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ORIGINAL RESEARCH ARTICLE

Evaluation of physicochemical, bacteriological and parasitological quality of selected well water samples in Awka and its environment, Anambra State, Nigeria

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ABSTRACT

Water quality is made up of physical, chemical and biological factors which influence the use of water for domestic purposes. Industrial and municipal solid and liquid wastes are being continuously leached into water reservoirs, thereby affecting its potability for domestic use. In this study, the physicochemical, bacteriological and parasitological evaluation of selected well water samples in Awka and its environment were evaluated during wet season. Standard methods for physicochemical, bacteriological and parasitological analyses were employed. Physicochemical analysis was done using standard analytical methods; bacteriological analysis was determined by dilution and membrane filtration techniques. Parasitological analysis was done using the centrifugation method. The result showed that 86.67% of the pH values were acidic, 6.67% of nitrate, 33.33% of phosphate, 20% of cadmium, 73.33% of lead, 26.67% of arsenic, 20% of iron, 100% of bacteria and parasites exceeded the WHO maximum containment level goal for domestic water while other parameters were within WHO standards for domestic water. The most polluted of all the well water samples is Aka well water while the least polluted is Emeka and Aqua well waters. *S. typhi* had the highest frequency of isolation (25.45%) while *Bacillus subtilis* had the least (1.56%). *Diplostomum* parasite had the highest frequency of isolation (42.86%) while *Ichthyobodo* and *Chilodonella* had the least (28.57% respectively). Since some of the physicochemical, bacteriological and parasitological parameters had values above World Health Organization admissible limits; governments, health and environmental experts must rectify (through water treatments and better sanitary practices) and enlighten the residents to prevent epidemics.

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INTRODUCTION

Fresh water has become a scarce commodity due to over-exploitation and pollution (Morrison *et al.*, 2001). The high demand for water has resulted to the increased number of dug wells in Awka and its environment; residents, individual farmers and organized groups have constructed shallow wells without considering the environmental and health implications (Umeh *et al.*, 2020). Industrial and municipal solid and liquid wastes are being continuously added to the water reservoirs affecting the physicochemical and bacteriological quality of well waters making them unfit for use (Morrison *et al.*, 2001). Heavy metals such as cadmium, zinc, mercury, chromium, copper, cobalt, nickel, manganese, iron, vanadium and molybdenum cause heavy pollution particularly in water (Ida, 2012). The toxic metal flux into the ecosystem occurs through discharge of raw and inadequately treated industrial and municipal effluent, vehicle service station or garage effluent and agricultural inputs like chemical fertilizers, herbicides and pesticides. The accumulation of these heavy metals over time leads to the suppression of immunity hence allowing the normal pathogenic microbes to cause ulceration and possible septicemia (toxins in the blood stream)

(Ida, 2012). Water quality generally means the component of water which must be present for optimum growth of aquatic organisms and humans (Ehiagbonare and Ogunrinde, 2010). It is made up of physical, chemical and biological factors which influence the use of water for domestic purposes. These factors include dissolved oxygen, pH, hardness, turbidity, alkalinity, ammonia, temperature etc. (Ehiagbonare and Ogunrinde, 2010). Microorganisms contribute a significant fraction of importance in the aquatic ecosystem and they have been observed to be among the factors that can cause the emergence of infectious diseases (Noga, 2010; Ikpi and Offem, 2011).

Nigeria has the highest populace in Africa with high demand for water. Due to the paucity of good waste management practices in the country, ample quantities of leachates move into water bodies. Inability of well owners to dig wells to fresh aquifers due to cost and lack of knowledge on good hygiene practices has also directly contributed to the pollution and degradation of well water quality thereby resulting to emergence of infections and diseases (Umeh *et al.*, 2020). Incidence of water-borne diseases such as cholera, typhoid fever, dysentery had been reported in this study area in 2018. The findings from this study have established the current quality of the well waters and also are used as a baseline for surveillance, prevention and control of water-borne diseases and infections. It therefore becomes vital that the physicochemical, bacteriological and parasitological quality of the well waters in this area should be examined, hence the need for this study.

The objectives of this research were to: evaluate the sanitary risk of the sampled points, determine the variability of physico-chemical parameters such as temperature, pH, electrical conductivity, total dissolved solids, total suspended solids, total solids, turbidity, nitrate, total alkalinity, phosphate, sulphate, total chloride, dissolved oxygen, total hardness, calcium hardness, magnesium hardness, carbonates, bicarbonates, total acidity, potassium, cadmium, lead, chromium, mercury, copper, arsenic, zinc and iron on the selected fish pond water samples and comparing with World Health Standard, enumerate the total bacterial load, total and faecal coliforms and other pathogenic bacteria present (*Staphylococcus aureus*, *Acinetobacter calcoaceticus* and *B. subtilis*) in the selected fish pond water samples and comparing with World Health Organization Standard, determine the parasites present in the selected fish pond water samples and characterize the bacteria present.

MATERIALS AND METHODS

Study area

The study area for this research is selected well waters in Awka and its environment, Anambra State, Nigeria. Awka is the capital of Anambra State, Nigeria. Awka is made up of two local government areas, namely: Awka South and Awka North. The area lies within the tropical rain-forest zone of West Africa with an average humidity of 80%. Its mean daily temperature is 20^{0}C, while the mean annual rainfall is 200cm as it witnesses two distinctive climatic changes in a year. The dry season occurs between early November and March with prevailing dust-laden Northeasterly wind and rainy season occurs from April up to October with Southwesterly moisture laden air mass moving. The area is mostly inhabited by mainly Christians (Figure 1)

Sanitary risk inspection of the sampled wells

The questions were adopted from (Umeh *et al.*, 2020) and modified in accordance with objectives of this research. Vital information about the wells such as depth of wells, proximity of wells to farm lands, Proximity of wells to septic tanks, height of well slab/apron, interior concrete linings, were obtained by oral interview and visual analysis. The depth of the wells was measured using calibrated long steel.

