Asian Journal of Biology

10(1): 1-28, 2020; Article no.AJOB.60272
ISSN: 2456-7124

Effects of Depth and Seasons on the Physicochemical and Bacteriological Quality of Selected Well Water Samples in Awka Urban, Anambra State, Nigeria

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Authors' contributions

This work was carried out in collaboration among all authors. Authors MUO, SCO and MOI designed the study, performed the statistical analysis and wrote the protocol. Authors ORU and MOI wrote the first draft of the manuscript. Authors MUO, SCO, ORU and MOI managed the analyses of the study. Authors ORU and MOI managed the literature searches. All authors read and approved the final manuscript.

Article Information

DOI: 10.9734/AJOB/2020/v10i130096
Editor(s):
(1) Dr. Jehad M. H. Ighbareyeh, Al-Quds Open University, Palestine.
Reviewers:
(1) R. P. Singh, Govt. P.G. College, India.
(2) Sushil K.Pagariya, Vidyabharati Mahavidyalaya, India.
Complete Peer review History: http://www.sdiarticle4.com/review-history/60272

Original Research Article

Received 15 June 2020
Accepted 20 August 2020
Published 02 September 2020

ABSTRACT

Background: The people of Awka urban show an increasing trend of using well water resulting to unreliable and quality-compromised water supply.
Aim: Effects of depth and seasons on the physicochemical and bacteriological quality of selected well water samples in Awka urban, Anambra State was conducted to determine their quality and suitability for domestic uses. A total of thirty shallow and deep well water samples were collected during the rainy and dry seasons.
Methods: Physicochemical analysis was carried out using standard analytical methods. The total bacterial count was determined by dilution method.
Results: Some of the physicochemical parameters ($_{P}^{H}$, dissolved oxygen, nitrate, cadmium, lead and arsenic) exceeded the World Health Organization maximum containment levels indicating that the samples were unfit for domestic uses. The bacterial counts ranged from 2.66 to 3.26 logcfu/ml

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during the rainy season and 2.54 to 3.20 logcfu/ml during the dry season. The total coliform counts also exceeded the W.H.O levels. *Citrobacter freundii*, *Shigella flexneri, Serratia marcescens, Proteus vulgaris, Vibrio cholerae, Salmonella typhi, Pseudomonas aeruginosa, Escherichia coli* and *Bacillus subtilis* were isolated during both seasons and identified using standard analytical procedures. The bacterium that had the highest frequency of occurrence during the rainy season was *Citrobacter freundii* (16.55%) while *Salmonella typhi* had the highest frequency of occurrence during the dry season (17.69%) respectively. *Proteus vulgaris* had the least frequency of occurrence 5.41% and 4.62% during the rainy and dry seasons respectively. The results were analyzed statistically using two-way analysis of variance. Higher bacterial counts were recorded in rainy season and shallow wells than dry season and deeper wells.

Conclusion: The presence of these bacteria above admissible limits showed that the water lacked proper water management services and may be harmful to humans. There is therefore a need to monitor the well water quality by employing better sanitary practices and subjecting the waters through various forms of water treatments before use to help prevent disease outbreak.

Keywords: Effects of depth and seasons; physicochemical and bacteriological.

1. INTRODUCTION

A reliable supply of clean wholesome water is highly essential in a bid to promoting healthy living among the inhabitants of a defined geographical region. Potable water is odorless, colorless, tasteless and free from faecal pollution [1]. Water provides essential elements, but when polluted it may become undesirable substance that is dangerous to human health. Potable water is one that is free from pathogens, low in compounds that are acutely toxic and have great long term effects on human health. Ground water represents the world's largest and most important source of fresh potable water. It has proven to be the most reliable resource for meeting rural water demands in the Sub-Saharan Africa [2].

Generally, well water quality varies from place to place depending on seasonal changes [3,4], the types of soils, rocks and surfaces through which it moves [5,6]. Naturally-occurring contaminants are present in the rocks and sediments. As ground water flows through the sediments, metals such as lead, cadmium, chromium, iron and manganese are dissolved and may later be found in high concentrations in the water [7]. Human activities can alter the natural composition of groundwater through the dissemination of chemicals and microbial matter on the land surface and into the soils, or through injection of wastes directly into groundwater. Agriculture, urban activities, groundwater plumage, industrial discharge and disposal of waste can affect groundwater quality. Pesticides and fertilizers applied to lawns and crops can accumulate and migrate to the water tables thus affecting both the physical, chemical and bacteriological quality of water [8]. In rural Africa, where the most common type of sanitation is the pit latrines, this poses a great risk on the bacteriological quality of groundwater. For instance, a septic tank can introduce bacteria to water and pesticides that seep into farmed soils can eventually end up in the water drawn from a well. Poor sanitary completion of wells may lead to contamination of ground water. Proximity of some wells to solid waste dumpsite and animal droppings being littered around them could also contaminate the quality of groundwater [8].

Nigeria has the highest populace in Africa with high demand for water; the high demand for water has resulted to the increased number of dug wells without considering the environmental and health implications [9]. Due to paucity of good waste management practices in the country, ample quantities of leachates move into these water bodies [9]. Inability of well owners to dig wells to fresh aquifers due to cost, lack of knowledge on good hygiene practices, most Awka urban dwellers have digressed to using shallow depth well water for drinking and domestic purposes leading to various diseases and infections [9]. In Africa, millions of people in the semi-urban communities and rural areas are dependent on groundwater. Consequently, the realization of the potential health hazards that may result from the contamination of drinking water from well water source is therefore of primary importance because of the danger and risk of water borne diseases [10]. The problems of ground water quality are much more acute in areas which are densely populated, thickly industrialized and have shallow groundwater tables. The rapid growth of urban areas has further affected ground water quality due to over

exploitation of resources and improper waste disposal practices [11]. The use of shallow well water sources for drinking and other domestic purposes is a common feature of many low income communities in developing towns like Awka.

The longer the polluted water travels through the soil formation, the better it becomes [12]. The major microorganisms of concern in contaminated water include *Salmonella* species*, Shigella* species*, Escherichia coli* and *Vibrio cholerae* [13]. The presence of faecal coliforms or *Escherichia coli* has been widely used as an indicator for the presence of any of these waterborne pathogens [14]. The World Health Organization recommends that no faecal coliform should be present in 100 ml of drinking water [15]. Wells should be located at least 30 m away from latrines and 17 m away from septic tanks [16]. These underground water supplies are usually considered safe provided they are properly located, constructed and operated according to the World Health Organization guidelines for drinking water [17].

The aim of this study was to determine the effects of depth and seasons on the physicochemical and bacteriological quality of selected well water in Awka urban, Anambra State, Nigeria.

The specific objectives were to evaluate the physicochemical quality (temperature, pH, electrical conductivity, total suspended solids, total dissolved solids, total solids, turbidity, well depth, total alkalinity, phosphate, sulphate, total chloride, dissolved oxygen, total hardness, calcium hardness, magnesium hardness, nitrate, lead, chromium, cadmium, copper, arsenic, zinc and iron) of the selected deep and shallow wells in Awka urban during the rainy and dry seasons, enumerate the total bacterial load, total and faecal coliforms present in the selected well water samples during both seasons, characterize and identify the bacterial isolates in the selected well water samples during both seasons.

2. MATERIALS AND METHODS

2.1 Study Area

The study area for this research is Awka Urban, Anambra State, Nigeria. Awka is the capital of Anambra State, Nigeria. It is made up of two local government areas, namely: Awka South and Awka North. Most of the wells under study were privately owned and sometimes open to general public. The climate is characterized by a rainy season (about 6 months), followed by a dry and dusty harmattan season lasting from November to February. The rainy season is preceded by a short hot dry spell with mean maximum daily temperature of between 35°C and 40°C. Annual total rainfall is about 149.88 mm and rain falls mostly from May to October.

2.2 Research Centre

The physicochemical analysis was done at Projects Development Institute (PRODA) Enugu while bacteriological analysis was done in Applied Microbiology and Brewing laboratory Nnamdi Azikiwe University, Awka Nigeria.

2.3 Sample Collection for Physicochemical and Bacteriological Analyses

Thirty water samples were collected from fifteen major wells (eight shallow and seven deep wells) in Awka urban, Anambra State during wet and dry season. These wells were: St Faith well water, Marian well water, Oli's close well water, Ginger well water, Eljoe well water, Mmaku well water, Nwakpodolu well water, Blooms well water, P.G Hostel, Muodozie well water, Ichoku well water, Kosta lodge well water, Camp's bay well water, Ada's close well water and Obi's close well water. These water samples were collected in the morning period (7am-8am). One liter of water samples were collected in one liter sterile bottles with stoppers. Prior to sample collection, all the sampling bottles were rinsed with the water samples to be collected. The sampling bottles were tied with a strong string to a piece of metal. The bottle caps were aseptically removed and the weighted bottle lowered into the well to a depth of about 1.5 meters. The sampling bottles were capped and labeled with dates and collection sites. The water samples were kept at 4°C in an ice box and transported to the laboratory within 3 hours for immediate sample analysis.

