophic bacteria count should not be more than 100cfu/ml [18]. The bacteria load for all the water samples analyzed in this study were generally high, but did not exceed the maximum acceptable limit. Results that the values of total bacterial count during the rainy season ranged from 3.65 log cfu/ml to 3.92 log cfu/ml (Table 10), and 3.54 log cfu/ml to 3.83 log cfu/ml during the dry season. For the rainy season, Oghonim borehole had the least bacterial load, while Omumu borehole had the highest value. During the dry season, Jodes borehole recorded the least number of isolates, while Omumu borehole had the highest value (Table 10). 100 % of the inlet values were within the WHO permissible limit for domestic water (100 cfu/ml). The average total bacterial count ranged from 43 cfu/ml - 77 cfu/ml for both seasons. These results are similar with the findings of [20] who recorded zero to 8.1 x 10^2 cfu/ml and zero to 2.5 x 10^2 cfu/ml for borehole water samples (rainy and dry seasons respectively) in Ijebu-ode with about eighty percent of the samples having bacterial count within the admissible limit of 100 cfu/ml for potable water. These findings are in agreement with the work carried out by [21] which stated that there were higher bacterial counts during rainy season than in dry season. It was observed that the number of bacterial counts during the rainy season was higher than the count obtained in dry season. This may be attributed to increased contamination from surface water run-offs, shallow depths and bad sanitary practices in rainy season. This result agrees with the findings of [22] that there are high counts of bacteria pathogens in most borehole water in some parts of Nigeria.

The total number of bacteria in the borehole water for both rainy and dry season were analyzed using two-way analysis of variance at Alpha level of 0.05 which showed that there was extreme significant difference ($p = 0.0421$) between the water samples. The average faecal coliform count obtained from both seasons ranged from 0 cfu/100 ml to 7 cfu/100ml (Table 13) and 80 % of the values exceeded [18] standard of 0 cfu/100ml. This indicated that a significant number of the borehole water samples are not fit for drinking and domestic purposes. This result corroborates with the findings of [23] who recorded similar faecal coliform values of 0 cfu/100 ml to 10 cfu/100 from Lokuwa borehole water samples located in Mubi Metropolis, Adamawa state, Nigeria. This may be as a result of poor sanitary results such as proximity to septic tanks, agricultural farms, and poultry houses which were against the W.H.O Standard (2006). WHO recommends that boreholes should be located at least 30m away from latrines and 17m from septic tank.

The average *Pseudomonas fluorescens* and *Pseudomonas aeruginosa* count obtained from both seasons ranged from 0 cfu/100 ml to 5 cfu/100ml and 0 cfu/100 ml to 6 cfu/100ml respectively. Also, 80% and 93.33% of the values exceeded [18] standard of 0 cfu/100ml. This indicated that a significant number of the borehole water samples are not fit for drinking and domestic purposes. These results agreed with the findings of [24] who reported that 85% of the *pseudomonas* species exceeded the acceptable limit from groundwater samples in Nsukka. The average total coliform count obtained from both seasons ranged from 7 cfu/100 ml to 18 cfu/100ml and 73.33 % of the values exceeded WHO (2006) standard of 10 cfu/100ml. This indicated that a significant number of the borehole water samples are not fit for drinking and domestic purposes. This may be as a result of the proximity of the borehole water systems to wastewater management systems. This result is similar to previous findings by [15], and [25], who isolated coliforms from potable borehole water systems located near waste water sewage systems. Also, it may be as a result of the fact that the pipes used for water distribution were rusty thus allowing seepage of microbial contaminants into the borehole water. Also, long term usage of borehole may lead to the deterioration of the water quality, because the pipeline may become corroded with random cracks and in most cases clogged with sediment, thus allows the passage of inorganic metals and bacteria. The Occurrence of the bacterial isolates in the borehole water samples during both rainy and dry season were analyzed using two-way analysis of variance at Alpha level of 0.05 which showed that there was extreme significant difference ($p < 0.0298$) between the water samples. This borehole water samples revealed the presence of *Escherichia coli* (13.26%), *Pseudomonas fluorescens* (10.95%), *Pseudomonas aeruginosa* (15.85%), *Klebsiella aerogenes* (19.60%), *Proteus mirabilis* strain LYRY45 (12.39%), *Proteus mirabilis* strain AMJ230 (10.66%), *Salmonella enterica* (17.29%) during the rainy season. Also, the borehole water samples revealed the presence of *Escherichia coli* (10.19%), *Pseudomonas fluorescens* (6.48%), *Pseudomonas*

aeruginosa (12.5%), *Klebsiella aerogenes* (23.6%), *Proteus mirabilis* strain LYRY45 (12.5%), *Proteus mirabilis* strain AMJ230 (7.41%), *Salmonella enterica* (27.32%) (Table 16) during the dry season. *Salmonella enterica* and *Pseudomonas fluorescens* had the highest and lowest percentage frequency of isolation respectively than the other isolates during both seasons. These findings were similar to the values obtained by [26], [23] and [27]. The slight differences in results may be due to collection methods, sanitary quality of the different studied areas and geographical location. [26] revealed the presence of 31 isolates belonging to the genera: *Bacillus* (19.35%), *Staphylococcus aureus* (16.14%), *Pseudomonas* (12.90%), *Escherichia coli* (12.90%),*Proteus* (12.90%), *Enterobacter* (6.45%), *Streptococcus* (6.45%), *Salmonella* (3.23%) and *Vibrio*(3.23%) from major sources of water for domestic uses in Calabar Metropolis, Cross river State, Nigeria. [23] stated that *Escherichia coli* (37.5%), *Citrobacter sp* (2.5%), *Enterobacter aerogenes* (12.5%), *Salmonella sp* (2.5%), *Proteus vulgaris* (27.5%) and *Klebsiella pneumoniae* (17.5%) were present in borehole water samples located in Mubi Metropolis, Nigeria. [27] isolated *Aeromonas hydrophila* (14.7%), *Serratia liquefaciens* (10.9%), *Micrococcus luteus* (13.1%), *Klebsiella oxytoca* (1.4%), *Serratia marcescens* (12.2%), *Proteus vulgaris* (9.9%), *Vibrio cholerae* (0.3%), *Citrobacter freundii* (0.8%), *Pseudomonas aeruginosa* (19.7%) and *Pseudomonas fluorescens* (17.0%) from Public Hand-Pump Borehole Water in Onueke, Ezza South local Government Area, Ebonyi State, Nigeria.

CONCLUSION

The water samples from the boreholes examined in Agbor, Delta State, Nigeria were of poor quality with regards to bacteriological parameters. The detection of total bacteria, total coliforms, faecal coliforms, and other pathogenic bacteria in significant numbers indicated that the water samples are not potable for human consumption and this may be attributed to poor sanitary practices by residents.

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