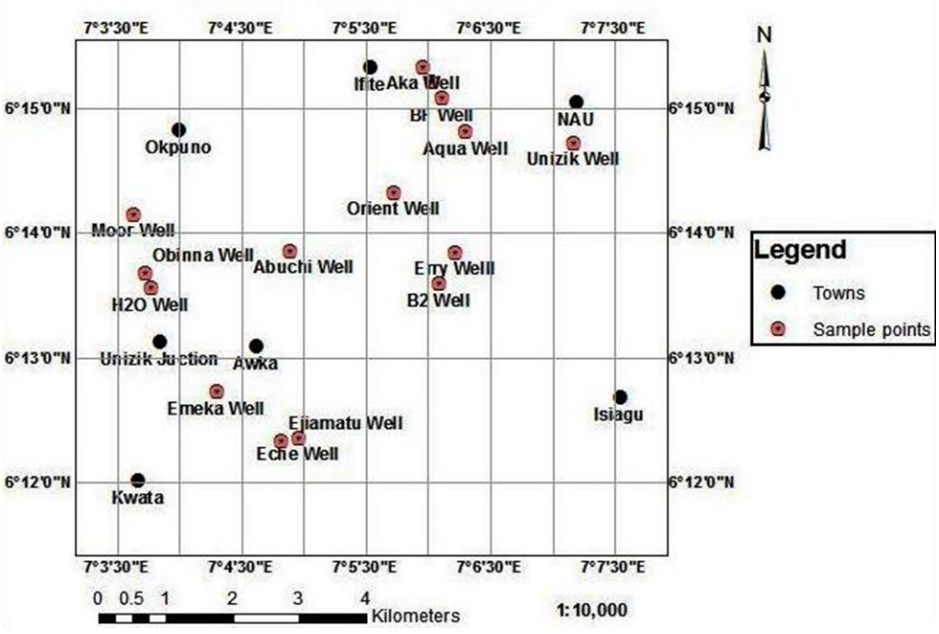

Figure 1. *Map of the study area.*

Figure 1. *Sampling site for collection of water samples at Unizik well.*

Figure 2. *Sampling site for collection of water samples at Aka well.*

Collection of samples

Fifteen water samples were collected from fifteen major well waters in Awka and its environment, Anambra State during the month of July, 2018. These water samples were collected in the early morning period (7AM-9AM). One liter of composite water samples were collected in one liter sterile containers with stoppers, from the wells. Prior to sample collection, all the sampling bottles were autoclaved and rinsed with the same water to be collected from the wells. The sampling bottles were labeled with dates and collection sites. The sampling bottles were tied with a strong string to a piece of metal and the bottle caps were aseptically removed and lowered into the well to a depth of 1 meter. The sampling bottles were capped. The water samples were kept at 4°C in an ice box and transported to the laboratory within 2 hours for immediate sample analysis. These well waters are: Erry, Unizik, H_2O, Aka ndi muo ozi, Aqua, Book foundation, Orient, Ejiamatu, Eche, B_2, Morr, Izu, Emeka, Abuchi and Obinna wells (Figure 1, 2).

Physicochemical analysis

The physicochemical parameters evaluated were temperature, pH, dissolved oxygen, turbidity, electrical conductivity, total dissolved solids, total suspended solids, total solids, total acidity, total alkalinity, total hardness, chloride, calcium hardness, magnesium hardness, nitrate, phosphates, potassium, sulphate, iron, lead, cadmium, chromium, zinc, copper, mercury. The evaluation was carried out using standard analytical methods (APHA, 2005). Some parameters (temperature, pH, dissolved oxygen, turbidity and electrical conductivity) were measured *in-situ* because of low stability.

Bacteriological analysis

Bacterial isolation was done according to the method described by (Cheesbrough, 2010). 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 160^0C 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

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).

$$\text{Colony forming unit / ml} = \frac{N}{V \times D}$$

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.

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 Mac Conkey agar medium at 37°C incubation for 48 hours was used for total coliforms.

Detection of *V. cholerae and V. parahaemolyticus*

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 were suspected to be *V. cholerae* and green colonies were suspected to be *V. parahaemolyticus*. 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.

Detection of *S. typhi and S. flexineri*

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 were suspected to be *Salmonella* species while colorless 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.

Detection of *P. aeruginosa* and *P. 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 were 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.

Detection of *C. perfringens*

The water samples (1 milliliter) were inoculated into labelled Petri-plates. Sterile Reinforced Differential Clostridial medium with nystatin at 45°C was dispensed into the plates, gently swirled and incubated anaerobically using an anaerobic jar at 25°C for 72 hours.

Detection of parasites

Parasitological analysis was done according to the method described by (Umeh *et al.*, 2020). The sample cans were shaken for 25 times and 10 milliliters of the samples were dispensed into a 10ml centrifuge tube, capped and cleaned using a sterile cotton wool. These tubes were placed inside a centrifuge machine for centrifugation at 360 revolutions per second for 10 minutes. The tubes were allowed to settle properly for five minutes and the supernatants were removed. The resulting residue was poured onto a clean grease-free glass slide. Two drops of Lugol's iodine were poured (to intensify reactions between cells and stain) and covered with a cover slide. Excess water was blotted using a sterile filter paper and viewed at ×10 and ×40 objective lens for the presence of parasite ova and cysts. The parasites were counted, identified and recorded per well water sample using Pouder *et al.* (2005) parasite guide for proper identification.

Characterization and identification of the bacterial isolates was done according to the method of (Cheesbrough, 2010).

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

Gram-staining and microscopic examination

This was done according to the procedure described by (Cheesbrough, 2010).

Biochemical tests

These biochemical tests were carried out according to (Cheesbrough, 2010). Catalase test, coagulase test, citrate utilization test, oxidase test, urease test, indole test, motility test, voges-proskauer test, methyl red test, sugar fermentation and hydrogen Sulphide Test.

Data analysis

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

RESULTS AND DISCUSSION

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, people resort to shallow wells, boreholes etc. as alternative water resources for domestic use. The effect of uncontrolled disposal systems and other bad sanitary practices in Nigeria and Awka in particular can render groundwater and surface waters unsafe for human, agricultural and recreational use, pose a threat to human life and is therefore against the principle of sustainable development. Studies on groundwater pollution have been carried out in different parts of Nigeria. Consistent in their findings is that groundwater is polluted from physical processes and anthropogenic activities. In Nigeria and other developing countries, these hazardous materials are disposed-off with municipal solid and liquid wastes into open dumps and surface water bodies, often used for domestic purposes (Onwughara *et al.*, 2010). When disposed through these routes, toxic substances can leach and eventually contaminate surface and groundwater's (Onwughara *et al.*, 2010). Most developing nations cannot afford to dig wells deep enough to reach fresh aquifers (Onwughara *et al.*, 2010).

Pollution of groundwater stems from different sources which include insanitary condition during borehole construction, splashing of runoff into wells, if left uncovered, flooding at borehole site, leachates from old buried waste pit or latrine into the hole through cracks in aquifer and annular of the hole, closeness of boreholes to septic tanks especially where space is a constraint and as such boreholes are drilled at times at old garbage landfill site formations through which the wastewater is retrieved from the holes (Obot and Edi, 2012). Sanitation at the surface around the well also affects the quality of the water as seepage through the soil surrounding the casing may also impart pollutant on the water quality. Pollution particles that run off the ground surface and polluted water which enters a stream through its channel sides and bottom may pollute surface streams and then, leach into the soil to pollute groundwater. Also, pollution might arise from a water runoff, laden with particle pollutants, that infiltrates into the soil to a shallow depth. The water from such a shallow sources does not guarantee good water quality for domestic use (Obot and Edi, 2012).

Results of sanitary risk assessment of the well waters revealed that the proximity of most of the wells to septic tanks, agricultural farms, solid waste dump site and animal droppings, depth of the well water, well cover and height of the apron showed poor sanitary quality and against World Health Standards (Plate 1 and 2). The physicochemical characteristics of the well waters varied and this may be attributed to different sanitary practices by owners. The variations observed in the physicochemical properties of the well waters carried out in Nigeria could be attributed to the influences of the micro-climatic, topographic and edaphic conditions of wells in the area. In addition, human and animal or livestock activities could also be a factor (Umeh *et al.*, 2020).