2.4 Physicochemical Analysis

The physicochemical parameters evaluated were temperature, pH, electrical conductivity, total suspended solids, total dissolved solids, total solids, turbidity, total alkalinity, phosphate, sulphate, total chloride, dissolved oxygen, total hardness, calcium hardness, magnesium hardness, nitrate, cadmium, lead, chromium,

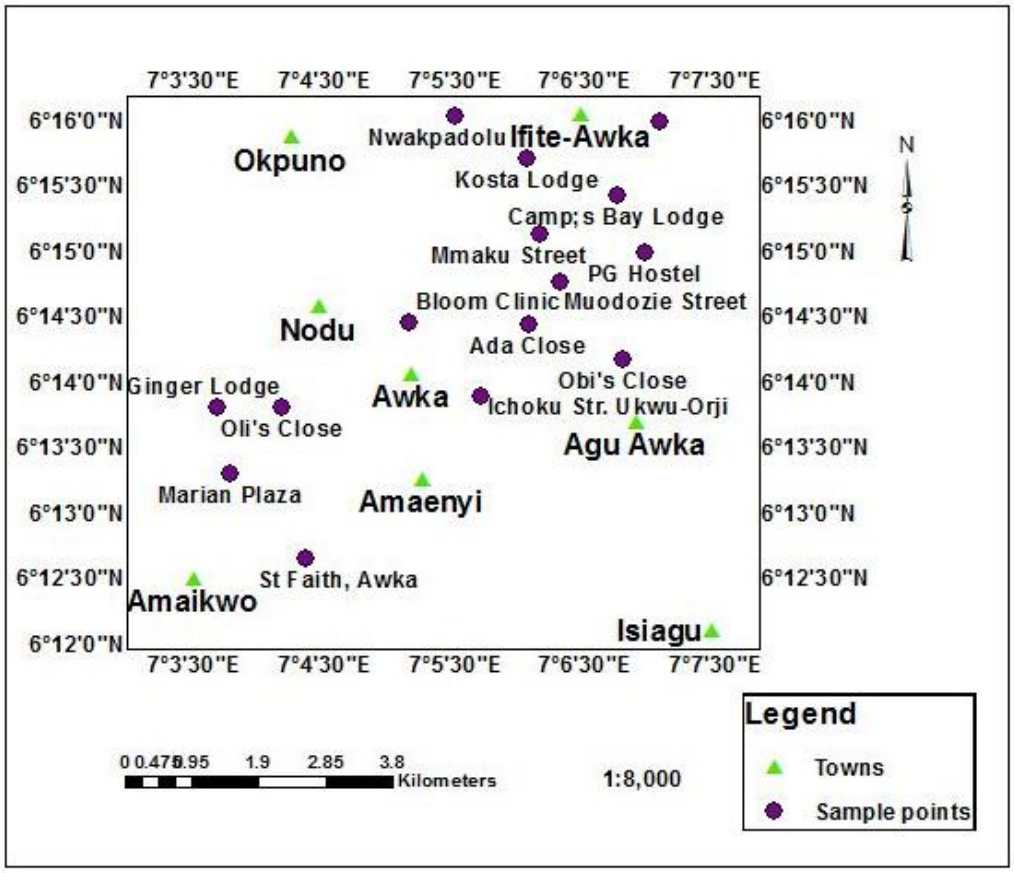

Fig. 1. Sample map of the study area

copper, arsenic, zinc and iron. The evaluation was carried out as described by [18].

2.5 Bacteriological Analysis

Bacterial isolation was done according to the method described by Cheesbrough M [19]. The media used were prepared according to the manufacturer's instruction stated on the media. 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°C 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).

2.6 Determination of Total Bacterial Count

Composite water samples collected from the wells were homogenized by shaking them for 25 times, beside a Bunsen burner. The bacterial load of the water samples from the well waters were determined by performing ten-fold serial dilution in test tubes containing peptone water up to 10^{-5}. Nine milliliters (mls) of peptone water was transferred aseptically into 5 sterile test tubes labeled 10^{-1} to 10^{-5}, one ml of the water samples were also aseptically transferred into the first tube (10^{-1}) with a sterile pipette then serial dilution. This was repeated until the 5^{th} tube. The total viable count (Total plate count) was determined using the pour plate technique, cultured in triplicates. 1 ml of the samples from 10^{-1} to 10^{-3} of the dilution test tubes were aseptically transferred into the Petri plates. The plates were labeled 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°C for 15 minutes at 15psi and then allowed to cool to 45°C before dispensing about twenty milliliters into 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°C for 24 hours. A control was

equally prepared without adding the sample. The bacterial colonies ranging from 30 to 300 were counted and expressed in colony forming unit per ml (CFU/ml).

Colony forming unit / ml = N/V×D

N = Average number of colonies
V = Aliquot volume
D = Dilution factor

The bacteria isolates were counted using a colony counter and sub-cultured on a freshly prepared nutrient agar for characterization and identification.

2.7 Examination of Total and Faecal Coliform by Membrane Filtration Method

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 cellulose compound 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 was no air bubbles trapped under the membrane paper. The sterile funnel was carefully and accurately replaced on the filter base and then screwed for another filtration. The Petri plates were incubated at an appropriate temperature with a selective and differential culture medium, characteristic colonies of total coliforms/ faecal coliforms developed and were counted using a colony counter. Eosine methylene blue agar at 44.5°C incubation for 24 hours was used for faecal coliforms, while MacConkey agar medium at 37°C incubation for 48 hours was used for total coliforms.

2.8 Detection of *Vibrio cholerae*

Thiosulphate Citrate Bile Salt Sucrose (TCBS) Agar was weighed and prepared based on the manufacturer's instruction. A given volume of sterile water was dispensed into the weighed medium, swirled, heated using a Bunsen flame, cooled, aseptically dispensed into the Petri dishes and allowed to gel. The membrane filter paper containing the bacteria was carefully placed with the grid-side uppermost on the prepared Thiosulphate Citrate Bile Salt Sucrose (TCBS) Agar. Duplicate plates were prepared and labeled for the water samples. Incubation was carried out in an inverted position at 37°C for 24 hours. The presence of yellow colonies was suspected to be *Vibrio cholerae*. The colonies that developed were counted using a colony counter and the result recorded. Each colony was sub-cultured and stored on a sterile nutrient agar slant for characterization and identification.

2.9 Detection of *Salmonella typhi and Shigella flexneri*

Salmonella-Shigella agar was weighed and prepared based on the manufacturer's instruction. A given volume of sterile water was dispensed into the weighed medium, swirled, heated using a Bunsen flame, cooled, aseptically dispensed into the Petri dishes and allowed to gel. The membrane filter paper containing the bacteria was carefully placed 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 position at 37°C for 24 hours. The presence of colorless colonies with black centers was suspected to be *Salmonella* species while colourless colonies without black centers were suspected to be *Shigella* species. The colonies that developed were counted using a colony counter 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.

2.10 Detection of *Pseudomonas aeruginosa and Pseudomonas fluorescens*

Cetrimide agar was weighed and prepared based on the manufacturer's instruction. 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 cetrimide agar. Duplicate plates were prepared

and labeled for the 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 was suspected to be *Pseudomonas* species. The colonies that developed were counted using a colony counter 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.

2.11 Characterization and Identification of the Bacterial Isolates was done According to the Method of [19]

The cultural characteristic of the respective isolates were examined and recorded.

2.12 Gram-Staining and Microscopic Examination

This was done according to the procedure described by Cheesbrough M [19].

2.13 Biochemical Tests

These biochemical tests were carried out according to Cheesbrough M [19].

Catalase test, coagulase test, citrate utilization test, oxidase test, urease test, indole test, motility test, voges-proskauer test, methyl red test, sugar fermentation, hydrogen sulphide test and Spore test.

2.14 Data Analysis

The data were subjected to analysis of variance to determine the level of significance among the physicochemical and bacteriological using SPSS 8.0 package.

3. RESULTS AND DISCUSSION

3.1 The Physical Parameters of the Well Water during the Rainy Season as Shown in Table 1

The temperature values ranged from 28°C to 29°C, pH ranged from 5.62 to 7.11, electrical conductivity ranged from 68 µs/cm to 266 µs/cm, suspended solids ranged from 0.10 mg/l to 5.62 mg/l, dissolved solids ranged from 9 mg/l to 86 mg/l, total solid values ranged from 9.22 mg/l to 91.62 mg/l while the turbidity values ranged from 0.43 NTU to 1.88 NTU and well depth ranged from 10 meters to 35 meters.

3.2 The Physical Parameters of the Well Water during the Dry Season as Shown in Table 2

The temperature values ranged from 26°C to 28°C, pH ranged from 4.00 to 6.80, electrical conductivity ranged from 48 µs/cm to 162 µs/cm, dissolved solids ranged from 4 mg/l to 55 mg/l, suspended solids ranged from 0.01 mg/l to 3.55 mg/l, total solids ranged from 4.07 mg/l to 58.55 mg/l, turbidity values ranged from 1.00 NTU to 2.55 NTU and well depth ranged from 10 meters to 35 meters.

3.3 The Results of Chemical Parameters of the Well Water during the Rainy Season as Shown in Table 3

The values for total alkalinity ranged from 3.16 mg/l to 48.21 mg/l, phosphate ranged from 0.03 mg/l to 0.37 mg/l, sulphate ranged from 0.00 mg/l to 0.07 mg/l, total chloride ranged from 11.50 mg/l to 81.05 mg/l, dissolved oxygen ranged from 5.23 mg/l to 9.21 mg/l, total hardness ranged from 12.03 mg/l to 48.17 mg/l, calcium hardness ranged from 4.35 mg/l to 33.35 mg/l, magnesium hardness ranged from 2.13 mg/l to 18.72 mg/l and nitrate values ranged from 0.50 mg/l to 10.3 mg/l.

3.4 The Results of the Chemical Parameters of the Well Water during the Dry Season as Shown in Table 4

The values for total alkalinity ranged from 2.89 mg/l to 44.53 mg/l, phosphate ranged from 0.01 mg/l to 0.29 mg/l, sulphate ranged from 0.00 mg/l to 0.1 mg/l, total chloride ranged from 09.10 mg/l to 75.19 mg/l, dissolved oxygen ranged from 4.11 mg/l to 7.06 mg/l, total hardness ranged from 5.21 mg/l to 43.83 mg/l, calcium hardness ranged from 2.99 mg/l to 31.05 mg/l, magnesium hardness ranged from 1.44 mg/l to 18.00 mg/l and nitrate values ranged from 0.31 mg/l to 6.55 mg/l.