Physical characteristics of the well waters

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. Temperature, an important parameter in this study influences the biological oxygen demand in wells. As water temperature increases, it holds less oxygen. Also plants and animals use more oxygen due to increased respiration. The temperature values observed in the well waters ranged from 26°C to 28°C (Table 1) and is within WHO (2006) maximum containment level goal (25°C-32°C). The values were similar to the report by Akubuenyi *et al.* (2013) who recorded a temperature range of 25°C-27°C. pH value is an indication of the level of acidity or alkalinity of a solution. The pH values observed in the well waters ranged from 5.51 to 7.07 (Table 1) and 86.67% of the pH values recorded in the well water samples were below WHO (2006) permissible limit of 6-9 and therefore acidic which may be attributed to solid and liquid wastes leaching into the shallow wells.

Electrical conductivity is a measure of the ability of water to conduct electricity (Umeh *et al.*, 2020). The conductivity values observed in the well waters ranged from 88.27 µs/cm to 283.40 µs/cm (Table 1) and 100 % of the conductivity values recorded in the well water samples were within WHO (2006) permissible limit of 1000 µs/cm and therefore fit for domestic use. These values agreed with the report of Bernard and Ayeni (2012) who observed a conductivity value of 135 µS/cm from groundwater samples in Kano, State. The excellent (low) conductivity values gotten from my analysis can be attributed to the rainy season in which the samples were collected. Previous studies have shown that dilution of water during the rainy season lowers the levels of electrical conductivity and it increases during dry season (Sipaúba-Tavares *et al.*, 2007).

Total dissolved solids (TDS) are an indication of the amount of dissolved substances (Umeh *et al.*, 2020). The total dissolved solids observed in the well waters ranged from 9 mgL^{-1} to 80 mgL^{-1} (Table 1) and 100 % of the conductivity values recorded in the well water samples were within WHO (2006) permissible limit of 500 mgL^{-1} and therefore fit for domestic use. The values agreed with the work of Anyanwu and Okoli, (2012), which stated TDS values of 6.8 mgL^{-1} to 8.0 mgL^{-1} from well waters and were below the 500 mgL^{-1} maximum permissible limit (WHO, 2006).

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 (Mahananda *et al.*, 2010). The total suspended solids observed in the well waters ranged from 0.37 mgL^{-1} to 13.89 mgL^{-1} (Table 1) and 100 % of the TSS values recorded in the well water samples were within WHO (2006) permissible limit of 30 mgL^{-1}

and therefore fit for domestic use. The values were below 31.3 mgL^{-1} to 55.0 mgL^{-1} reported by Onwughara *et al.* (2013) from groundwater samples in Abia State, which he attributed to high presence of suspended matters. Total solids (TS) are a combination of dissolved solids and total suspended solids. The solids observed in the well water samples ranged from 9.58 mgL^{-1} to 93.89 mgL^{-1} (Table 1) and 100 % of the TS values recorded in the well water samples were within WHO (2006) permissible limit of 500 mgL^{-1} and therefore fit for domestic use. The values were above 0.31 mgL^{-1} to 20.09 mgL^{-1} reported by Onuorah *et al.* (2017) from hand-dug shallow well water samples in Awka Metropolis, which may be 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.

Table 1. The physical parameters of the well waters in milligram per liter (mgL^{-1}).

Pond Names	Temperature (^0C)	pH	E.C (µs/cm)	TDS (mgL^{-1})	TSS (mgL^{-1})	TS (mgL^{-1})	Turbidity (NTU)	Well depth (M)
Morr	28	5.88	257.60	47	01.33	48.33	03.90	11
Aka	28	7.07	283.40	80	13.89	93.89	05.94	11
Erry	26	6.05	093.50	10	00.51	10.51	02.92	14
Unizik	28	6.89	260.70	62	09.64	71.64	05.65	11
H_2O	27	6.10	146.00	44	01.86	45.86	03.52	13
Eche	26	5.71	091.22	27	01.05	28.05	04.78	12
Ejiamatu	27	5.61	205.00	49	01.11	50.11	04.11	11
Abuchi	27	5.62	104.11	36	00.47	36.47	01.51	14
Aqua	27	5.92	153.27	40	00.72	40.72	01.40	13
Emeka	26	5.51	088.27	09	00.58	09.58	01.33	14
B.F.	27	6.09	112.50	38	00.97	38.97	04.37	11
Orient	26	5.62	107.59	32	00.37	32.37	01.49	14
Obinna	27	6.20	187.33	47	00.90	47.90	04.65	11
B_2	27	5.92	193.66	30	00.59	30.59	03.88	12
Izu	27	5.55	217.93	51	01.06	52.06	04.27	11
W.H.O (2006)	25-32	6.5-8.5	1000	500	30	500	5	>15

Key: B.F pond = Book foundation pond; E.C = Electrical conductivity; NTU = Nephelometric turbidity unit; M = Meters; ^0C = Degree centigrade; TDS = Total dissolved solids; MgL^{-1} = Milligram per milliliter; TSS = Total suspended solids; µs/cm =Microsiemens per centimeter; TS = Total solids.

Table 2. The chemical parameters of the well waters in milligram per liter (mgL^{-1}).

Pond Names	Ni.	T.A.	Pho.	Sul.	T.C.	DO	T.H.	C.H.	M.H.	Car.	Bic.	T.A.	Po
Morr	1.41	32	0.44	0.17	38.34	5.43	95.55	65.54	30.01	0.53	31.47	28	0.13
Aka	11.49	44	7.71	0.09	24.89	5.19	70.44	49.23	21.21	0.83	43.17	13	1.49
Erry	1.37	13	0.08	0.03	31.44	6.55	82.11	58.93	23.18	0.95	12.05	17	0.07
Unizik	7.15	41	0.83	0.11	29.11	5.58	69.30	42.99	26.31	1.40	39.60	15	1.12
H_2O	1.53	23	0.12	3.71	59.53	6.20	88.73	51.83	36.90	1.89	21.11	17	0.15
Eche	1.69	40	0.19	0.07	23.40	6.17	71.50	40.85	30.65	0.81	39.19	29	0.36
Ejiamatu	1.55	37	0.05	0.01	27.39	5.79	76.08	55.23	22.85	0.58	36.42	31	0.31
Abuchi	1.14	16	0.02	0.08	22.00	5.89	62.34	35.22	27.12	0.12	15.88	31	0.19
Aqua	1.07	13	0.06	0.06	36.81	6.19	65.32	39.07	26.25	0.21	12.79	26	0.10
Emeka	0.13	12	0.01	0.01	19.03	5.73	75.89	41.76	34.80	0.87	11.13	33	0.04
B.F.	1.72	29	0.15	0.39	45.94	5.97	89.51	52.18	37.33	1.45	27.55	15	0.51
Orient	0.81	19	0.09	0.21	24.00	6.07	70.92	45.33	25.59	1.01	17.99	30	0.25
Obinna	1.35	40	1.03	0.33	63.56	6.13	76.88	49.86	27.02	0.94	39.06	14	0.58
B_2	1.17	23	0.74	0.16	36.02	6.04	84.14	62.94	21.20	0.73	22.27	25	0.24
Izu	1.20	27	0.89	0.87	43.07	5.66	67.40	40.88	26.52	1.05	25.95	33	0.46
W.H.O (2006)	10	250	0.5	250	250	5	250	75	50	-	-	50	5

Key: Ni = Nitrate; T.A = Total alkalinity; T.H = Total hardness; T.A = Total acidity; Pho = Phosphate; C.H = Calcium hardness; Po = Potassium; Sul = Sulphate; M.H = Magnesium hardness; T.C = Total chloride; Car = Carbonates; DO = Dissolved oxygen; Bic = Bicarbonates.

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. The turbidity values observed in the well water samples ranged from 1.33 NTU to 5.94 NTU (Table 1) and 100 % of the turbidity values recorded in the well water samples were within WHO (2006) permissible limit of 10 NTU and therefore fit for domestic use. The values were similar to the work of Sadiya *et al.* (2018) who tabled turbidity value of 3.43 NTU. Turbidity affects the appearance of water. Water with high turbidity is normally associated with high microbiological contamination which is in congruence with the bacterial population in Aka well water which had the highest value of turbidity in this study. This high turbidity in Aka well water may be as a result of poor sanitary risks such as low or absence of apron, fissured interior linings in the wells. Emeka pond had the lowest value of turbidity due to better sanitary practice. The well depth (source of water) ranged from 11 meters to 14 meters (Table 1) and is classified as shallow wells according to WHO Standard (2006). The results of the physical parameters varied significantly (*P<0.001*) different using two-way analysis of variance (ANOVA).

Chemical characteristics of the well waters

Nitrate represents the final product of the biochemical oxidation of ammonia (Mahananda *et al.*, 2010). It is important that the level of nitrate in a well is controlled to avoid eutrophication. Nitrates cause methaemoglobinemia in humans when it exceeds the maximum containment level goal. The nitrate values observed in the well water samples ranged from 0.13 mgL^{-1} to 11.49 mgL^{-1} (Table 2) and 6.67 % of the nitrate values recorded in the water samples were above W.H.O (2006) permissible limit of 10 mgL^{-1} and therefore not fit for domestic use. This is similar to the value (12.2 mgL^{-1}) recorded by Otieno *et al.* (2015) from well water samples in Kenya. High nitrate levels may be as a result of proximity of well waters to farmlands (fertilizers), septic tanks, poultry farms etc.

Water alkalinity is a measure of its capacity to neutralize acids (Umeh *et al.*, 2020). It can be referred to as the buffering capacity of water. Waters with high alkalinity are undesirables. The alkalinity values observed in the well water samples ranged from 12 mgL^{-1} to 44 mgL^{-1} (Table 2) and 100 % of the total alkalinity values recorded in the well water samples were within WHO (2006) permissible limit of 250 mgL^{-1} and therefore fit for domestic use. This is below the report of Sadiya *et al.* (2018) who recorded a total alkalinity value of 116.32 mgL^{-1} from well water samples in Abuja and attributed it to high carbonate and bicarbonate level. Phosphate is the chemical term for the various combinations of phosphorous and oxygen (Umeh *et al.*, 2020). Phosphate is the main nutrient for algae. The phosphate values observed in the well water samples ranged from 0.01 mgL^{-1} to 7.71 mgL^{-1} (Table 2) and 33.33 % of the phosphate values recorded in the well water samples were above WHO (2006) permissible limit of 0.5 mgL^{-1} and therefore not fit for domestic use. This is similar to values (0.56 mgL^{-1} to 2.15 mgL^{-1}) recorded by (Akubuenyi *et al.*, 2013). High phosphate levels may be as a result of proximity of well waters (which serves as the source of water) to farmlands (fertilizers), septic tanks, geologic formations, domestic (human wastes, synthetic detergents) and industrial waste waters (Umeh *et al.*, 2020). Higher values could lead to eutrophication (Umeh *et al.*, 2020).

The sulphate values observed in the well water samples ranged from 0.01 mgL^{-1} to 3.71 mgL^{-1} (Table 2) and 100 % of the sulphate values recorded in the well water samples were within WHO (2006) admissible limit of 250 mgL^{-1} and therefore fit for domestic use. This is smaller than value (18.39 mgL^{-1}) recorded by Otieno *et al.* (2015) which he attributed to agricultural activities and geological formation of the area. The main natural sources of sulphate in water is the process of chemical weathering and dissolution of sulfur containing minerals, predominantly gypsum ($CaSO_4 2H_2O$), 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 (Umeh *et al.*, 2020).

Chloride ion is a common constituent of all natural water and it's generally regarded as a non-harmful constituent (Nduka *et al.*, 2008). 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 (Nduka *et al.*, 2008). The chloride values observed in the well water samples ranged from 19.03 mgL^{-1} to 63.56 mgL^{-1} (Table 2) and 100 % of the total chloride values recorded in the water samples were within WHO (2006) permissible limit of 250 mgL^{-1} and therefore fit for domestic use. Chloride at low concentration is not harmful to humans but the water will taste salty if the chloride level exceeds 250 mgL^{-1}. Otieno *et al.* (2015) reported chloride values of 55.54 mgL^{-1} in well water samples in Kenya.

Dissolved oxygen (DO) is defined as the measure of the amount of gaseous oxygen dissolved in an aqueous solution (Dhavran and Karu, 2002). It has been reported that natural waters are saturated with dissolved oxygen in equilibrium with air. The concentration at this saturation is known to decrease as the temperature of water increases (Eze and Ogbaran, 2010). The dissolved oxygen observed in the well water samples ranged from 5.19 mgL^{-1} to 6.55 mgL^{-1} (Table 2) and 100 % of the dissolved oxygen values recorded in the well water samples were within WHO (2006) permissible limit of >5 mgL^{-1} and therefore fit for domestic use. This is above the values reported by Akubuenyi *et al.* (2013); he recorded DO values of 3.16 mgL^{-1} to 4.61 mgL^{-1}. The high DO in this study may be as a result of high aeration (from trees) in the sampled areas.

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 (Singh *et al.*, 2010). The total hardness observed in the well water samples ranged from 62.34 mgL^{-1} to 95.55 mgL^{-1} (Table 2) and 100 % of the total hardness values recorded in the well water samples were within WHO (2006) permissible limit of 250 mgL^{-1} and therefore fit for domestic use. This is below the report of

Otieno *et al.* (2015) who recorded a total hardness value of 139.38 mgL^{-1} from well water samples in Kenya and attributed it to high calcium and magnesium ions. Bhatnagar and Devi (2013) opined that the total hardness value of less 20 mgL^{-1} would cause stress due to lack of calcium and magnesium needed for bone and scale formation. It might therefore be necessary to add some calcium, and magnesium supplements since these are necessary for bone and scale formation.

The calcium hardness observed in the well water samples ranged from 35.22 mgL^{-1} to 65.54 mgL^{-1} (Table 2) and are within WHO (2006) permissible limit of 75 mgL^{-1}. The values are similar to 4.8 mgL^{-1} to 139.5 mgL^{-1} reported by Olusiji *et al.* (2011) from hand-dug wells in Ekiti State. The magnesium hardness observed in well water samples ranged from 21.20 mgL^{-1} to 37.33 mgL^{-1} (Table 2) and are within WHO (2006) permissible limit of 50 mgL^{-1}. The values are above 3.4 mgL^{-1} to 25.9 mgL^{-1} reported by Olusiji *et al.* (2011) from hand-dug wells in Ekiti State. Magnesium in water can come from the leaching of minerals such as clay. The carbonate values observed in the well water samples ranged from 0.12 mgL^{-1} to 1.89 mgL^{-1} (Table 2) with Abuchi's well having the least value of 0.12 mgL^{-1} while H_2O well had the highest value of 1.89 mgL^{-1}. The bicarbonate values observed in the well water samples ranged from 11.13 mgL^{-1} to 43.17 mgL^{-1} (Table 2) with Emeka's well having the least value of 11.13 mgL^{-1} while Aka's well had the highest value of 43.17 mgL^{-1}.