Table 1. Physical characteristics of the well waters during the rainy season

Wells location	Well type	Temp (°C)	pH	E.C. (µs/cm)	TSS (mg/l)	TDS (mg/l)	TS (mg/l)	Turbidity (NTU)	Well depth (M)
St. faith	Deep	29	7.04	77	0.12	11	11.12	0.61	30
Marian	Deep	29	7.11	80	0.18	17	17.18	0.80	20
Oli's close	Deep	29	6.93	68	0.10	19	19.10	0.67	25
Ginger	Deep	28	6.88	76	0.15	14	14.15	0.43	28
Muodozie	Deep	29	7.00	93	0.22	9	9.22	0.58	35
Kosta	Deep	28	6.41	105	0.21	12	12.21	1.02	28
Eljoe	Deep	29	6.72	84	0.17	18	18.17	0.64	30
Ichoku	Shallow	28	6.55	117	0.29	27	27.29	0.83	20
Mmaku	Shallow	29	5.98	139	1.90	31	32.90	1.86	13
Nwakpadolu	Shallow	28	6.14	165	2.25	40	42.25	1.37	14
Obi's close	Shallow	28	5.96	181	2.77	54	56.77	1.60	12
P.G Hostel	Shallow	29	6.21	266	5.62	86	91.62	1.88	10
Ada's close	Shallow	29	6.08	203	2.94	62	64.94	1.79	13
Camp's bae	Shallow	28	5.62	229	3.08	49	52.08	1.14	14
Blooms	Shallow	28	5.79	160	3.01	55	58.01	1.15	14
W.H.O (2006)		**25-32**	**6.5-8.5**	**1000**	**-**	**500**	**500**	**5**	**>15**

Table 2. Physical characteristics of the well water during the dry season

Wells location	Well type	Temp (°C)	pH	E.C. (µs/cm)	TSS (mg/l)	TDS (mg/l)	TS (mg/l)	Turbidity (NTU)	Well depth (M)
St. faith	Deep	27	6.61	52	0.03	5	5.03	1.04	30
Marian	Deep	27	6.80	67	0.05	13	13.05	1.35	20
Oli's close	Deep	28	6.22	55	0.02	12	12.02	1.17	25
Ginger	Deep	27	6.05	59	0.01	9	9.01	1.00	28
Muodozie	Deep	28	6.33	48	0.07	4	4.07	1.13	35
Kosta	Deep	27	5.72	72	0.05	7	7.05	1.67	28
Eljoe	Deep	28	5.96	65	0.03	10	10.03	1.10	30
Ichoku	Shallow	26	5.48	86	0.08	18	18.08	1.45	20
Mmaku	Shallow	27	4.51	93	0.43	24	24.43	2.37	13
Nwakpadolu	Shallow	27	5.03	108	0.71	29	29.71	1.98	14
Obi's close	Shallow	26	4.49	115	1.04	37	38.04	2.41	12
P.G Hostel	Shallow	26	5.17	162	3.55	55	58.55	2.55	10
Ada's close	Shallow	27	5.39	131	0.82	40	40.82	2.30	13
Camp's bae	Shallow	26	4.00	150	1.10	32	33.10	1.77	14
Blooms	Shallow	27	4.66	97	1.02	33	34.02	1.80	14
W.H.O (2006)		**25-32**	**6.5-8.5**	**5**	**1000**	-	**500**	**5**	**>15**

3.5 The Heavy Metal Parameters of the Well Water during the Rainy Season as Shown in Table 5

The values for cadmium ranged from 0.00 mg/l to 0.07 mg/l, lead values ranged from 0.01 mg/l to 0.11 mg/l, chromium ranged from 0.00 mg/l to 0.05 mg/l, copper ranged 0.02 mg/l to 0.82 mg/l, arsenic ranged from 0.00 mg/l to 0.10 mg/l, zinc values ranged from 0.01 mg/l to 0.15 mg/l and iron values ranged from 0.02 mg/l - 0.20 mg/l.

3.6 The Heavy metal Parameters of the Well Water during the Dry Season as Shown in Table 6

The values for cadmium ranged from 0.00 mg/l to 0.05 mg/l, lead values ranged from 0.00 mg/l to 0.07 mg/l, chromium ranged from 0.00 mg/l to 0.02 mg/l, copper ranged from 0.00 mg/l to 0.22 mg/l, arsenic ranged from 0.00 mg/l to 0.06 mg/l, zinc values ranged from 0.00 mg/l to 0.03mg/l and iron values ranged from 0.00 mg/l to 0.12 mg/l.

The physicochemical characteristics of the well water varied and this may be attributed to depth of the wells and seasonal variations.

Temperature of an organism is defined as the level of hotness or coldness in the body of a living organism either in water or land. As water temperature increases, it holds less oxygen. These factors commonly result in less available oxygen in water. The temperature values observed in the well waters during the rainy and dry seasons ranged from 28°C to 29°C (Table 1) and 26°C to 28°C (Table 2) respectively and are within W.H.O (2006) limit (25°C-32°C). The rainy season values were similar to the report by Umeh OR et al. [9] who recorded a temperature range of 26°C-28°C from the well water samples in Awka and its Environment, Anambra State. The dry season values were similar to the report by Onuorah S et al. [20] who also recorded a temperature range of 27°C-28°C from the well water in Awka Metropolis. The observed water temperatures in the rainy and dry are considered normal for use.

pH is the negative logarithm of hydrogen ion concentration. This value is an indication of the level of acidity or alkalinity of a solution. It has been reported that the pH between 6.5 to 8.5 is appropriate for domestic use [21]. The pH values observed in during rainy season ranged from 5.62 to 7.11 (Table 1) and 53.3% of the pH values recorded were below W.H.O (2006) permissible limit of 6.5-8.5 and therefore acidic which may be attributed to solid and liquid wastes leaching into the shallow well waters. The pH values obtained during dry season ranged from 4.00 to 6.80 (Table 2) and 86.67% of the pH values were below W.H.O (2006) maximum containment level goal of 6.5-8.5 and therefore acidic which may be attributed to solid and liquid wastes leaching into the shallow well waters. The rainy season values were similar to the report by Olusiji SA et al.[22] who reported that the pH level of some hand-dug wells in Ekiti State ranged from 6.0-7.3 indicating that the water was slightly acidic to alkaline. The dry season values were slightly different from the report of Onuorah S et al. [20] who recorded pH range of 4.1-5.5from hand-dug well waters in Awka Metropolis. The pH values obtained during the dry season may be attributed to the contamination of the wells by acidic leachates from the soil.

Electrical conductivity is a measure of the ability of water to conduct electricity. It is dependent on the ionic concentration and water temperature. The total load of salts in a water body is directly related to its conductivity. Conductivity is also regarded as an indication of its freshness or otherwise of a water body. The conductivity values observed in the well waters during rainy season ranged from 68 µs/cm to 266 µs/cm (Table 1) and 100% of the conductivity values recorded in the water samples were within W.H.O (2006) permissible limit of 1000 µs/cm and therefore fit for domestic use. These values agreed with the report of Bernard E et al. [23] who observed a conductivity value of 135 µS/cm from groundwater samples in Kano, State. The excellent conductivity values gotten from my analysis can be attributed to the rainy season in which the samples were collected. Conductivity values reported in the dry season samples ranged from 48 µS/cm to 162 µS/cm (Table 2). These values fall within the W.H.O. (2006) limits of 1000 µS/cm, and disagreed with the report of Amr-Mostafa H et al. [24] who observed higher values of 449 and 1027 µs/cm from Microbiological and Physicochemical Evaluation of Groundwater in Egypt so the studied well waters would be regarded as safe for domestic uses. The excellent conductivity values gotten from my analysis can be attributed to better temperature range during dry season.

Table 3. Chemical characteristics of the well water during the rainy season

Wells location	Well type	Total alkalinity (mg/l)	Phosphate (mg/l)	Sulphate (mg/l)	Total chloride (mg/l)	Dissolved oxygen (mg/l)	Total hardness (mg/l)	Ca. hardness (mg/l)	Mg. hardness (mg/l)	Nitrate (mg/l)
St. faith	Deep	4.21	0.04	0.03	11.50	9.21	21.00	13.65	7.35	0.64
Marian	Deep	9.17	0.03	0.01	19.38	7.01	28.20	14.21	13.99	4.21
Oli's close	Deep	3.84	0.05	0.00	14.20	7.74	41.79	23.07	18.72	2.57
Ginger	Deep	4.38	0.04	0.05	31.74	8.09	23.10	11.5	11.60	1.00
Muodozie	Deep	3.16	0.03	0.02	23.10	7.33	20.09	16.08	4.01	0.89
Kosta	Deep	5.58	0.07	0.02	35.19	7.48	12.45	10.32	2.13	0.81
Eljoe	Deep	6.31	0.04	0.01	13.32	8.17	25.50	23.5	2.00	0.50
Ichoku	Shallow	7.32	0.06	0.00	29.00	5.89	19.36	15.2	4.16	4.72
Mmaku	Shallow	18.54	0.15	0.05	51.12	6.46	12.03	5.38	6.65	5.58
Nwakpadolu	Shallow	32.04	0.20	0.05	47.96	7.00	25.98	19.54	6.44	5.13
Obi's close	Shallow	26.07	0.28	0.04	81.05	6.11	48.17	33.35	14.82	6.19
P.G Hostel	Shallow	40.74	0.37	0.07	69.18	5.23	40.02	29.61	10.41	10.3
Ada's close	Shallow	48.21	0.26	0.02	31.27	6.10	19.11	13.03	6.08	5.97
Camp's bae	Shallow	11.25	0.19	0.03	55.90	6.82	19.04	4.35	14.69	6.66
Blooms	Shallow	17.92	0.17	0.02	47.23	6.09	31.27	29.14	2.13	4.34
W.H.O (2006)		**250**	**0.5**	**250**	**250**	**>5**	**250**	**75**	**50**	**10**

Table 4. Chemical characteristics of the well water during the dry season

Wells location	Well type	Total alkalinity (mg/l)	Phosphate (mg/l)	Sulphate (mg/l)	Total chloride (mg/l)	Dissolved oxygen (mg/l)	Total hardness (mg/l)	Ca. hardness (mg/l)	Mg. hardness (mg/l)	Nitrate (mg/l)
St. faith	Deep	4.04	0.01	0.00	11.18	7.06	18.15	11.35	6.80	0.31
Marian	Deep	8.94	0.03	0.00	17.04	6.10	25.99	12.56	13.43	2.55
Oli's close	Deep	3.11	0.02	0.00	09.10	7.00	39.10	21.10	18.00	1.09
Ginger	Deep	4.17	0.02	0.1	31.00	5.77	18.50	7.40	11.10	0.46
Muodozie	Deep	2.89	0.01	0.00	22.47	7.04	17.55	15.00	2.55	0.33
Kosta	Deep	5.07	0.04	0.00	29.68	4.98	5.21	3.38	1.83	0.37
Eljoe	Deep	5.55	0.01	0.00	13.55	6.45	17.72	16.28	1.44	0.48
Ichoku	Shallow	7.00	0.03	0.00	26.30	5.18	15.97	12.20	3.77	2.07
Mmaku	Shallow	18.34	0.07	0.02	52.13	5.67	11.00	4.70	6.30	4.13
Nwakpadolu	Shallow	31.50	0.13	0.01	47.90	6.15	25.97	19.88	6.09	3.77
Obi's close	Shallow	26.14	0.21	0.00	75.19	4.27	43.83	31.05	12.78	3.45
P.G Hostel	Shallow	40.08	0.29	0.02	66.00	4.11	36.94	27.11	9.83	6.55
Ada's close	Shallow	44.53	0.17	0.02	27.85	5.39	18.08	14.52	3.56	3.21
Camp's bae	Shallow	9.76	0.10	0.00	71.44	4.90	17.02	2.99	14.03	1.97
Blooms	Shallow	17.21	0.08	0.00	38.10	5.12	25.67	23.70	1.97	2.06
W.H.O (2006)		**250**	**0.5**	**250**	**250**	**>5**	**250**	**250**	**75**	**10**

Table 5. Heavy metal characteristics of the well water during the rainy season

Wells location	Well type	Lead (mg/l)	Chromium (mg/l)	Cadmium (mg/l)	Copper (mg/l)	Arsenic (mg/l)	Zinc (mg/l)	Iron (mg/l)
St. faith	Deep	0.03	0.00	0.00	0.06	0.02	0.02	0.02
Marian	Deep	0.04	0.00	0.00	0.09	0.00	0.04	0.05
Oli's close	Deep	0.01	0.00	0.00	0.11	0.05	0.02	0.04
Ginger	Deep	0.02	0.02	0.02	0.04	0.03	0.05	0.06
Muodozie	Deep	0.02	0.01	0.02	0.13	0.09	0.02	0.03
Kosta	Deep	0.01	0.01	0.01	0.31	0.05	0.02	0.04
Eljoe	Deep	0.01	0.00	0.00	0.09	0.02	0.01	0.06
Ichoku	Shallow	0.05	0.02	0.01	0.03	0.00	0.04	0.02
Mmaku	Shallow	0.02	0.04	0.00	0.37	0.06	0.03	0.04
Nwakpadolu	Shallow	0.01	0.03	0.03	0.82	0.05	0.08	0.02
Obi's close	Shallow	0.05	0.02	0.00	0.19	0.10	0.03	0.17
P.G Hostel	Shallow	0.11	0.05	0.04	0.25	0.09	0.03	0.13
Ada's close	Shallow	0.02	0.03	0.05	0.02	0.03	0.01	0.20
Camp's bae	Shallow	0.06	0.03	0.07	0.14	0.02	0.15	0.15
Blooms	Shallow	0.03	0.01	0.03	0.02	0.07	0.04	0.03
W.H.O (2006)		**0.01**	**0.05**	**0.03**	**2.0**	**0.01**	**3.0**	**0.3**

Table 6. Heavy metal characteristics of the well water during the dry season

Wells location	Well type	Lead (mg/l)	Chromium (mg/l)	Cadmium (mg/l)	Copper (mg/l)	Arsenic (mg/l)	Zinc (mg/l)	Iron (mg/l)
St. faith	Deep	0.00	0.00	0.00	0.01	0.01	0.00	0.00
Marian	Deep	0.01	0.00	0.00	0.01	0.00	0.00	0.02
Oli's close	Deep	0.00	0.00	0.00	0.03	0.03	0.00	0.00
Ginger	Deep	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Muodozie	Deep	0.00	0.00	0.01	0.07	0.05	0.00	0.00
Kosta	Deep	0.00	0.00	0.00	0.10	0.01	0.00	0.01
Eljoe	Deep	0.00	0.00	0.00	0.03	0.00	0.00	0.01
Ichoku	Shallow	0.02	0.01	0.00	0.00	0.00	0.00	0.00
Mmaku	Shallow	0.02	0.02	0.00	0.16	0.03	0.01	0.00
Nwakpadolu	Shallow	0.00	0.01	0.02	0.22	0.02	0.03	0.00
Obi's close	Shallow	0.04	0.00	0.00	0.04	0.06	0.00	0.10
P.G Hostel	Shallow	0.07	0.00	0.00	0.08	0.00	0.00	0.05
Ada's close	Shallow	0.01	0.02	0.03	0.00	0.01	0.00	0.12
Camp's bae	Shallow	0.03	0.01	0.05	0.06	0.01	0.01	0.08
Blooms	Shallow	0.01	0.00	0.01	0.00	0.02	0.00	0.00
W.H.O (2006)		**0.01**	**0.05**	**0.03**	**2.0**	**0.01**	**3.0**	**0.3**

The total suspended solids (TSS) are made up of carbonates, bicarbonates, chlorides, phosphates and nitrates of metals such as calcium, magnesium sodium, potassium, magnesium as well as other particles. TSS affects the turbidity of water bodies [25]. The total suspended solids observed during rainy season ranged from 0.10 mg/l to 5.62 mg/l (Table 1) and 100% of the TSS values recorded in the well water samples were within W.H.O (2006) permissible limit of 30 mg/l and therefore fit for domestic purposes. The values were below 31.3 mg/l to 55.0 mg/l reported by Onwughara NI et al. [26] from groundwater samples in Abia State, which he attributed to high presence of suspended matters. The values obtained during dry season ranged from 0.01 mg/l to 3.55 mg/l (Table 2). The values obtained were within the W.H.O permissible limit of 30 mg/l which is good for optimum use. The TSS values were below 1250 mg/l to 1580 mg/l recorded by Oladipo IC et al. [27] from well water used for Drinking and Domestic Purposes in Ogbomosho, Nigeria. This may be due to better sanitary practices.

Total Dissolved Solids (TDS) is an indication of the amount of dissolved substances. The total dissolved solids observed in the well waters during rainy season ranged from 9 mg/l to 86 mg/l (Table 1) and 100% of the conductivity values recorded in the water samples were within W.H.O (2006) permissible limit of 500 mg/l and therefore fit for domestic uses. The rainy season values agreed with the work of [28], who stated that TDS values obtained were below the 500 mg/l maximum permissible limit (W.H.O 2006). The TDS values obtained during dry season ranged from 4 mg/l to 55 mg/l (Table 2). These values were within W.H.O (2006) maximum containment level goal of 500 mg/l. The dry season values were below findings (174.67 mg/l) recorded by Sadiya A et al. [29] from well water samples in Abuja. Water with total dissolved solids above the recommended limit contains high level of ions which can lead to staining of fabrics.

Total solids (TS) are a combination of dissolved solids and total suspended solids. The solids observed during the rainy season ranged from 9.22 mg/l to 91.62 mg/l (Table 1) and 100% of the TS values recorded in the well water samples were within W.H.O (2006) permissible limit of 500 mg/l and therefore potable for domestic use. The values were similar to 9.58 mg/l to 93.89 mg/l reported by Umeh OR et al. [9] from the well water samples in Awka and its Environment, Anambra State, which he attributed to high presence of suspended matters because most of the wells were not covered and have shallow aprons which can bring about surface water infiltration. The values obtained during dry season ranged from 4.07 mg/l to 58.55 mg/l (Table 2). The values obtained are within the W.H.O permissible limit of 500 mg/l which is good for optimum use. The TS values were below 1363.33 mg/l to 1760 mg/l recorded by Oladipo IC et al. [27] from well water used for Drinking and Domestic Purposes in Ogbomosho, Nigeria. This may be due to better sanitary practices.

Turbidity is an indication of the clarity of water or a measure of the ability of water to transmit the light that restricts light penetration and limit photosynthesis [25]. Turbidity consists of suspended particles in water and is usually affected by factors such as clay particles, dispersion of plankton organism, particulate organic matters as well as pigments caused by decomposition of organic matter. The turbidity values observed during rainy season ranged from 0.43 NTU to 1.88 NTU (Table 1) and 100% of the turbidity values recorded in the well water samples were within W.H.O (2006) permissible limit of 10 mg/l and therefore good for use. The rainy season values were similar to the work of [28] who tabled turbidity values of 0.05 NTU to 2.65 NTU. Turbidity values reported during dry season ranged from 1.00 NTU to 2.55 NTU (Table 2) and were within the W.H.O. (2006) permissible limit of 10 NTU. The turbidity results in the dry season were above [27] findings, who reported lower turbidity values of 0.67 NTU to 1 NTU and this may be attributed to bad sanitary practices. Turbidity affects the appearance of water. Water with high turbidity is normally associated with high microbiological contamination.

The well depth (source of water) ranged from 10 meters to 35 meters. Wells below 15 meters are classified as shallow wells according to W.H.O Standard (2006).

The result of the physical parameters varied significantly ($p < 0.05$) at 0.05 alpha level of significance between the two depths (shallow and deep) and seasons (rainy and dry) using two-way analysis of variance (ANOVA).