The total acidity observed in the well water samples ranged from 13 mgL^{-1} to 33 mgL^{-1} (Table 2) and 100 % were above WHO (2006) permissible limit of 0.3 mgL^{-1}. Onuorah *et al.* (2017) recorded high values (21 mgL^{-1} to 86.3 mgL^{-1}) of acidity from studied shallow wells in Awka Metropolis. The potassium content observed in the well water samples ranged from 0.04 mgL^{-1} to 1.49 mgL^{-1} (Table 2) and is within WHO (2006) permissible limit of 5 mgL^{-1}. The values are lower than 1.9 mgL^{-1} to 32 mgL^{-1} reported by Mensah, (2011) from wells in Ghana. The results of the chemical parameters varied significantly (*P<0.001*) different using two-way analysis of variance (ANOVA).

Heavy metal characteristics of the well waters

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 (Duruibe *et al.*, 2007). Heavy metals refer to metallic chemical element that has a relatively high density and is toxic or poisonous at low concentrations (Danyal *et al.*, 2006). The heavy metals: lead, chromium, mercury, copper, arsenic, iron, cadmium and zinc concentrations in well waters in all the sampling sites were compared with WHO (2006) standard. The obtained results showed that, with the exception of cadmium, lead, arsenic and iron, the heavy metal concentrations in the well water did not exceed WHO (2006) standard. Heavy metals pollutants after entering into aquatic environment accumulate in tissues and organs of aquatic organisms and humans (Umeh *et al.*, 2020).

The cadmium content observed in the well water samples ranged from 0. 00 mgL^{-1} to 0.04 mgL^{-1} (Table 5) and 20% of the cadmium values were above WHO (2006) admissible limit of 0.03 mgL^{-1}, therefore not fit for domestic use. The values were above 0.001 mgL^{-1} to 0.081 mgL^{-1} reported by Momodu and Anyakora (2010) from selected well waters in Surulere, Lagos State. Cadmium is a metal with no known beneficial properties that supports life. Contamination of groundwater with cadmium is possible through the application of fertilizer that is common in the study area. According to Asolker *et al.* (2001), 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, humans etc. Aquatic animals absorb cadmium through gills, liver, kidney which can be transferred to humans causing cancer, birth defects and genetic mutations (Asolker *et al.*, 2002).

Table 3. Heavy metal characteristics of the various well waters.

Pond Names	Cadmium (mgL^{-1})	Lead (mgL^{-1})	Chromium (mgL^{-1})	Mercury (mgL^{-1})	Copper (mgL^{-1})	Arsenic (mgL^{-1})	Zinc (mgL^{-1})	Iron (mgL^{-1})
Morr	0.01	0.02	0.00	0.00	0.02	0.02	0.03	0.03
Aka	0.04	0.21	0.04	0.00	0.03	0.02	0.05	1.16
Erry	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.01
Unizik	0.04	0.16	0.03	0.00	0.03	0.00	0.04	1.35
H_2O	0.00	0.02	0.00	0.00	0.01	0.00	0.03	0.05
Eche	0.02	0.04	0.02	0.00	0.03	0.01	0.03	0.30
Ejiamatu	0.02	0.03	0.02	0.00	0.04	0.01	0.02	0.17
Abuchi	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.03
Aqua	0.00	0.02	0.00	0.00	0.00	0.00	0.00	0.01
Emeka	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.03
B.F.	0.01	0.02	0.03	0.00	0.01	0.01	0.03	0.06
Orient	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.02
Obinna	0.05	0.27	0.04	0.00	0.02	0.02	0.03	1.28
B_2	0.03	0.03	0.00	0.00	0.01	0.01	0.02	0.12
Izu	0.02	0.09	0.01	0.00	0.02	0.02	0.02	0.08
W.H.O (2006)	0.03	0.01	0.05	0.001	2.0	0.01	3.0	0.3

The lead content observed in the well water samples ranged from 0.01 mgL^{-1} to 0.27 mgL^{-1} (Table 3) and 73.33% are above WHO (2006) permissible limit of 0.01 mgL^{-1} and therefore not fit for domestic use. Higher values may be as a result of fissured water pipes, sewage effluents, automobile exhaust fumes, run off wastes and atmospheric depositions within the study area. The values were above 0.001 mgL^{-1} to 0.019 mgL^{-1} reported by Momodu and Anyakora (2010) from well water samples in Surulere, Lagos State.

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. The above facts could offer explanation for the presence of high lead content in some well water samples analyzed. High level of lead in water can lead to cancer, interference in vitamin D metabolism, adverse effects in mental development in infants and toxicity to the central and peripheral nervous systems. In human beings, it binds with SH group of proteins, apart from that, lead damages blood circulation, central nervous system, liver and kidneys (Kori-siakpere and Ubogu, 2008). In addition, lead can delay embryonic development, suppress reproduction, and inhibit growth, increase mucus formation, neurological problem, enzyme inhalation and kidney dysfunction in humans (Kori-siakpere and Ubogu, 2008).

The chromium content observed in the well water samples ranged from 0.00 mgL^{-1} to 0.04 mgL^{-1} (Table 3) and 100% of the chromium values were below W.H.O (2006) permissible limit of 0.05 mgL^{-1}, therefore fit for domestic use. The values were lower than 0.05 mgL^{-1} to 0.11 mgL^{-1} reported by Yusuf *et al.* (2017) from well water samples in Kashere and its Environs, Benue State. 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. The analysis shows that well water samples contain very low concentrations of chromium, which are within the acceptable limit of WHO (2006). Mercury was totally absent in the well water samples and were within the WHO recommended standard of 0.001 mgL^{-1} and therefore fit for domestic use (Table 3).

The copper content observed in the well water samples ranged from 0.00 mgL^{-1} to 0.04 mgL^{-1} (Table 3) and 100 % of the values were within WHO (2006) permissible limit of 2.0 mgL^{-1}, therefore fit for domestic use. The values were below 0.09 mgL^{-1} to 0.24 mgL^{-1} reported by Yusuf *et al.* (2017) from well water samples in Kashere and its Environs, Benue State. 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 and necrotic changes in the liver and kidneys of humans. Long term exposure to copper, higher than normal levels can cause nausea, vomiting, stomach cramps, or diarrhea when ingested by humans from aquatics (Javed and Usmani, 2013).

The arsenic content observed in the well water samples ranged from 0.00 mgL^{-1} to 0.02 mgL^{-1} (Table 3) and 26.67% of the arsenic values were above WHO (2006) admissible limit of 0.01 mgL^{-1} and therefore not fit for domestic use. The values were below 3.10 mgL^{-1} to 39.82 mgL^{-1} reported by Onuorah *et al.* (2017) from shallow well waters in Awka Metropolis which he attributed to agricultural practices since the inhabitants of the study area are mostly arable farmers or from natural arsenic bearing rock as reported by (Smedley and Kinniburgh, 2002).

The zinc content observed in the well water samples ranged from 0.00 mgL^{-1} to 0.05 mgL^{-1} (Table 3) and 100 % of the values were within WHO (2006) permissible limit of 3.0 mgL^{-1}, therefore fit for domestic use. The values were below 0.18 mgL^{-1} to 0.44 mgL^{-1} reported by Imam *et al.* (2018) from well water samples in Kaduna Metropolis. The main source of zinc into well waters 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 (Ozuturk *et al.*, 2009).

The iron content observed in the well water samples ranged from

Table 4. Mean and logarithm of total bacterial counts isolated from the well water samples.

Pond names	Mean cfu/ml (10^{-2})	Log cfu/ml (10^{-2})
Morr	54	3.73
Aka	76	3.88
Erry	34	3.53
Unizik	72	3.85
H_2O	44	3.64
Eche	66	3.81
Ejiamatu	61	3.78
Abuchi	37	3.56
Aqua	31	3.53
Emeka	31	3.49
B.F.	54	3.73
Orient	40	3.60
Obinna	63	3.79
B_2	49	3.69
Izu	51	3.70
W.H.O (2006)	100	-

0.01 mgL^{-1} to 1.35 mgL^{-1} (Table 3) and 20% of the iron values were above WHO (2006) permissible limit of 0.3 mgL^{-1}, therefore not fit for domestic use. The values were similar to 0.58 mgL^{-1} reported by Otieno *et al.* (2015) from well water samples in Kenya. The high amount of iron which exceeded the limits (WHO, 2006) may be attributed to the use of iron sheets as well shelters, high density of people with buildings having iron sheets roofs. Due to corrosion, the iron ions find their way into the wells (Umeh *et al.*, 2020). The results of the heavy metal parameters varied significantly at $P<0.05$ level of significance among the well waters using two-way analysis of variance (ANOVA).

Bacteriological characteristics of the well waters

The mean total bacterial count for 10^{-2} dilution tube ranged from 31 cfu/ml to 76 cfu/ml. The logarithmic values for 10^{-2} dilution tube ranged from 3.49 cfu/ml to 3.88 cfu/ml. The mean values for 10^{-2} dilutions were within the 100cfu/ml World Health Standard. The faecal coliform count ranged from 0 cfu/100ml to 5 cfu/100ml where 53.33% had values above 0cfu/100ml WHO Standard. *S. aureus* count ranged from0 cfu/ml to 2 cfu/ml where 33.33% had values above 0cfu/100ml WHO Standard. *B. subtilis* count ranged from 0 cfu/ml to 4 cfu/ml where 13.33% had values above 0cfu/100ml WHO Standard. *P. aeruginosa* count ranged from 0 cfu/100ml to 6 cfu/100ml where 66.67% had values above 0cfu/100ml WHO Standard. *V. cholerae* count ranged from 0 cfu/100ml to 5 cfu/100ml where 60% had values above 0cfu/100ml WHO Standard. *V. parahaemolyticus* count ranged from 0 cfu/100ml to 5 cfu/100ml where 40% had values above 0cfu/100ml WHO Standard. Total coliform count ranged from 5 cfu/100ml to 27 cfu/100ml where 80% had values above 0cfu/100ml WHO Standard. *C. perfringens* count ranged from 0 cfu/100ml to 0 cfu/100ml and is within 0cfu/ml WHO limit. *P. fluorescens* count ranged from 0 cfu/100ml to 7 cfu/100ml where 20% had values above 0cfu/ml WHO Standard. *A. calcoaceticus* count ranged from 0 cfu/ml to 6 cfu/ml where 26.67% had values above 0cfu/ml WHO Standard (Tables 4, 5, 6).

The analysis of the total bacterial count in the well water samples revealed the presence of heterotrophic bacteria in all the well water samples (Table 4). The WHO standard for heterotrophic bacteria in potable water states that the total heterotrophic bacteria count should not be more than 100cfu/ml (WHO 2006). The presence of counts exceeding the WHO limits indicates that the water samples contain high concentration of bacteria that could make the water unsafe for domestic purposes. Result (Table 4) shows that Emeka samples had the least bacterial load while Aka had the highest value. 100 % of the values were within the WHO permissible limit for domestic water (100 cfu/ml). This result agrees with the findings of Bello *et al.* (2013) who recorded zero to 2.5 x 10^2 cfu/ml and zero to 8.1 x 10^2 cfu/ml for borehole and well water 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.

The faecal coliform obtained from the water samples are shown in (Table 5). This indicated that the water samples (except Emeka, Aqua, H_2O, Orient, B_2, Abuchi, and Erry wells) are not fit for domestic purposes. This result corroborates with the findings of Azuonwu Obioma *et al.* (2017) who recorded similar faecal coliform values of 3 cfu/100 ml to 6 cfu/100 ml from well water samples located in Khana L. G. A of Rivers State, Niger Delta. 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 WHO Standard (2006). WHO recommends that boreholes should be located at least 30m away from latrines and 17m from septic tank. The total coliform obtained from the water samples are shown in (Table 6). This indicated that the water samples (except Emeka, Aqua and Erry wells) are not fit for domestic purposes. This result corroborates with the findings of Azuonwu Obioma *et al.* (2017) who recorded high total coliform values of 20 cfu/100 ml to 32 cfu/100 ml in well water samples located in Khana L. G. A of Rivers State, Niger Delta. 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 WHO Standard (2006). WHO recommends that boreholes should be located at least 30m away from latrines and 17m from septic tank.

Table 5. Bacteriological characteristics of the well water samples.

Pond Names	Faecal coliform count (cfu/100ml)	*S. aureus* count (cfu/ml)	*B. subtilis* count (cfu/ml)	*P. aeruginosa* count (cfu/100ml)	*V. cholerae* count (cfu/100ml)
Morr	2	0	0	3	3
Aka	5	2	2	3	4
Erry	0	0	0	0	1
Unizik	3	2	4	4	2
H_2O	0	0	0	0	0
Eche	3	2	0	0	5
Ejiamatu	2	0	0	3	1
Abuchi	0	0	0	0	0
Aqua	0	1	0	1	0
Emeka	0	0	0	1	0
B.F.	2	0	0	6	2
Orient	0	0	0	0	0
Obinna	2	0	0	4	3
B_2	0	0	0	2	1
Izu	2	1	0	3	0
W.H.O (2006)	0	0	0	0	0

Key: *S. aureus*: *Staphylococcus aureus; P. aeruginosa*: *Pseudomonas aeruginosa.*

Table 6. Bacteriological characteristics of the well water samples continued.