Water alkalinity is a measure of its capacity to neutralize acids. It can be referred to as the buffering capacity of water. Waters with high alkalinity are undesirables. The alkalinity values observed during rainy season ranged from 3.16 mg/l to 48.21 mg/l mg/l (Table 3) and 100% of the total alkalinity values recorded in the well water samples were within W.H.O (2006) permissible limit of 250 mg/l and therefore fit for domestic use. This is better than the report of Sadiya A et al. [29] who recorded a total alkalinity value of 116.32 mg/l from well water samples in Abuja and attributed it to high bicarbonate level. The obtained alkalinity values during dry season ranged from 2.89 mg/l to 44.53 mg/l (Table 4). This is in line with the report of Onuorah S et al. [20] who recorded a total alkalinity value of 4 mg/l to 32 mg/l from hand dug well water samples in Awka Metropolis.

Phosphate is the chemical term for the various combinations of phosphorous and the element oxygen. Phosphate is the main nutrient for algae. The phosphate values observed during rainy season ranged from 0.03 mg/l to 0.37 mg/l (Table 3) and 100% of the phosphate values recorded in the well water samples were within W.H.O. (2006) permissible limit of 0.5 mg/l and therefore not fit for domestic purposes. This is

similar to values (0.09 to 0.347 mg/l) recorded by Mensah MK [30]. The values observed from dry season ranged from 0.01 mg/l to 0.29 mg/l (Table 4) and 100% of the phosphate values were within W.H.O. permissible limit of 0.5 mg/l and therefore good for use. This is similar to values (0.01 to 1.86 mg/l) recorded by Sabrina S et al. [31] from well water samples in Cameroon. Higher values could lead to eutrophication.

The sulphate values observed during rainy season ranged from 0.00 mg/l to 0.07 mg/l (Table 3) and 100% of the sulphate values recorded in the well water samples were within W.H.O (2006) admissible limit of 250 mg/l and therefore fit for domestic use. This is smaller than values (210.0 mg/l to 345.0 mg/l) recorded by Chukwuka CO [28] which he attributed to agricultural activities and geological formation of the area. The dry season well water samples investigated had sulphate values ranging from 0.00 mg/l to 0.1 mg/l (Table 4) which is within W.H.O permissible limit of 250 mg/l and below values (2.4 mg/l to 3.2 mg/l) reported by Anyanwu CU et al. [32]. Sulphate is known as one of the least toxic anions [33].The main natural sources of sulphate in water is the process of chemical weathering and dissolution of sulfur containing minerals, predominantly gypsum ($CaS0_42H_20$), oxidation of sulfides and elemental sulfur, and the decomposition of animal and plant residues. Direct anthropogenic sources of sulphates include industrial and municipal wastes, agricultural drainage and runoff.

Chloride ion is a common constituent of all natural water and it's generally regarded as a non-harmful constituent [33]. Though chloride is present in all natural water bodies, high concentration is an indication of pollution from sewage, industrial or intrusion of seawater or saline water into fresh water aquifer [33]. The chloride values observed during rainy season ranged from 11.50 mg/l to 81.05 mg/l (Table 3) and 100 % of the total chloride values recorded in the water samples were within W.H.O (2006) permissible limit of 250 mg/l and therefore good for use. Anyanwu CU et al. [32] reported chloride values of 2.0 mg/l to 2.3 mg/l from well water samples in Nsukka. Chloride content obtained during dry season ranged from 9.10 mg/l to 75.19 mg/l (Table 4). These values are within W.H.O (2006) permissible limits of 250 mg/l and similar to values (11.62 mg/l to 320.69 mg/l) obtained by Onuorah S et al. [20]. Higher concentrations may be harmful to life.

Dissolved Oxygen (DO) is defined as the measure of gaseous oxygen dissolved in water [34]. The solubility of oxygen in water decreases as the water temperature increases. The dissolved oxygen observed during rainy season ranged from 5.23 mg/l to 9.21 mg/l (Table 3) and 100% of the dissolved oxygen values recorded in the well water samples were within W.H.O (2006) permissible limit of >5mg/l and therefore fit for domestic purposes. This is above the values reported by Akubuenyi FC et al. [35], he recorded DO values of 4.61 mg/l to 3.16 mg/l. The high DO in this study may be as a result of high aeration in the sampled areas. The DO values obtained from the dry season study ranged between 4.11 mg/l to 7.06 mg/l (Table 4) 26.67% of the dry season values were below recommended value by W.H.O (2006) and therefore not suitable for use. This is within the values (5.86 mg/l) reported by Sadiya A et al. [29].

Total hardness of water is used to describe the effect of dissolved minerals (mainly Ca and Mg) suitable for domestic and industrial purposes which is attributed to the presence of bicarbonates, sulphates, chlorides and nitrates. Calcium and Magnesium are essential for bone and scale formation [36]. The total hardness observed during rainy season ranged from 12.03 mg/l to 48.17 mg/l (Table 3) and 100% of the total hardness values recorded in the well water samples were within W.H.O (2006) permissible limit of 250 mg/l and therefore fit for domestic use. This is in line with the report of Oladipo IC et al. [27] who recorded a total hardness value of 58.47 mg/l to 72.30 mg/l from well water used for drinking and domestic purposes in Ogbomosho, Nigeria and this can be attributed to moderate calcium and magnesium ions. Total hardness observed during dry season ranged from 5.21 mg/l to 43.83 mg/l (Table 4). These values are within the W.H.O (2006) permissible limit of 250 mg/land higher values (64.6 mg/l to 68 mg/l) were reported by Anyanwu CU et al. [32] which he attributed to high calcium and magnesium content.

The calcium hardness observed during rainy season ranged from 4.35 mg/l to 33.35 mg/l (Table 3) and are within W.H.O (2006) permissible limit of 75 mg/l. The rainy season values were below 35.22 mg/l to 65.54mg/l reported by Umeh OR et al. [9] from the well water samples in Awka and its environment, Anambra State. The calcium hardness values during dry season ranged from 2.99 mg/l to

31.05 mg/l (Table 4). The dry season values were in agreement with the W.H.O (2006) permissible limit of 75 mg/l and therefore suitable for domestic use. The dry season values were similar to the values (1.40 mg/l to 29.46 mg/l) reported by Onuorah S et al. [20].

The magnesium hardness observed during rainy season ranged from 2.13 mg/l to 18.72 mg/l (Table 3) and are within W.H.O (2006) permissible limit of 50 mg/l. The rainy season values are below 48 mg/l to 59 mg/l reported by Shittu OB et al. [37] from shallow wells in Awka. Magnesium in water can come from the leaching of minerals such as clay. Magnesium hardness values obtained during dry season ranged from 1.44 mg/l to 18.00 mg/l (Table 4). The dry season values are in agreement with the W.H.O permissible limit of 50 mg/l and therefore suitable for domestic use. The values are similar to the values (6.69 mg/l to 5.20 mg/l) obtained by Akubuenyi FC et al. [35].

Nitrate represents the final product of the biochemical oxidation of ammonia [25]. It is important that the level of nitrate in well water is controlled to avoid eutrophication. Nitrates cause methaemoglobinemia in humans when it exceeds the maximum containment level goal. The nitrate values observed during rainy season ranged from 0.50 mg/l to 10.3 mg/l (Table 3) and 6.66% of the nitrate values recorded were above W.H.O (2006) permissible limit of 10 mg/l and therefore not fit for domestic use. This is similar to values (4.03 mg/l to 19.33 mg/l) recorded by Chukwuka CO et al. [28]. Nitrate concentrations during dry season ranged from 0.31 mg/l to 6.55 mg/l (Table 4) and 100% of the nitrate values were within W.H.O. permissible limit of 10 mg/l and therefore good for domestic purposes. This is above the values (0.00 mg/l to 1.86 mg/l) recorded by Sabrina S et al. [31]. This may be as a result of proximity of wells to farmlands (fertilizers), septic tanks etc.

The result of the chemical parameters varied significantly ($p < 0.05$) at 0.05 alpha level of significance between the two depths (shallow and deep) and seasons (rainy and dry) using two-way analysis of variance (ANOVA) except sulphate, total hardness, calcium and magnesium hardness.

Heavy metals are chemical elements with a specific gravity that is at least four to five times the specific gravity of water at the same temperature and pressure [38]. Heavy metals refer to metallic chemical element that has a relatively high density and is toxic or poisonous at low concentrations [39]. The heavy metals: lead, chromium, mercury, copper, arsenic, iron, cadmium and zinc concentrations in the well waters in all the sampling sites were compared with W.H.O (2006) standard. The obtained results showed that, with the exception of lead, cadmium and arsenic the heavy metal concentrations in the well waters did not exceed W.H.O. (2006) standard.

The lead content observed during rainy season ranged from 0.01 mg/l to 0.11 mg/l (Table 5) and 73.33% are above W.H.O (2006) permissible limit of 0.01 mg/l and therefore not fit for domestic use. The rainy season values were within 0.01 mg/l to 0.27 mg/l reported by Umeh OR et al. [9] from the well water samples in Awka and its Environment, Anambra State. The values for lead in dry season ranged from 0.00 mg/l to 0.07 mg/l (Table 6). 33.3% were above the W.H.O. recommended standard of 0.01 mg/l and therefore not fit for domestic use. This result corroborates the [20], who reported a lead concentration of 0.00 mg/l to 0.09 mg/l in shallow well water samples in Awka, which may be as a result of fissured water pipes, sewage effluents, automobile exhaust fumes, run off wastes and atmospheric depositions. Lead rarely occurs naturally in water, it usually gets into drinking water through the delivery systems. Materials that contain lead have frequently been used in the construction of water supply distribution and plumbing systems in private homes and other buildings. Lead in these materials can contaminate drinking water as a result of corrosion that takes place when water comes into contact with these materials for a long time. In human beings, it binds with SH group of proteins, apart from that, lead damages blood circulation, central nervous system, liver and kidneys [40]. In addition, lead can delay embryonic development, suppress reproduction, and inhibit growth, increase mucus formation, neurological problem, enzyme inhalation and kidney dysfunction [40].

The chromium content observed during rainy season ranged from 0.00 mg/l to 0.05 mg/l (Table 5) and 100% of the chromium values were within W.H.O. (2006) permissible limit of 0.05 mg/l, therefore fit for domestic use. The values for chromium during dry season ranged from 0.00 mg/l to 0.02 mg/l (Table 6). These values were within the W.H.O. recommended standard of 0.05 mg/l and therefore good for domestic

purposes. Chromate compounds are used at homes and school laboratories. Chromium therefore may have entered the groundwater through leaching. Again some chemical operation like fossil fuel combustion and waste incineration, might have contributed by releasing chromium to the atmosphere [41]. The analysis shows that the well water samples for both seasons contain very low concentrations of chromium, which are within the acceptable limit of W.H.O. (2006).

The cadmium content observed during rainy season ranged from 0.00 mg/l to 0.07 mg/l (Table 5) and 20% of the cadmium values were above W.H.O. (2006) admissible limit of 0.03 mg/l and were therefore not fit for domestic use. The rainy season values were above 0.00 mg/l to 0.04 mg/l reported by Umeh OR et al. [9] from the well water samples in Awka and its environment, Anambra State which he attributed to any of the factors below. The values for cadmium during dry season ranged from 0.00 mg/l to 0.05 mg/l (Table 6). 6.67% of the well waters exceeded the W.H.O. recommended standard of 0.03 mg/l and therefore not fit for domestic use. The dry season values were similar to 0.01 mg/l to 0.33 mg/l reported by Onuorah S et al. [20] from shallow well waters in Awka. Cadmium is a metal with no known beneficial properties that supports life. Chukwuka CO et al. [28] stated that the source of contamination may be attributed to the interaction of the groundwater and the rock layers or soil minerals. Contamination of groundwater with cadmium can also be possible through the application of fertilizer that is common in the study area. According to Asolker SR et al. [42], cadmium may also enter drinking water through weathering of soil and bedrock, corrosion of galvanized pipes, atmospheric decomposition of direct discharge from industrial operation, burning of coal and house hold wastes, volcanic eruptions, leakages from landfills and from the use of fertilizers. Therefore the presence of cadmium in the water could be attributed to any of the above factors. At low concentrations, it is toxic to plants, birds and humans etc. Cadmium causes cancer, birth defects and genetic mutations to humans Asolker SR et al. [42].

The copper content observed during rainy season ranged from 0.02 mg/l to 0.82 mg/l (Table 5) and 100% of the values were within W.H.O. (2006) permissible limit of 2.0 mg/l, therefore fit for domestic use. The rainy season values were similar to 0.00 mg/l to 0.11 mg/l reported by Onwuneme P et al. [43] from water samples in University of Nigeria, Nsukka. The values for copper in the dry season ranged from 0.00 mg/l to 0.22 mg/l (Table 6). These values were within the W.H.O. recommended standard of 2.0 mg/l and therefore fit for domestic use. Copper is often used to plumb residential and commercial structures that are connected to water distribution systems. Copper contaminates drinking water as a result of the corrosion of copper pipes that remain in contact with water for a prolonged period. Copper toxicity in natural water arising from pollutants may cause severe damage to humans. Long term exposure to copper, higher than normal levels can cause nausea, vomiting, stomach cramps, or diarrhea when ingested by humans [44].

The arsenic content observed during rainy season ranged from 0.00 mg/l to 0.10 mg/l (Table 5) and 86.6% of the arsenic values were above W.H.O. (2006) admissible limit of 0.01 mg/l and therefore not fit use. The rainy season values were below 3.10 mg/l to 39.82 mg/l reported by Onuorah S et al. [20] from shallow well waters in Awka Metropolis which he attributed to agricultural practices. The values for arsenic in dry season ranged from 0.00 mg/l to 0.06 mg/l (Table 6). 40% of the dry season values exceeded the W.H.O. recommended standard of 0.01 mg/l and therefore not fit for use. The dry season values were below 0.01 mg/l to 0.10 mg/l reported by Onuorah S et al. [20] from shallow well waters in Awka Metropolis.

The zinc content observed during rainy season ranged from 0.01 mg/l to 0.15 mg/l (Table 5) and 100% of the values were within W.H.O (2006) permissible limit of 3.0 mg/l, therefore fit for use. The rainy season values were similar to 0.001 mg/l to 0.04 mg/l reported by Onwuneme P [43] from water samples in University of Nigeria, Nsukka. The dry season values ranged from 0.00 mg/l to 0.03 mg/l are within the set values by W.H.O. (2006) of 3.0 mg/l (Table 6). The main source of zinc into wells is dissolved zinc from zinc related appliances such as galvanized pipes. Low levels can be attributed to less zinc load from industrial, agricultural, domestic and urban waste waters [45]. Zinc accumulation results in several dysfunctions in humans. It exerts adverse effects by accruing structural damage which affects the growth, development and survival [40].

The iron content observed during rainy season ranged from 0.02 mg/l to 0.20 mg/l (Table 5) and 100% of the iron values were within W.H.O. (2006) permissible limit of 0.3 mg/l, therefore fit for use. The rainy season values were below 0.01 mg/l to 1.35 mg/l reported by Umeh OR et al. [9] from well water samples in Awka and its environment, Anambra State, Nigeria which he attributed to corrosion of iron well covers. The values for iron in dry season ranged from 0.00 mg/l to 0.12 mg/l (Table 6) and 100% of the results were within the W.H.O. (2006) recommended standard of 0.3 mg/l and therefore fit for use. The dry season values were below 0.05 mg/l to 15 mg/l reported by Sabrina S et al. [31] from well water samples in Cameroon.

The result of the heavy metal parameters varied significantly ($p < 0.05$) at 0.05 alpha level of significance between the two depths (shallow and deep) and seasons (rainy and dry) using two-way analysis of variance (ANOVA) except copper, arsenic zinc and iron.

3.7 The Bacteriological Parameters Present in the Well Water during the Rainy Season as Shown in Tables 7 and 8

The mean total bacterial count for 10^{-1} dilution tube during rainy season ranged from 46 cfu/ml to 186 cfu/ml. The logarithmic values for 10^{-1} dilution tube ranged from 2.66 cfu/ml to 3.26 cfu/ml. Some of the mean values for 10^{-1} dilutions were within the 100 cfu/ml World Health Standard. The faecal coliform count ranged from 0 cfu/100 ml to 13 cfu/100 ml. The total coliform count ranged from 11 cfu/100 ml to 70 cfu/100 ml. *Bacillus subtilis* count ranged from 0 cfu/ml to 11 cfu/ml. *Pseudomonas aeruginosa* count ranged from 0 cfu/100 ml to 9 cfu/100 ml. *Vibrio cholerae* count ranged from 0 cfu/100ml to 13 cfu/100 ml.

3.8 The Results of the Bacteriological Parameters Present in the Well Waters during Dry Season as Shown in Tables 7 and 9

The mean total bacterial count for 10^{-1} dilution tube during dry season ranged from 35 cfu/ml to 160 cfu/ml. The logarithmic values for 10^{-1} dilution tube ranged from 2.54 cfu/ml to 3.20 cfu/ml. Some of the mean values for 10^{-1} dilutions were within the 100 cfu/ml World Health Standard. The faecal coliform count ranged from 0 cfu/100 ml to 8 cfu/100 ml. The total coliform count ranged from 9 cfu/100 ml to 52 cfu/100 ml. *Bacillus subtilis* count ranged from 0 cfu/ml to 8 cfu/ml. *Pseudomonas aeruginosa* count ranged from 0 cfu/100 ml to 5 cfu/100 ml. *Vibrio cholerae* count ranged from 0 cfu/100 ml to 6 cfu/100 ml.

Table 7. Mean and logarithm value of total bacterial counts isolated from the well water during the rainy and dry season

Wells location	Well type	Mean cfu/ml (10^{-1}) (Rainy)	Log cfu/ml (10^{-1}) (Rainy)	Mean cfu/ml (10^{-1}) (Dry)	Log cfu/ml (10^{-1}) (Dry)
St.Faith	Deep	69	2.83	51	2.70
Marian	Deep	54	2.73	47	2.67
Oli's close	Deep	57	2.75	43	2.63
Ginger	Deep	46	2.66	35	2.54
Muodozie	Deep	71	2.85	59	2.77
Kosta	Deep	50	2.69	37	2.56
Eljoe	Deep	62	2.79	48	2.68
Ichoku	Shallow	95	2.97	83	2.91
Mmaku	Shallow	186	3.26	160	3.20
Nwakpadolu	Shallow	104	3.01	85	2.92
Obi's close	Shallow	121	3.08	91	2.95
P.G Hostel	Shallow	155	3.19	109	3.03
Ada's close	Shallow	112	3.04	93	2.96
Camp's bae	Shallow	143	3.15	114	3.05
Bloom's	Shallow	166	3.22	131	3.11
W.H.O (2006)		**100**	**-**	**100**	**-**

Table 8. Bacteriological characteristics of the well water during the rainy season

Wells location	Well type	Faecal coliform count (cfu/100 ml)	Total coliform count (cfu/100 ml)	*Bacillus subtilis* count (cfu/ml)	*P. aeruginosa* count (cfu/100 ml)	*Vibrio cholerae* count (cfu/100 ml)
St. faith	Deep	3	37	4	0	3
Marian	Deep	2	21	0	2	0
Oli's close	Deep	0	26	2	1	2
Ginger	Deep	8	22	0	3	0
Muodozie	Deep	0	35	0	8	9
Kosta	Deep	3	11	0	1	0
Eljoe	Deep	7	23	0	2	3
Ichoku	Shallow	11	39	7	0	4
Mmaku	Shallow	5	70	7	6	4
Nwakpadolu	Shallow	4	38	11	0	7
Obi's close	Shallow	7	41	6	0	6
P.G Hostel	Shallow	4	51	8	9	2
Ada's close	Shallow	1	46	3	0	1
Camp's bae	Shallow	13	53	5	2	10
Blooms	Shallow	5	63	5	0	13
W.H.O (2006)		**0**	**10**	**0**	**0**	**0**

Key: P. aeruginosa: Pseudomonas aeruginosa.