Pond Names	*V. parahaemolyticus* count (cfu/100ml)	Total coliform count (cfu/100ml)	*C. perfringens* count (cfu/100ml)	*P. fluorescens* count (cfu/100ml)	*A. calcoaceticus* count (cfu/ml)
Morr	0	21	0	2	0
Aka	5	21	0	0	0
Erry	0	10	0	0	0
Unizik	3	19	0	0	0
H_2O	3	18	0	0	0
Eche	0	27	0	0	2
Ejiamatu	4	19	0	0	0
Abuchi	0	15	0	7	3
Aqua	0	9	0	0	6
Emeka	0	5	0	0	0
B.F.	0	18	0	0	0
Orient	0	14	0	3	0
Obinna	3	22	0	0	0
B_2	0	13	0	0	5
Izu	2	19	0	0	0
W.H.O (2006)	0	10	0	0	0

Table 7. Distribution of bacteria in the well water samples.

Pond Names	*S. Typhi*	*B. subtilis*	*E. coli*	*S. aureus*	*V. cholerae*	*P. aeruginosa*	*C. perfringens*
Morr	+	-	+	-	+	+	-
Aka	+	+	+	+	+	+	-
Erry	+	-	-	-	+	-	-
Unizik	+	+	+	+	+	+	-
H_2O	+	-	-	-	-	-	-
Eche	+	-	+	+	+	-	-
Ejiamatu	-	-	+	-	+	+	-
Abuchi	-	-	-	-	-	-	-
Aqua	-	-	-	+	-	+	-
Emeka	+	-	-	-	-	+	-
B.F.	+	-	+	-	+	+	-
Orient	+	-	-	-	-	-	-
Obinna	+	-	+	-	+	+	-
B_2	-	-	-	-	+	+	-
Izu	+	-	+	+	-	+	-

Table 8. Distribution of bacteria in the well water samples continued.

Pond Names	*P. fluorescens*	*V. parahaemolyticus*	*K. pneumoniae*	*S. flexineri*	*P. mirabilis*	*A. calcoaceticus*
Morr	+	-	+	-	+	-
Aka	-	+	+	-	+	-
Erry	-	-	+	-	+	-
Unizik	-	+	+	-	-	-
H_2O	-	+	-	+	+	-
Eche	-	-	+	-	-	+
Ejiamatu	-	+	+	+	-	-
Abuchi	+	-	-	+	-	+
Aqua	-	-	+	-	+	+
Emeka	-	-	-	-	-	-
B.F.	-	-	-	+	-	-
Orient	+	-	-	-	+	-
Obinna	-	+	+	-	-	-
B_2	-	-	-	-	+	+
Izu	-	+	+	-	-	-

Distribution of bacteria present in the well waters

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. The distribution of the bacterial isolates in the well water samples showed that *S. typhi* was present in all the wells except Ejiamatu, Abuchi, Aqua and B_2. *B. subtilis* was only detected in Aka and Unizik wells, *Escherichia coli* was not found in Erry, H_2O, Abuchi, Aqua, Emeka, Orient and B_2 wells. *S. aureus* was only present in Aka, Unizik, Eche, Aqua and Izu wells. *V. cholerae* was not detected in H_20, Abuchi, Aqua, Emeka, Orient and Izu wells, *P. aeruginosa* was not found in Erry, H_2O, Eche, Abuchi, and Orient wells. *C. perfringens* was completely absent in all the wells. *P. fluorescens* was only present in Morr, Abuchi and Orient wells. *V. parahaemolyticus* was present in Aka, Unizik, H_2O, Ejiamatu, Obinna and Izu wells. *Klebsiella pneumoniae* was not detected in H_2O, Abuchi, Aqua, Emeka, Book foundation (B.F), Orient and B_2 wells. *S. flexineri* was only present in H_20, Ejiamatu, Abuchi and Book foundation (B.F) wells. *P. mirabilis* was not detected in Unizik, Eche, Ejiamatu, Abuchi, Emeka, Book foundation (B.F), Obinna and Izu wells. *A. calcoaceticus* was only detected in Eche, Abuchi, Aqua and B_2 wells (Tables 7 and 8).

Frequency of occurrence and percentage frequency of bacteria present in the well water

Eighty colonies of *K. pneumonia*e were isolated from all the well waters with a percentage frequency of 20.78%. Sixteen colonies of *A. calcoaceticus* were isolated from all the well water samples with a percentage frequency of 4.16%. Twenty-one colonies of *E. coli* were isolated from all the well water samples with a percentage frequency of 5.45%. Eight colonies of *S. aureus* were isolated from all the well water samples with a percentage frequency of 2.08%. Twenty-two colonies of *V. cholerae* were isolated from all the well water samples with a percentage frequency of 5.71%. Twelve colonies of *P. fluorescens* were isolated from all the well water samples with a percentage frequency of 3.12%. Thirty colonies of *P. aeruginosa* were isolated from all the well water samples with a percentage frequency of 7.79%. Thirty-five colonies of *P. mirabilis* were isolated from all the well water samples with a percentage frequency of 9.10%. Twenty colonies of *V. parahaemolyticus* were isolated from all the well water samples with a percentage frequency of 5.19%. Six colonies of *B. subtilis* were isolated from all the well water samples with a percentage frequency of 1.56%. Thirty-seven colonies of *S. flexineri* were isolated from all the well water samples with a percentage frequency of 9.61%. Ninety-eight colonies of *S. typhi* were isolated from all the well water samples with a percentage frequency of 25.45% (Tables 9, 10, 11). These findings were similar to the values obtained by Akubuenyi *et al.* (2013) below. The slight differences in results may be due to collection methods, sanitary quality of the different studied areas and geographical location. Akubuenyi *et al.* (2013) revealed the presence of 31 isolates belonging to the genera: *Bacillus* (19.35%), *S. aureus* (16.14%), *Pseudomonas* (12.90%), *E. 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.

The result of the bacteriological characteristics showed that Gram negative bacteria were dominant in the studied well waters. The bacterial identification revealed the presence of twelve isolates; *E. coli*, *S. typhi*, *S. flexineri*, *P. aeruginosa*, *P. fluorescens*, *P. mirabilis*, *K. pneumoniae*, *V. cholerae*, *V. parahaemolyticus*, *E. aerogenes*, *S. aureus* and *B. subtilis* (Tables 12 and 13). The coliforms isolated were an indication of the contamination of the well water with fecal materials. The fecal material may be as a result of bailers, poor sanitary level such as low apron and proximity to septic tanks and poultry droppings which is inoculated directly into the wells. The presence of pathogenic microorganisms especially *S. typhi*, *S. flexineri*, *E. coli* and *V. cholerae* can lead to the transmission of water borne diseases such as, Diarrhea, Typhoid fever, Cholera. *S. typhi* was the most dominant organism occurring in studied wells (Table 9). The presence of *S. typhi and E. coli* in water or food indicates the possible presence of causative agents of many gastrointestinal diseases (Ampofo and Clerk, 2010). The results of the bacteriological characteristics varied significant at $P< 0.05$ level of significance using two-way ANOVA.

Parasites are common in most ecological system and all free living organisms can be potential hosts to parasites; parasitism in itself is one of the most common lifestyles on earth (Madanire -Moyo and Barson, 2010). One reason of concern is parasites not only impact other animals but humans also. Parasites have been known to cause illnesses, deformations and even prove fatal for the parasite's host (Roberts and Janovy, 2005). In small numbers of each of these parasites, there may be little or no harm caused to the humans. But in larger numbers, the parasites identified have been known to cause anemia, lethargy, ulcers, lesions, shedding skin, erratic behavior, and death (Roberts and Janovy, 2005).