Table 9. Bacteriological characteristics of the well water during the dry season

Wells location	Well type	Faecal coliform count (cfu/100 ml)	Total coilform count (cfu/100 ml)	*Bacillus subtilis* count (cfu/ml)	*P. aeruginosa* count (cfu/100 ml)	*Vibrio cholerae* count (cfu/100 ml)
St. faith	Deep	1	29	0	0	3
Marian	Deep	2	13	0	0	0
Oli's close	Deep	2	15	2	0	3
Ginger	Deep	1	10	0	1	0
Muodozie	Deep	0	19	0	2	5
Kosta	Deep	2	14	3	1	0
Eljoe	Deep	4	9	0	0	1
Ichoku	Shallow	8	30	5	3	1
Mmaku	Shallow	3	52	7	5	0
Nwakpadolu	Shallow	6	25	8	0	3
Obi's close	Shallow	5	28	3	0	5
P.G Hostel	Shallow	3	37	5	5	1
Ada's close	Shallow	0	35	4	0	0
Camp's bae	Shallow	8	40	3	2	6
Blooms	Shallow	2	30	0	0	4
W.H.O (2006)		**0**	**10**	**0**	**0**	**0**

Key: P. aeruginosa: Pseudomonas aeruginosa

3.9 The Distribution of the Bacteria Present in the Well Water during the Rainy and Dry Season as Shown in Tables 10 and 11 Respectively

The bacteria isolated from the well water samples were denoted using a positive (+) sign while those bacteria not found in some well water samples were shown using a negative (-) sign.

3.10 Frequency of Occurrence and Percentage Frequency of Bacteria Present in the Well Water during the Rainy and Dry as Shown in Table 12

Ninety-Eighty colonies of *Citrobacter freundii* were isolated from all the well waters during the rainy season with a percentage frequency of 16.55% while 62 colonies of the same bacterium

were isolated from the well waters during the dry season with a percentage frequency of 15.89%. Ninety-two colonies of *Shigella flexneri* were isolated from all the well waters during the rainy season with a percentage frequency of 15.54% while 68 colonies of the same bacterium were isolated from the well waters during the dry season with a percentage frequency of 17.44%. Forty-four colonies of *Serratia marcescens* were isolated from all the well waters during the rainy season with a percentage frequency of 7.43% while 35 colonies of the same bacterium were isolated from the well waters during the dry season with a percentage frequency of 8.97%. Thirty-two colonies of *Proteus vulgaris* were isolated from all the well waters during the rainy season with a percentage frequency of 5.41% while 18 colonies of the same bacterium were isolated from the well waters during the dry season with a percentage frequency of 4.62%. Sixty-four colonies of *Vibrio cholerae* were isolated from all the well waters during the rainy season with a percentage frequency of 10.81% while 32 colonies of the same bacterium were isolated from the well waters during the dry season with a percentage frequency of 8.21%. Ninty-seven colonies of *Salmonella typhi* were isolated from all the well waters during the rainy season with a percentage frequency of 16.39% while 69 colonies of the same bacterium were isolated from the well waters during the dry season with a percentage frequency of 17.69%. Thirty-four colonies of *Pseudomonas aeruginosa* were isolated from all the well waters during the rainy season with a percentage frequency of 5.74% while 19 colonies of the same bacterium were isolated from the well waters during the dry season with a percentage frequency of 4.87%. Seventy- three colonies of *Escherichia coli* were isolated from all the well waters during the rainy season with a percentage frequency of 12.33% while 47 colonies of the same bacterium were isolated from the well waters during the dry season with a percentage frequency of 12.05%. Fifty-eight colonies of *Bacillus subtilis* were isolated from all the well waters during the rainy season with a percentage frequency of 9.80% while 40 colonies of the same bacterium were isolated from the whole well water samples during dry season with a percentage frequency of 10.26%.

The result of the bacteriological characteristics showed that Gram negative bacteria were dominant in the studied well waters for both rainy and dry seasons. The bacterial identification revealed the presence of nine isolates; *Citrobacter freundii*, *Shigella flexneri, Serratia marcescens, Proteus vulgaris, Vibrio cholerae, Salmonella typhi, Pseudomonas aeruginosa, Escherichia coli* and *Bacillus subtilis* (Table 13). The isolates were detected in higher number in rainy season and shallow wells than dry season and deep wells (Tables 7 and 12). This may be attributed to contamination from surface water run-offs, shallow depths and bad sanitary practices. The coliforms isolated were an indication of the contamination of the well waters with faecal materials. The faecal materials may be as a result of bad sanitary practices like low aprons, proximity to septic tanks and agricultural farms. The diverse groups of bacteria isolated from these wells are in line with the report of Ajayi AO [46] who worked on well waters at various locations within Akungba-Akoko, Ondo state. The presence of pathogenic microorganisms especially *Salmonella typhi, Shigella flexneri, Escherichia coli* and *Vibrio cholerae* can lead to the transmission of water borne diseases such as, Diarrhea, Typhoid fever, Cholera. *Citrobacter freundii* was the most dominant bacteria in rainy season while *Salmonella typhi* dominated during dry season (Table 12). The presence of *Salmonella typhi and Escherichia coli* in water indicates the possible presence of causative agents of many gastrointestinal diseases [47].

The analysis of the total bacterial count in the water samples revealed the presence of heterotrophic bacteria in all the well waters for both seasons (Table 7). The W.H.O standard for heterotrophic bacteria in potable water states that the total heterotrophic bacteria count should not be more than 100 cfu/ml (W.H.O, 2006). The presence of counts exceeding the W.H.O limits indicates that the water samples contain high concentration of bacteria that could make the water unsafe for domestic purposes. Result shows that the values of total bacterial count ranged from 2.66 log cfu/ml to 3.26 log cfu/ml for the rainy season (Table 7). The dry season values ranged from 2.54 log cfu/ml to 3.20 log cfu/ml (Table 7). Ginger well water had the least bacterial load for both seasons while Mmaku well waters had the highest values for both seasons. 100% of the deep well water values were within the W.H.O. permissible limit for domestic water (100 cfu/ml) while 87.5% of the shallow well water values exceeded the W.H.O. permissible limit for domestic water (100 cfu/ml). The rainy season result agrees with the findings of Bello et al. (2013) who recorded zero to 8.1 x 10^2 cfu/ml for well water samples in Ijebu-ode with about

Table 10. Distribution of bacterial isolates in the well waters during rainy season [49]

Wells location	Well type	*Salmonella typhi*	*Bacillus subtilis*	*Escherichia coli*	*Citrobacter freundii*	*Vibrio cholerae*	*Shigella flexneri*	*Proteus vulgaris*	*Pseudomonas aeruginosa*	*Serratia marcescens*
St. faith	Deep	+	+	+	+	+	+	+	-	+
Marian	Deep	+	-	+	+	-	+	-	+	+
Oli's close	Deep	+	+	-	+	+	+	-	+	+
Ginger	Deep	+	-	+	-	-	+	+	+	-
Muodozie	Deep	-	-	-	+	+	+	-	+	+
Kosta	Deep	-	-	+	-	-	-	+	+	+
Eljoe	Deep	+	-	+	+	+	+	+	+	-
Ichoku	Shallow	+	+	+	+	+	+	-	-	+
Mmaku	Shallow	+	+	+	+	+	+	+	+	+
Nwakpadolu	Shallow	+	+	+	+	+	+	+	-	+
Obi'sclose	Shallow	+	+	+	+	+	+	+	-	+
P.G Hostel	Shallow	+	+	+	+	+	+	-	+	-
Ada's close	Shallow	+	+	+	+	+	+	+	-	+
Camp's bae	Shallow	+	+	+	+	+	+	+	+	+
Blooms	Shallow	+	+	+	+	+	+	-	-	-

Table 11. Distribution of bacterial isolates in the well waters during the dry season [49]

Wells location	Well type	*Salmonella typhi*	*Bacillus subtilis*	*Escherichia coli*	*Citrobacter freundii*	*Vibrio cholerae*	*Shigella flexneri*	*Proteus vulgaris*	*Pseudomonas aeruginosa*	*Serratia marc.*
St. faith	Deep	+	-	+	+	+	+	+	-	+
Marian	Deep	+	-	+	+	-	-	-	-	+
Oli's close	Deep	+	+	+	-	+	+	-	-	-
Ginger	Deep	+	-	+	-	-	+	+	+	-
Muodozie	Deep	-	-	-	+	+	+	-	+	+
Kosta	Deep	-	+	+	-	-	+	+	+	+
Eljoe	Deep	-	-	+	+	+	+	-	-	-
Ichoku	Shallow	+	+	+	+	+	+	-	+	+
Mmaku	Shallow	+	+	+	+	-	+	+	+	+
Nwakpadolu	Shallow	-	+	+	+	+	+	+	-	-
Obi's close	Shallow	+	+	+	+	+	+	+	-	+
P.G Hostel	Shallow	+	+	+	+	+	+	-	+	-
Ada's close	Shallow	+	+	-	+	-	+	+	-	+
Camp's bae	Shallow	+	+	+	+	+	+	+	+	+
Blooms	Shallow	+	-	+	+	+	+	-	-	-

Key: Serratia marc: Serratia marcescens

Table 12. Frequency of occurrence and percentage frequency of the bacterial isolates in the well water during both seasons

Bacterial isolates	Number of colonies isolated (rainy)	Frequency of isolation (%) (rainy)	Number of colonies isolated (dry)	Frequency of isolation (%) (dry)
Citrobacter freundii	98	16.55	62	15.89
Shigella flexneri	92	15.54	68	17.44
Serratia marcescens	44	7.43	35	8.97
Proteus vulgaris	32	5.41	18	4.62
Vibrio cholerae	64	10.81	32	8.21
Salmonella typhi	97	16.39	69	17.69
Pseudomonas aeruginosa	34	5.74	19	4.87
Escherichia coli	73	12.33	47	12.05
Bacillus subtilis	58	9.80	40	10.26
Total	**592**	**100**	**390**	**100**

eighty percent of the samples having bacterial count within the admissible limit of 100 cfu/ml for potable water. The dry season result agrees with the findings of Shittu OB eet al. [37] who recorded 6.3 x 10^6 cfu/ml to 1.57 x 10^7 cfu/ml in water used for drinking and swimming purposes in Abeokuta, Nigeria and stated that the water samples had bacterial count above the admissible limit of 100 cfu/ml.

The total coliform count obtained from the well water samples in rainy season ranged from 11 cfu/100 ml to 70 cfu/100 ml (Table 8) and 100% of the values exceeded W.H.O. (2006) Standard of 10 cfu/100 ml. This indicated that the water samples are not fit for domestic purposes. This result was higher to the findings of Umeh OR et al. [9] who recorded lower total coliform values of 5 cfu/100 ml to 27 cfu/100 ml from well water samples in Awka and its environment, Anambra State which may be attributed to shallow depth of the wells.

The total coliform count obtained from the well water samples in dry season ranged from 9 cfu/100 ml to 52 cfu/100 ml (Table 9) and 86.6% of the values exceeded W.H.O. (2006) Standard of 10 cfu/100 ml. This indicated that the water samples were not fit for domestic purposes. This result corroborates with the findings of Amr-Mostafa H et al. [24] who recorded high total coliform values of 0 cfu/100 ml to 30 cfu/100 ml in groundwater in Egypt and stated that most of the water samples had total coliform count above the permissible limit of 10 cfu/100 ml.

The faecal coliform count obtained from the well water samples in rainy season ranged from 0 cfu/100 ml to 13 cfu/100 ml (Table 8) and 86.6% of the values exceeded W.H.O. (2006) standard of 0 cfu/100 ml. This indicated that the water samples (except Oli and Muodozie wells) are not fit for domestic purposes. This result corroborates with the findings of Ampofo JA et al. [47] who recorded similar feacal coliform values of 0 cfu/100 ml to 10 cfu/100 from Lokuwa water samples located in Mubi Metropolis, Adamawa state, Nigeria. This may be as a result of poor sanitary result such as proximity to septic tanks, agricultural farms, and poultry houses which were against the W.H.O Standard (2006). W.H.O. recommends that water sources should be located at least 30 m away from latrines and 17m from septic tank.

The faecal coliform obtained from the well water samples in dry season ranged from 0 cfu/100 ml to 8 cfu/100 ml (Table 10) and 86.6% of the values exceeded W.H.O. (2006) Standard of 0 cfu/100ml. This indicated that the well water samples are not fit for domestic purposes. This result is similar to the findings of Amr-Mostafa H et al. [24] who recorded feacal coliform values of 0 cfu/100 ml to 13 cfu/100 from groundwater samples in Egypt. This may be as a result of poor sanitary result such as proximity to septic tanks, agricultural farms, and poultry houses which were against the 2006 W.H.O Standard [41]. W.H.O. recommends that boreholes should be located at least 30m away from latrines and 17m from septic tank.

This well water samples (rainy season) revealed the presence of *Citrobacter freundii* (16.55%), *Shigella flexneri* (15.54%), *Serratia marcescens* (7.43%), *Proteus vulgaris* (5.41%), *Vibrio cholerae* (10.81%), *Salmonella typhi* (16.39%), *Pseudomonas aeruginosa* (5.74%), *Escherichia coli* (12.33%) and *Bacillus subtilis* (9.80%) (Table 12). These findings were similar to the values obtained by Akubuenyi FC et al. [35]. The slight differences in results may be due to collection methods and geographical location.

Akubuenyi FC et al. [35] 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.

This well water samples (dry season) revealed the presence of *Citrobacter freundii* (15.89%), *Shigella flexneri* (17.44%), *Serratia marcescens* (8.97%), *Proteus vulgaris* (4.62%), *Vibrio cholerae* (8.21%), *Salmonella typhi* (17.69%), *Pseudomonas aeruginosa* (4.87%), *Escherichia coli* (12.05%) and *Bacillus subtilis* (10.26%) (Table 12). These findings were similar to the values obtained by Tula MY et al. [48] and Umeh OR et al. [9] below. The slight differences in results may be due to collection methods and geographical location.

Tula MY et al. [48] 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 water samples located in Mubi Metropolis, Nigeria.

Umeh OR et al. [9] stated that *Escherichia coli, Bacillus subtilis, Salmonella typhi* and *Klebsiella pneumoniae* were present in well water samples located in Awka and its environment, Anambra State, Nigeria.

The distribution of the bacterial isolates in the well water samples (rainy season) showed that *Citrobacter freundii* was present in all the well water samples except Ginger and Kosta wells. *Shigella flexneri* was present in all the well water samples except Kosta well. *Serratia marcescens* was present in all the well water samples except Ginger, Eljoe, P. G. Hostel and Blooms wells. *Proteus vulgaris* was present in all the well water samples except Marian, Oli, Muodozie, Ichoku, P. G. Hostel and Blooms wells. *Vibrio cholerae* was present in all the well water samples except Marian, Ginger and Kosta wells. *Salmonella typhi* was present in all the well water samples except Muodozie and Kosta wells. *Pseudomonas aeruginosa* was present in all the well water samples except St. Faith, Ichoku, Nwakpadolu, Obi's close, Ada's close and Bloom's wells. *Escherichia coli* was present in all the well water samples except Oli's close and Moudozie wells. *Bacillus subtilis* was present in all the well water samples except Marian, Ginger, Muodozie, Kosta and Eljoe wells (Table 10).

The distribution of the bacterial isolates in the well water samples (dry season) showed that *Citrobacter freundii* was present in all the well water samples except Oli, Ginger and Kosta wells. *Shigella flexneri* was present in all the well water samples except Marian well. *Serratia marcescens* was present in all the well water samples except Oli, Ginger, Eljoe, Nwakpadolu, P. G. Hostel and Blooms wells. *Proteus vulgaris* was present in all the well water samples except Marian, Oli, Muodozie, Eljoe, Ichoku, P. G. Hostel and Bloom wells. *Vibrio cholerae* was present in all the well water samples except Marian, Ginger, Kosta, Mmaku and Ada wells. *Salmonella typhi* was present in all the well water samples except Muodozie, Kosta, Eljoe and Nwakpadolu wells. *Pseudomonas aeruginosa*was present in all the well water samples except St. Faith, Marian, Oli, Eljoe, Nwakpadolu, Obi's close, Ada's close and Bloom's wells. *Escherichia coli* was present in all the well water samples except Moudozie and Ada wells. *Bacillus subtilis* was present in all the well water samples except St. Faith, Marian, Ginger, Muodozie, Eljoe and Bloom wells (Table 11).

The result of the bacteriological parameters varied significantly ($p < 0.05$) at 0.05 alpha level of significance between the two depths (shallow and deep) and seasons (rainy and dry) using two-way analysis of variance (ANOVA) except *Pseudomonas aeruginosa* and *Vibrio cholerae*.

Table 13. Morphological and biochemical characteristics of the bacteria from the well water samples for both seasons

Isolates	Colony morphology	Microscopy	Gram stain	Catalase test	Coagulase test	Citrate utilization test	Oxidase test	Urease test	Indole test
1	Round colourless colonies with black centers	Rods	-	+	-	+	-	-	-
2	Large, circular and jagged colonies	Rods in chain/pairs	+	+	-	+	-	-	-
3	Green metallic sheen	Rods	-	+	-	-	-	-	+
4	Colorless on MacConkey	Rods	-	+	-	+	-	+	-
5	Small, round yellowish colonies	Curved rods	-	+	-	+	+	-	+
6	Round colourless colonies	Rods	-	+	-	-	-	-	-
7	Colourless colonies on MacConkey	Short rods	-	-	-	-	-	+	+
8	Circular, lemon green colonies	Rods	-	+	-	+	+	-	-
9	Pink on MacConkey	Rods	**-**	**+**	**-**	**+**	**-**	**+**	**-**

Table 14. Morphological and biochemical characteristics of the bacteria from the well water samples for both seasons continued

Isolates	Motility	Voges-Proskauer test	Methyl red test	Glucose fermentation test	Sucrose fermentation test	Lactose fermentation test	Maltose fermentation test	Hydrogen sulphide test	Spore test	Bacterial identity
1	+	-	+	A	-	-	A	+	-	*Salmonella typhi*
2	+	+	-	A	A	-	A/G	-	+	*Bacillus subtilis*
3	+	-	+	A/G	A	A/G	A/G	-	-	*Escherichia coli*
4	+	-	+	A/G	A/G	A/G	A/G	+	-	*Citrobacter freundii*
5	+	-	+	A/G	A/G	-	A/G	-	-	*Vibrio cholerae*
6	-	-	+	A	-	-	A	+	-	*Shigella flexneri*
7	+	-	+	A/G	A/G	-	A/G	+	-	*Proteus vulgaris*
8	+	-	-	-	-	-	-	-	-	*Pseudomonas aeruginosa*
9	+	+	-	A/G	A/G	-	A/G	-	-	*Serratia marcescens*

4. CONCLUSION

The levels of contamination among the fifteen well water samples varied. The results showed that shallow wells yielded water of very poor quality with regards to physicochemical and bacteriological quality than the deeper wells. Higher values and counts were recorded in rainy season than the dry season. The study also indicated that the well water samples contained significant amounts of nitrate, phosphate, lead, cadmium and arsenic. All the wells sampled failed to meet the zero coliform per 100 ml standard set by World Health Organization. The results from this study clearly demonstrated that the water quality obtained from the wells is unfit for human consumption. The location and construction play a large part in reducing the contaminants in these wells, but do not guarantee that the water obtained from deep wells will be safe to drink.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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