Distribution of parasites in the well water samples

The parasites isolated from the well water samples were denoted using a positive (+) sign while those parasites not found in some well water samples were shown using a negative (-) sign. The distribution of parasites in the water samples showed that *Ichthyobodo* species was only present in Aka wells while *Diplostomum* species was only present in Aka and Unizik wells. *Chilodonella* species was only present in Unizik well waters (Table 10).

Frequency of occurrence and percentage frequency of parasites in the well water samples

Two *Ichthyobodo* species were isolated from all the well water samples with a percentage frequency of 28.57%. Three *Diplostomum* species were isolated from all the well water samples with a percentage frequency of 42.86%. None of the *Myxobolus* species were isolated from all the well water samples and have a percentage frequency of 0%. Two *Chilodonella* species were isolated from all the well water samples with a percentage

frequency of 28.57%. None of the *Bothriocephalus* species were isolated from all the well water samples and have a percentage frequency of 0%. None of the *Ambiphrya* species were isolated from all the well water samples and have a percentage frequency of 0%. None of the *Leech* species were isolated from all the well water samples and have a percentage frequency of 0% (Table 11). The presence of these parasites in Aka and Unizik wells may be attributed to worst sanitary result they possess. The wells were opened with fissured interior linings, grasses grew inside and around these wells, birds do perch atop the wells after wards they visit the bailer (on the well) to aspirate water and the well water apron is 3 cm long from the ground. The differences in results may be due to collection methods, sanitary quality of the different studied areas and geographical location (Umeh *et al.*, 2020). The results of the parasitological characteristics were not significant at ($P>0.05$) level of significance among the well water samples using paired T-test.

Morphological and biochemical characteristics of bacteria isolated from the well water

S. typhi, *B. subtilis*, *E. coli*, *S. aureus*, *V. cholerae*, *P. aeruginosa*, *P. fluorescens*, *V. parahaemolyticus*, *K. pneumoniae*, *S. flexineri*, *P. mirabilis*, and *A. calcoaceticus* were identified based on their morphology and biochemical tests (Tables 12, 13).

Table 9. Frequency of occurrence and percentage frequency of bacteria in the well water samples.

Bacterial isolates	Number of colonies isolated	Frequency of isolation (%)
K. pneumoniae	80	20.78
A. calcoaceticus	16	4.16
E. coli	21	5.45
S. aureus	8	2.08
V. cholerae	22	5.71
P. fluorescens	12	3.12
P. aeruginosa	30	7.79
P. mirabilis	35	9.10
V. parahaemolyticus	20	5.19
B. subtilis	6	1.56
S. flexineri	37	9.61
S. typhi	98	25.45
Total	385	100

Table 10. Distribution of parasites in well water samples.

Pond Names	*Ichthyobodo* Species	*Diplostomum* Species	*Chilodonella* Species
Morr	-	-	-
Aka	+	+	-
Erry	-	-	-
Unizik	-	+	+
H_2O	-	-	-
Eche	-	-	-
Ejiamatu	-	-	-
Abuchi	-	-	-
Aqua	-	-	-
Emeka	-	-	-
B.F.	-	-	-
Orient	-	-	-
Obinna	-	-	-
B_2	-	-	-
Izu	-	-	-

Table 11. Frequency of occurrence and percentage frequency of the parasites in the well water samples.

Parasite species	Number of parasites isolated from the well water samples	Frequency of isolation (%)
Ichthyobodo	2	28.57
Diplostomum	3	42.86
Chilodonella	2	28.57
Total	7	100

Table 12. Morphological and biochemical characteristics of the bacteria from the well water samples.

Isolates	Colony morphology	Microscopy	Gram stain	Catalase test	Coagulase test	Citrate utilization test	Oxidase test	Urease test	Indole test
51	Raised mucoid pink colonies	Rods	-	+	-	+	-	+	-
24	Small, mucoid yellow -greenish colonies	Rods	-	+	ND	+	-	-	-
12	Green metallic sheen	Rods	-	+	-	-	-	-	+
48	Round golden yellow	Cocci in clusters	+	+	+	+	-	+	-
42	Small, round yellowish colonies	Curved rods	-	+	-	+	+	-	+
63	Circular, lemon green colonies	Rods	-	+	-	+	+	+	-
21	Circular, lemon green colonies	Rods	-	+	-	+	+	-	-
30	Colourless mucoid colonies	Rods	-	+	-	+	-	+	-
31	Small, round greenish colonies	Curved rods	-	+	-	+	+	+	+
57	Large, circular and jagged colonies	Rods in chain/pairs	+	+	-	+	-	-	-
25	Round colourless colonies	Rods	-	+	-	-	-	-	-
44	Round colourless colonies with black centers	Rods	-	+	-	+	-	-	-

Table 13. Morphological and biochemical characteristics of the bacteria from the well water samples continued.

Isolates	Motility	Voges Proskauer test	Methyl red test	Glucose fermentation test	Sucrose fermentation test	Lactose fermentation test	Maltose fermentation test	Hydrogen sulphide test	Bacterial identity
51	-	+	-	A/G	A/G	A/G	A/G	-	*K. pneumoniae*
24	-	+	-	A/G	A/G	-	-	-	*A. calcoaceticus*
12	+	-	+	A/G	A	A/G	A/G	-	*E. coli*
48	-	+	+	A	A	A	A	-	*S. aureus*
42	+	-	+	A/G	A/G	-	A/G	-	*V. cholerae*
63	+	-	-	-	-	-	-	+	*P. fluorescens*
21	+	-	-	-	-	-	-	-	*P. aeruginosa*
30	+	-	+	A/G	-	-	-	+	*P. mirabilis*
31	+	-	-	A/G	-	-	A/G	-	*V. parahaemolyticus*
57	+	+	-	A	A	-	A/G	-	*B. subtilis*
25	-	-	+	A	-	-	A	+	*S. flexineri*
44	+	-	+	A	-	-	A	+	*S. typhi*

Key: A: Acid ; - : No acid and gas; A/G: Acid and gas; ND: Not done.

Conclusion

The assessment of the physicochemical parameters of selected well water samples in Awka and its environment showed serious contamination and may not be suitable for domestic purposes. The well water quality did not compare well with stipulated of WHO standards for potability. Therefore, health defects due to consumption of waters containing high levels of these parameters (acidic pH, nitrate, phosphate, cadmium, lead, arsenic and iron) may occur among inhabitants in the study area if they accumulate beyond the tolerable concentrations in the body. The result showed that 86.67% of the pH values were acidic, 6.67% of nitrate, 33.33% of phosphate, 20% of cadmium, 73.33% of lead, 26.67% of arsenic and 20% of iron exceeded the WHO maximum containment level goal for domestic water while other physicochemical parameters were within WHO standards for domestic water. The water from the wells examined in Awka and its environment were of poor quality with regards to bacteriological parameters. The detection of total coliforms, faecal coliforms, parasites and other pathogenic bacteria in significant numbers indicated that the water samples are not potable for domestic use and this may be attributed to bad sanitary practices by inhabitants of the study areas.

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Conflict of interests

Authors declare that no conflict of interest exists.

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